# NIRS / PC EXHIBITS

# Volume 4

Louisiana Energy Services, L.P. Dkt. No. 70-3103 ASLBP No. 04-826-01-ML

s in s Station

## RAS 9307

DOCKETED USNRC

February 4, 2005 (2:30pm)

OFFICE OF SECRETARY RULEMAKINGS AND ADJUDICATIONS STAFF

Docket No. 70-3103-ML

## THE FERNALD DOSIMETRY **RECONSTRUCTION PROJECT**

<u>NARSTER</u>

Tasks 2 and 3

Radionuclide Source Terms and Uncertainties

station by

Radiological Assessments Corporation 417 Till Road Neeses, SC 29107. £(803) 536-4883

RAC Report No.-CDC-5

June 1995

**INSTITUTE FUR ENERGY &** ENVIRONMENTAL RESEARCH 6935 Laurel Avenue

Jec 11

Takoma Park, MD 20912

#### THE FERNALD DOSIMETRY RECONSTRUCTION PROJECT

Tasks 2 and 3

#### **Radionuclide Source Terms and Uncertainties**

Radiological Assessments Corporation 417 Till Road Neeses, SC 29107

RAC Report CDC-5

June 1995

#### Contributing Authors on the Radiological Assessments Corporation Research Team

Paul G. Voillequé<sup>1</sup> Kathleen R. Meyer<sup>2</sup> Duane W. Schmidt<sup>3</sup> Susan K. Rope<sup>4</sup> George G. Killough<sup>5</sup> Marilyn Case<sup>6</sup> Robert E. Moore<sup>7</sup> Bernard Shleien<sup>8</sup> John E. Till

<sup>1</sup> MJP Risk Assessment, Inc. Idaho Falls, Idaho

<sup>2</sup> Keystone Scientific, Inc., Fort Collins, Colorado

<sup>3</sup> Health Physics Applications, Darnestown, Maryland

<sup>4</sup> Environmental Perspectives, Inc., Idaho Falls, Idaho

<sup>5</sup> Hendecagon Corporation, Oak Ridge, Tennessee

<sup>6</sup> Eagle Rock Scientific, Inc., Idaho Falls, Idaho

<sup>7</sup> Moore Technical Associates, Inc., Oak Ridge, Tennessee

<sup>8</sup> Scinta, Inc., Silver Spring, Maryland

. ورژ ش . . . . . .

. *.* '

### CONTENTS

GLOSSARY OF TERMS AND ACRONYMS	GL		v
EXECUTIVE SUMMARY       ri         INTRODUCTION AND OVERVIEW       1         PLANT PROCESSES AND WASTES       3         FMPC PRODUCTION INFORMATION       6         OTHER RADIONUCLIDE RELEASES       7         FMPC RELEASES TO THE ENVIRONMENT: FACTORS TO CONSIDER       8         Period of Time Studied       9         Characteristics of Radionuclide Releases       9         Uncertainties in Estimating Releases       10         Sources of Information       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       14         Dust Collector Operation       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       14         Current Estimates of Release From FMPC Dust Collectors       15         DISCHARGES FROM PLANT 2/3 DENITRATION OPERATIONS       18         RELEASES FROM PLANT 8/SCHUBBERS       21         OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE       24         Accidental Releases       26         Current Estimates of Radon Releases       26         Current Estimates of Radon Releases       29         DURECT EXPOSURES FROM FAMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32		DSSARY OF TERMS AND ACRONYMS	··· ·
INTRODUCTION AND OVERVIEW	EX	CUTIVE SUMMARY	xi
PLANT PROCESSES AND WASTES       3         FMPC PRODUCTION INFORMATION       6         OTHER RADIONUCLIDE RELEASES       7         FMPC RELEASES TO THE ENVIRONMENT: FACTORS TO CONSIDER       8         Period of Time Studied       9         Characteristics of Radionuclide Releases       9         Uncertainties in Estimating Releases       10         Sources of Information       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       14         Dust Collector Operation       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       14         Dust Collector Operation       14         Current Estimates of Release From FMPC Dust Collectors       15         DISCHARGES FROM PLANT 2/3 DENITRATION OPERATIONS       18         RELEASES FROM PLANT SCRUBBERS       21         OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32         Other Radionuclides Refeased in Li	INT	RODUCTION AND OVERVIEW	1
FMPC PRODUCTION INFORMATION       6         OTHER RADIONUCLIDE RELEASES       7         FMPC RELEASES TO THE ENVIRONMENT: FACTORS TO CONSIDER       8         Period of Time Studied       9         Characteristics of Radionuclide Releases       9         Uncertainties in Estimating Releases       10         Sources of Information       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       14         Dust Collector Operation       14         Current Estimates of Release From FMPC Dust Collectors       15         DISCHARGES FROM PLANT 2/3 DENITRATION OPERATIONS       18         RELEASES FROM PLANT 8 SCRUBBERS       21         OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMAR ADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Groundwater Contamination       36      <	· PL	NT PROCESSES AND WASTES	3
OTHER RADIONUCLIDE RELEASES       7         FMPC RELEASES TO THE ENVIRONMENT: FACTORS TO CONSIDER.       8         Period of Time Studied       9         Characteristics of Radionuclide Releases       9         Uncertaintics in Estimating Releases       10         Sources of Information       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       14         Dust Collector Operation       12         ATMOSPHERIC RELEASES FROM PLANT 2/3 DENITRATION OPERATIONS       18         Releases OURCES AND PRODUCT RELEASES TO THE ATMOSPHERE       24         Miscellaneous Unmonitored Emissions       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Relages from FMPC<	FM	C PRODUCTION INFORMATION	6
FMPC RELEASES TO THE ENVIRONMENT: FACTORS TO CONSIDER       8         Period of Time studied       9         Characteristics of Radionuclide Releases       9         Uncertainties in Estimating Releases       9         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       14         Dust Collector Operation       12         Dist CharGES FROM PLANT 2/3 DENITRATION OPERATIONS       14         RELEASES FROM PLANT 8 SCRUBBERS       21         OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Other Radionuclides Released in Liquid Effluents from the FMPC       32         Other Radionuclides Released in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Information       36         Estimated Uranium Concentrations in Frivate Wells       37         TASK 2 AND 3 SUMMAR	OT	IER RADIONUCLIDE RELEASES	7
Period of Time Studied.       9         Characteristics of Radionuclide Releases       9         Uncertaintics in Estimating Releases       10         Sources of Information       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS.       14         Dust Collector Operation       14         Current Estimates of Release From FMPC Dust Collectors.       15         DISCHARGES FROM PLANT 2/3 DENITRATION OPERATIONS.       18         RELEASES FROM PLANT 3 SCRUBBERS       21         OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE.       24         Miscellaneous Unnonitored Emissions.       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC.       28         Current Estimates of Radon Releases.       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC.       32         Releases of Uranium in Liquid Effluents from the FMPC.       32         Releases of Uranium in Liquid Effluents.       33         URANTUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC.       35         Potential Sources of Information       37         TASK 2 AND 3 SUMMARY AND CONCLUSIONS.       40 </th <th>FM</th> <th>C RELEASES TO THE ENVIRONMENT: FACTORS TO CONSIDER</th> <th>8</th>	FM	C RELEASES TO THE ENVIRONMENT: FACTORS TO CONSIDER	8
Characteristics of Radionuclide Releases       9         Uncertaintics in Estimating Releases       10         Sources of Information       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       14         Dust Collector Operation       14         Current Estimates of Release From FMPC Dust Collectors       15         DISCHARGES FROM PLANT 2/3 DENITRATION OPERATIONS       18         RELEASES FROM PLANT 2/3 DENITRATION OPERATIONS       24         Accidental Releases       21         OTHER SOURCES AND DEPISODIC RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Ur		Period of Time Studied	9
Uncertainties in Estimating Releases       10         Sources of Information       12         ATMOSPHERIC RELEASES FROM DUST COLLECTORS       14         Dust Collector Operation       14         Current Estimates of Release From FMPC Dust Collectors       15         DISCHARGES FROM PLANT 2/3 DENITRATION OPERATIONS       18         RELEASES FROM PLANT 2/3 DENITRATION OPERATIONS       18         RELEASES FROM PLANT 8 SCRUBBERS       21         OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE       24         Miscellaneous Unnonitored Emissions       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Reléases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Other Radionuclides Refeased in Liquid Effluents       33         Other Radionuclides Refeased in Liquid Effluents       33         URANTUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Information       37         B. Plant Processes and Wastes       37         C. FMPC Production Information       40 </th <th></th> <th>Characteristics of Radionuclide Releases</th> <th>9</th>		Characteristics of Radionuclide Releases	9
ATMOSPHERIC RELEASES FROM DUST COLLECTORS		Uncertainties in Estimating Releases	10
A Hody Tick Relicions TROM PLANT 2/3 DENTRATION OPERATIONS			12
Dusc Concent of Decision of Concentration       15         Dischardses of Release From FMPC Dust Collectors       15         Dischardses FROM PLANT 2/3 DENITRATION OPERATIONS       18         RELEASES FROM PLANT 8 SCRUBBERS       21         OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE       24         Miscellaneous Unmonitored Emissions       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32         Other Radionuclides Refeased in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Groundwater Contamination       36         Estimated Uranium Concentrations in Private Wells       37         TASK 2 AND 3 SUMMARY AND CONCLUSIONS       40         REFERENCES       44         APPENDICES       A. Sources of Information         B. Plant Processes and Wastes       F. Fitting Particle Size Distributions for FMPC Dust Collectors	AI	Dust Callestor Operation	14
DISCHARGES FROM PLANT 2/3 DENITRATION OPERATIONS [18] RELEASES FROM PLANT 8 SCRUBBERS [21] OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE [24] Miscellaneous Unmonitored Emissions [26] Accidental Releases [26] RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS [28] History of K-65 Silos and K-65 Material at the FMPC [28] Current Estimates of Radon Releases [29] DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS [31] LIQUID WASTE DISCHARGES FROM FMPC [32] Other Radionuclides Refeased in Liquid Effluents from the FMPC [32] Other Radionuclides Refeased in Liquid Effluents [33] URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC [33] DISCHARGES FROM FORC [32] Other Radionuclides Refeased in Liquid Effluents [33] WRANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC [35] Potential Sources of Groundwater Contamination [36] Estimated Uranium Concentrations in Private Wells [37] TASK 2 AND 3 SUMMARY AND CONCLUSIONS [40] REFERENCES [44] APPENDICES [44] APPENDICES [44] APPENDICES [56] Structure Releases [56] Effluents from Dust Collector Exhausts [57] Fitting Particle Size Distributions for FMPC Dust Collectors [56] Estimates of Bias in Effluent Sampling for Particles [56] H. Discharges from Plant 2/3 Denitration Operations [16] Releases [16] Estimates of Bias in Effluent Sampling for Particles [36] H. Discharges from Plant 8 Scrubber Systems [36] Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos [36] [36] [36] [36] [36] [36] [36] [36]	·	Current Estimates of Release From FMPC Dust Collectors	
RELEASES FROM PLANT & SCRUBBERS       21         OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE       24         Miscellaneous Unmonitored Emissions       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32         Other Radionuclides Refeased in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Groundwater Contamination       36         Estimated Uranium Concentrations in Private Wells       37         TASK 2 AND 3 SUMMARY AND CONCLUSIONS       40         REFERENCES       44         APPENDICES       A. Sources of Information         D. Other Radionuclide Releases       5         E. Effluents from Dust Collector Exhausts       5         F. Fitting Particle Size Distributions for FMPC Dust Collectors       3         G. Estimates of Bias in Effluent Sampling for Particles       4         H. Discharges from	פוס	CUITER EXIMATES OF RELEASE FROM THE C DUST CONCERNS	18
OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE       24         Miscellaneous Unmonitored Emissions       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32         Other Radionuclides Refeased in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Groundwater Contamination       36         Estimated Uranium Concentrations in Private Wells       37         TASK 2 AND 3 SUMMARY AND CONCLUSIONS       40         REFERENCES       44         APPENDICES       44         A. Sources of Information       51         B. Plant Processes and Wastes       52         C. FMPC Production Information       54         D. Other Radionuclide Releases       53         E. Effluents from Dust Collector Exhausts       54         F. Fitting Particle Size Distributions for FMPC Dust Collectors       54      <	RE	EASES FROM PLANT & SCRUBBERS	21
Miscellaneous Unmonitored Emissions       24         Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32         Other Radionuclides Refeased in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Groundwater Contamination       36         Estimated Uranium Concentrations in Private Wells       37         TASK 2 AND 3 SUMMARY AND CONCLUSIONS       40         REFERENCES       44         APPENDICES       4         A. Sources of Information       40         REFERENCES       44         APPENDICES       5         A. Sources of Binformation       40         REFERENCES       44         APPENDICES       5         A. Sources of Information       5         D. Other Radionuclide Releases       5         E. Effluents from Dust Collector Exhausts       7	OT	IER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE	
Accidental Releases       26         RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS       28         History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32         Other Radionuclides Released in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Groundwater Contamination       36         Estimated Uranium Concentrations in Private Wells       37         TASK 2 AND 3 SUMMARY AND CONCLUSIONS       40         REFERENCES       44         APPENDICES       4         A. Sources of Information       44         D. Other Radionuclide Releases       44         E. Effluents from Dust Collector Exhausts       5         F. Fitting Particle Size Distributions for FMPC Dust Collectors         G. Estimates of Bias in Effluent Sampling for Particles         H. Discharges from Plant 2/3 Denitration Operations         I. Releases from Plant 8 Scrubber Systems         J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos		Miscellaneous Unmonitored Emissions.	24
<ul> <li>RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS</li> <li>28</li> <li>History of K-65 Silos and K-65 Material at the FMPC</li> <li>28</li> <li>Current Estimates of Radon Releases</li> <li>29</li> <li>DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS</li> <li>31</li> <li>LIQUID WASTE DISCHARGES FROM FMPC</li> <li>32</li> <li>Releases of Uranium in Liquid Effluents from the FMPC</li> <li>33</li> <li>URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC</li> <li>35</li> <li>Potential Sources of Groundwater Contamination</li> <li>36</li> <li>Estimated Uranium Concentrations in Private Wells</li> <li>37</li> <li>TASK 2 AND 3 SUMMARY AND CONCLUSIONS</li> <li>40</li> <li>REFERENCES</li> <li>A. Sources of Information</li> <li>B. Plant Processes and Wastes</li> <li>C. FMPC Production Information</li> <li>D. Other Radionuclide Releases</li> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>		Accidental Releases	26
History of K-65 Silos and K-65 Material at the FMPC       28         Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32         Other Radionuclides Released in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Groundwater Contamination       36         Estimated Uranium Concentrations in Private Wells       37         TASK 2 AND 3 SUMMARY AND CONCLUSIONS       40         REFERENCES       44         APPENDICES       4         A. Sources of Information       44         D. Other Radionuclide Releases       44         F. FMPC Production Information       57         D. Other Radionuclide Releases       58         E. Effluents from Dust Collector Exhausts       57         F. Fitting Particle Size Distributions for FMPC Dust Collectors       50         G. Estimates of Bias in Effluent Sampling for Particles       51         H. Discharges from Plant 2/3 Denitration Operations       51         I. Releases from Plant 8 Scrubber Systems       51         J. Emissions of Radon, Radon Daughters and Gamma Radiation fr	RA	OON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS	28
Current Estimates of Radon Releases       29         DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32         Other Radionuclides Refeased in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Groundwater Contamination       36         Estimated Uranium Concentrations in Private Wells       37         TASK 2 AND 3 SUMMARY AND CONCLUSIONS       40         REFERENCES       44         APPENDICES       44         A. Sources of Information       44         D. Other Radionuclide Releases       44         F. FMPC Production Information       44         D. Other Radionuclide Releases       5         E. Effluents from Dust Collector Exhausts       5         F. Fitting Particle Size Distributions for FMPC Dust Collectors       6         E Estimates of Bias in Effluent Sampling for Particles       4         H. Discharges from Plant 2/3 Denitration Operations       1         Releases from Plant 8 Scrubber Systems       3         J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos			20
DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS       31         LIQUID WASTE DISCHARGES FROM FMPC       32         Releases of Uranium in Liquid Effluents from the FMPC       32         Other Radionuclides Released in Liquid Effluents       33         URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC       35         Potential Sources of Groundwater Contamination       36         Estimated Uranium Concentrations in Private Wells       37         TASK 2 AND 3 SUMMARY AND CONCLUSIONS       40         REFERENCES       44         APPENDICES       44         A. Sources of Information       44         B. Plant Processes and Wastes       44         F. FMPC Production Information       50         D. Other Radionuclide Releases       51         E. Effluents from Dust Collector Exhausts       75         F. Fitting Particle Size Distributions for FMPC Dust Collectors       6         G. Estimates of Bias in Effluent Sampling for Particles       10         H. Discharges from Plant 2/3 Denitration Operations       1         Releases from Plant 8 Scrubber Systems       3         J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos		History of K-65 Silos and K-65 Material at the FMPC	40
LIQUID WASTE DISCHARGES FROM FMPC		History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	29
Releases of Uranium in Liquid Effluents from the FMPC	DIF	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS	29
Other Radionuclides Released in Liquid Effluents	DIF LIC	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC	
<ul> <li>DRANIOM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC</li></ul>	DIF LIQ	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC Releases of Uranium in Liquid Effluents from the FMPC	29 31 32 32
APPENDICES A. Sources of Information B. Plant Processes and Wastes C. FMPC Production Information D. Other Radionuclide Releases E. Effluents from Dust Collector Exhausts F. Fitting Particle Size Distributions for FMPC Dust Collectors G. Estimates of Bias in Effluent Sampling for Particles H. Discharges from Plant 8 Scrubber Systems J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos	DIF	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC Releases of Uranium in Liquid Effluents from the FMPC Other Radionuclides Released in Liquid Effluents	29 31 32 32 32 33
TASK 2 AND 3 SUMMARY AND CONCLUSIONS	DIF LIC UR	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC Releases of Uranium in Liquid Effluents from the FMPC Other Radionuclides Released in Liquid Effluents	29 31 32 32 33 35
APPENDICES A. Sources of Information B. Plant Processes and Wastes C. FMPC Production Information D. Other Radionuclide Releases E. Effluents from Dust Collector Exhausts F. Fitting Particle Size Distributions for FMPC Dust Collectors G. Estimates of Bias in Effluent Sampling for Particles H. Discharges from Plant 2/3 Denitration Operations I. Releases from Plant 8 Scrubber Systems J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos	DIF LIQ UR	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC Releases of Uranium in Liquid Effluents from the FMPC Other Radionuclides Released in Liquid Effluents NIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC Potential Sources of Groundwater Contamination Estimated Uranium Concentrations in Britate Wells	29 31 32 32 33 35 36 37
<ul> <li>APPENDICES</li> <li>A. Sources of Information</li> <li>B. Plant Processes and Wastes</li> <li>C. FMPC Production Information</li> <li>D. Other Radionuclide Releases</li> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIQ UR	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	28 29 31 32 32 33 35 36 37
<ul> <li>APPENDICES <ul> <li>A. Sources of Information</li> <li>B. Plant Processes and Wastes</li> <li>C. FMPC Production Information.</li> <li>D. Other Radionuclide Releases</li> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul> </li> </ul>	DIF LIC UR TA	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	28 29 31 32 32 33 35 36 37 40 40
<ul> <li>APPENDICES <ul> <li>A. Sources of Information</li> <li>B. Plant Processes and Wastes</li> <li>C. FMPC Production Information</li> <li>D. Other Radionuclide Releases</li> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul> </li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC Releases of Uranium in Liquid Effluents from the FMPC Other Radionuclides Released in Liquid Effluents	28 29 31 32 32 33 35 36 37 40 44
<ul> <li>A. Sources of Information</li> <li>B. Plant Processes and Wastes</li> <li>C. FMPC Production Information</li> <li>D. Other Radionuclide Releases</li> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC Releases of Uranium in Liquid Effluents from the FMPC Other Radionuclides Released in Liquid Effluents NIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC Potential Sources of Groundwater Contamination Estimated Uranium Concentrations in Private Wells K 2 AND 3 SUMMARY AND CONCLUSIONS ERENCES	28 29 31 32 32 33 35 36 37 40 44
<ul> <li>B. Plant Processes and Wastes</li> <li>C. FMPC Production Information</li> <li>D. Other Radionuclide Releases</li> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC Releases of Uranium in Liquid Effluents from the FMPC Other Radionuclides Released in Liquid Effluents NIÚM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC Potential Sources of Groundwater Contamination Estimated Uranium Concentrations in Private Wells K 2 AND 3 SUMMARY AND CONCLUSIONS ERENCES	28 29 31 32 32 33 35 36 37 40 44
<ul> <li>C. FMPC Production Information</li> <li>D. Other Radionuclide Releases</li> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	28 29 31 32 32 33 35 36 37 40 44
<ul> <li>D. Other Radionuclide Releases</li> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	28 29 31 32 32 33 35 36 37 40 44
<ul> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	28 29 31 32 32 33 35 36 37 40 44
<ul> <li>E. Entuents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	28 29 31 32 32 33 35 36 37 40 44
<ul> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	28 29 31 32 32 33 35 36 37 40 44
<ul> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	28 29 31 32 32 33 35 36 37 40 44
<ul> <li>H. Discharges from Plant 2/3 Denitration Operations</li> <li>I. Releases from Plant 8 Scrubber Systems</li> <li>J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos</li> </ul>	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases	28 29 31 32 32 33 35 36 37 40 44
I. Releases from Plant 8 Scrubber Systems J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos	DIF LIC UR TA RE	<ul> <li>History of K-65 Silos and K-65 Material at the FMPC</li></ul>	28 29 31 32 32 33 35 36 37 40 44
J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Silos	DIF LIQ UR TA: REI	<ul> <li>History of K-65 Silos and K-65 Material at the FMPC. Current Estimates of Radon Releases</li> <li>ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS.</li> <li>UID WASTE DISCHARGES FROM FMPC. Releases of Uranium in Liquid Effluents from the FMPC. Other Radionuclides Refeased in Liquid Effluents.</li> <li>INIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC.</li> <li>Potential Sources of Groundwater Contamination.</li> <li>Estimated Uranium Concentrations in Private Wells.</li> <li>K 2 AND 3 SUMMARY AND CONCLUSIONS.</li> <li>ERENCES.</li> <li>PENDICES</li> <li>A. Sources of Information</li> <li>B. Plant Processes and Wastes</li> <li>C. FMPC Production Information.</li> <li>D. Other Radionuclide Releases</li> <li>E. Effluents from Dust Collector Exhausts</li> <li>F. Fitting Particle Size Distributions for FMPC Dust Collectors</li> <li>G. Estimates of Bias in Effluent Sampling for Particles</li> <li>H. Discharges from Plant 2/3 Denitration Operations</li> </ul>	28 29 31 32 32 33 35 36 37 40 44
	DIF LIC UR TA REI	History of K-65 Silos and K-65 Material at the FMPC. Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC Releases of Uranium in Liquid Effluents from the FMPC Other Radionuclides Refeased in Liquid Effluents	28 29 31 32 32 33 35 36 37 40 44
K. Uther Sources and Episodic Releases to the Atmosphere	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC. Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC Releases of Uranium in Liquid Effluents from the FMPC. Other Radionuclides Released in Liquid Effluents NIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC. Potential Sources of Groundwater Contamination Estimated Uranium Concentrations in Private Wells. K 2 AND 3 SUMMARY AND CONCLUSIONS ERENCES PENDICES A. Sources of Information B. Plant Processes and Wastes C. FMPC Production Information D. Other Radionuclide Releases E. Effluents from Dust Collector Exhausts F. Fitting Particle Size Distributions for FMPC Dust Collectors G. Estimates of Bias in Effluent Sampling for Particles H. Discharges from Plant 2/3 Denitration Operations I. Releases from Plant 8 Scrubber Systems J. Emissions of Radon, Radon Daughters and Gamma Radiation from K-65 Sil-	28 29 31 32 32 33 35 36 37 40 44
	DIF LIC UR TA RE	History of K-65 Silos and K-65 Material at the FMPC Current Estimates of Radon Releases ECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS UID WASTE DISCHARGES FROM FMPC	28 29 31 32 32 33 35 36 37 40 44

\* a \* 5 . . .

٠.,

·...

L. Surface Water DischargesM. Groundwater Contamination Outside the FMPC

#### **GLOSSARY OF TERMS AND ACRONYMS**

Each term or acronym is in italics the first time it appears in the text.

Activation products are radionuclides that result from the absorption of neutrons by uranium and other materials present in a nuclear reactor. An example is plutonium-239 produced following neutron absorption by uranium-238.

AMAD – Activity median aerodynamic diameter, a measure of particle size.

AMS – Air monitoring stations

Anisokinetic sampling -refers to a mismatch between the air or fluid velocity in the sampling probe and that in the stack releasing airborne effluents. It is a source of bias in effluent sampling. In contrast, *isokinetic sampling* results in an unbiased sample of the stack effluent.

Assessment Domain is the region surrounding a facility for which radiation doses to people are calculated; for this project, a circular region with a radius of 10 kilometers (km) (6.25 mi.) with its center in the FMPC production area.

**Background Radioactivity** – refers to radioactive elements in the natural environment including those in the crust of the earth (like radioactive potassium, uranium and thorium isotopes) and those produced by cosmic rays.

Bias is a systematic distortion of measurements that makes the results inaccurate.

CDC - Centers for Disease Control and Prevention, who funded the Fernald study.

**Chemical Symbols** are abbreviations for different elements and compounds. Examples of elements include U for uranium, O for oxygen, N for nitrogen and F for fluorine. Examples of compounds include  $UF_4$  for uranium tetrafluoride (green salt) and  $UO_3$ , or uranium trioxide (orange oxide).

**Contamination** refers to unwanted radioactive material, or to the deposition of radioactive material in the environment or in any place where it may make surfaces or equipment unsuitable for some specific use.

**Decay (daughter) products** refer to the isotopes or radionuclides that result from radioactive decay of isotopes, such as the uranium and thorium isotopes. In most of the feeds received by the FMPC, the uranium had previously been separated chemically from the other decay products. As a result, the facility's effluents consisted primarily of uranium, and decay product radionuclides were generally present in small quantities. In naturally-occurring uranium ores, the decay products include isotopes of uranium, protactinium, thorium, radium, radon and radon daughter products. *Radon daughter products* that are

derived from uranium are the short-lived decay products from radon-222, and include polonium-218, lead-214, bismuth-214 and polonium-214.

**Denitration** – a process in Plant 2/3 in which nitrates were driven off by heating uranyl nitrate hexahydrate (UNH) to produce uranium trioxide (UO<sub>3</sub>, or orange oxide).

**Derbies** are masses of uranium metal fabricated in Plant 5. The derbies were then remelted and cast into ingots of metallic uranium.

**Direct exposure –** refers to one pathway of exposure of people to radiation from the FMPC. In this exposure pathway, penetrating radiation emitted from radioactive material is partially absorbed by individuals exposed to it. The amount of exposure decreases with distance from the source. An example is gamma radiation from the K-65 silos that resulted in low-level exposure of nearby residents.

DOE - U.S. Department of Energy

Dose is a general term denoting the quantity of radiation or energy that is absorbed by the body. There are technical terms with specific definitions, such as absorbed dose, dose equivalent, effective dose, etc.

**Dust Collector** is one type of filtration system for airborne effluents used at the FMPC to remove airborne particulate material before it was discharged through the stack to the outside. The filtering medium is similar to that used for large fiber vacuum cleaner bags.

Effluent is a gas or liquid containing contaminants that flows from a process, building or the site into the surrounding environment.

Empirical values are values which are measured (as opposed to theoretically determined or calculated values).

Enrichment of uranium – a process by which the relative abundances of the isotopes of uranium are altered, thereby producing a form of the element that has been enriched in one particular isotope and depleted in its other isotope. For example, natural or "normal" uranium contains 0.72% <sup>235</sup>U. Enriched uranium contains more than the natural concentration of <sup>235</sup>U, while depleted uranium contains significantly less than 0.72% <sup>235</sup>U.

Entrainment is a process in which the uranium-containing liquid droplets in a scrubber are carried by the exhaust air stream and are vented to the atmosphere with the exhaust gases.

Environmental exposure - exposure to radiation through environmental pathways.

Epidemiology - the study of diseases in human populations.

Fission products are radionuclides that result from the splitting of heavy elements like uranium in a nuclear reactor. Examples are strontium-90 (<sup>90</sup>Sr), technetium-99 (<sup>99</sup>Tc), ruthenium-106 (<sup>106</sup>Ru) and cesium-137 (<sup>137</sup>Cs).

FDRP - Fernald Dosimetry Reconstruction Project

FEMP - Fernald Environmental Management Project, the new name of the FMPC beginning in 1991.

FMPC – Feed Materials Production Center

And And And

**GM** – <u>G</u>eometric <u>M</u>ean, or median, the central point of a distribution. Half of the values are larger than the median value and half are smaller.

GSD - Geometric Standard Deviation, a measure of the spread of a distribution. A large GSD indicates a wide range of measured or calculated values.

**Grab samples** – samples, usually of relatively small volume, taken at random or at preselected frequencies. These samples define the concentration of a contaminant at the specific time when they are collected and differ from continuous or proportional samples which are intended to reflect the time averaged value.

Great Miami River is the major water flow near the Feed Materials Production Center (FMPC) that receives most of the liquid effluents from the FMPC. The river, located about a mile east and south of the FMPC, runs in a southerly direction and enters the Ohio River approximately 18 miles (29 km) downstream of Cincinnati. Upstream of the FMPC on the Great Miami River lie the communities of Fairfield, Hamilton, Middletown, and Dayton. The flow of the river at the Hamilton gauge averages 3300 cubic feet per second (cfs) (93.4 m<sup>3</sup> s<sup>-1</sup>) with a maximum of 352,000 cfs (9970 m<sup>3</sup> s<sup>-1</sup>) measured in March 1913 and a minimum of 100 cfs (2.8 m<sup>3</sup> s<sup>-1</sup>) measured in September 1941.

**Green salt** is the common name for uranium tetrafluoride  $(UF_4)$ , the product from the Plant 4 operations that was sent to Plant 5 for conversion to derbies.

**Gulping operations** refers to a process in Plant 2/3 in which orange oxide (uranium trioxide, or  $UO_3$ ) from the denitration pots was transferred by a vacuum hose to a storage hopper. It appeared that the hose was "gulping" the orange oxide.

IH&R - Industrial Hygiene and Radiation Department at the FMPC

ICRP - International Commission on Radiological Protection

IT - International Technology Corporation

Page viii

di ti

K-65 Silos – The K-65 Storage Silos are large concrete tank-like structures that store residues from the extraction of uranium from ores that were processed during the early years of FMPC operations.

kilo – a prefix that multiplies a basic unit by 1000. For example, 1 kilogram = 1000 grams.

Lognormal distribution – If the logarithms of a set of values are distributed according to a normal ("bell-shaped") distribution the values are said to have a lognormal distribution, or be distributed "lognormally".

MTU – abbreviation for metric ton of uranium; one MTU equals 1,000 kg or 2,200 pounds

NCRP - National Council on Radiation Protection and Measurements

NKES – Northern Kentucky Environmental Services

NLO – National Lead Company of Ohio, the contractor for the FMPC through the end of 1985.

 $NO_{\tau}$  – nitrogen oxides, such as NO<sub>2</sub> and NO<sub>3</sub>.

**ODH** – Ohio Department of Health

**Orange oxide** – abbreviation for uranium trioxide  $(UO_3)$ , the product from the Plant 2/3 refinery that was sent to Plant 4 for further processing.

OSTI – the Office of Scientific and Technical Information, located in Oak Ridge, Tennessee, is the national center for worldwide literature on scientific and technical energy-related matters. It was one of the sources of information that RAC used for completion of the project.

Paddy's Run – a small intermittent stream lying along the west boundary of the site that joins the Great Miami River approximately 3 kilometers south of the FMPC. The flow in Paddy's Run, which generally exists only during January to May, averaged 2 to 4 cfs (0.065 to  $0.1 \text{ m}^3 \text{ s}^{-1}$ ). Since flow in Paddy's Run is dependent upon rainfall, discharges from the site to Paddy's Run generally occurred during periods of heavy rain and runoff when the storm sewer outfall overflowed, or when 'runoff from the west side the of site flowed into the Paddy's Run.

pico – a prefix that multiplies a basic unit by 1/1,000,000,000,000 or  $1 \ge 10^{-12}$ . For example, one picocurie (pCi) equals  $1 \ge 10^{-12}$  curie (Ci).

**RAC** – Radiological Assessments Corporation was the group chosen by CDC to do the Fernald Dosimetry Reconstruction Project.

ζ.

111 .

A CAN'S REVING

2

**Recycled uranium** is uranium that had been irradiated in nuclear reactors, where finished uranium products were used. As a result, when the uranium was recovered and returned to the FMPC, small amounts of fission and activation products were introduced into the process stream.

**Reentrainment** is a process whereby the exhaust airflow creates new droplets from liquid that had been previously collected by a screen type filter.

Scrubber – a type of treatment system for airborne effluents that uses liquid droplets to remove particulate matter and reactive gases from airborne waste streams before they were discharged through the stack to the outside. At the FMPC, scrubbers were used in Plant 2/3 (refinery) and in Plant 8 (scrap recovery).

Scrub Liquor – the scrub liquor is the liquid in a scrubber that cleans or scrubs the exhaust air from certain plant operations. The liquid removes reactive gases and particles in the airstream before the airstream is discharged to the atmosphere.

**South Plume** –refers to the groundwater that has been contaminated by uranium from the FMPC. It extends southward from a point south of the waste pits and reflects the movement of contaminated groundwater.

**Source Term** – refers to the quantity, and chemical and physical form of radioactive materials released to the environment from various locations onsite.

**SSOD** – The Storm Sewer Outfall Ditch is a drainage ditch that runs south from the FMPC production area near the storm sewer lift station to Paddy's Run.

TLD - A thermoluminescent dosimeter is a device used at the FMPC to measure the amount of external radiation in the environment. These devices measure both radiation from naturally-occurring radioactivity in the soil and from the K-65 silos.

TRU - transuranic nuclides refer to isotopes heavier than uranium that are created by neutron capture by heavy elements.

**Uncertainty** -term used to describe probable bounds on, or how much evidence we have to support, our key findings. Uncertainty can result from two process: the first is due to random variations in sampling, measurement, and operational procedures. The second type of uncertainty occurs because of a lack of information about particular processes. This may occur because the right measurements were not done during part or most of the period of facility operation.

 $UF_4$  – uranium tetrafluoride, or green salt was the product from Plant 4 that was sent on to Plant 5 for conversion to derbies.

5

UNH - uranyl nitrate hexahydrate was an intermediate step in the denitration process in Plant 2/3; nitrates were removed from UNH to produce uranium trioxide (UO3, or orange oxide).

 $UO_3$  – uranium trioxide, often called orange oxide, was produced in the Plant 2/3 refinery and was sent to Plant 4 for further processing. . P. Oak

 $UO_2(NO_3)_2$  - uranyl nitrate was a product of the digestion phase in the Plant 2/3 refinery. 1997 3979

USGS - United States Geological Survey

1.

Validation is the comparison of available measurements of the radionuclides in the local environment during the period of study with corresponding predictions from mathematical models. ·

WMCO - Westinghouse Materials Company of Ohio, the FMPC site contractor from 1986 through 1992. 1.01

1. i.c. 1.1 . : 

· . . . . : LANDEL P. L . . . 18 . 19 . S. . . . . . ! or the second ..... - Igar Contemporary and the the south the Second Light to the 

· · ·

#### EXECUTIVE SUMMARY

The purpose of the Fernald Dose Reconstruction Project (FDRP) is to estimate radiation doses to people who lived near the Fernald (Ohio) Feed Materials Production Center (FMPC) during its years of operation from 1951 to 1988. Exposures resulted from both planned and unplanned releases of radionuclides to the environment. The study was conducted for the Centers for Disease Control and Prevention.

The project was divided into seven tasks. The goal of Task 2 was to determine the radionuclide source term for the facility; that is, to determine both the amounts of radioactive material released to the environment and the variability of release rates. The Task 3 objective was to determine the uncertainties associated with those past releases.

This final report describes our estimates for source terms for the period 1951-1988. In finalizing this report, *RAC* has considered comments and suggestions received from a number of sources on our draft report (Voillequé et al. 1993). Initially we examined a three-year period in the early sixties to develop the methods that would be applicable to all years (Voillequé et al. 1991).

Our calculations are based on a thorough search of records documenting operations and effluent and environmental monitoring at the FMPC. In some cases, effluent measurement data from which estimates could be derived directly were not available. These situations were handled using statistical methods that simulate a possible range of values that could have existed. Source terms were divided into three categories of release: emissions to air, emissions to surface water, and *contamination* of groundwater.

The principal activity at the FMPC was processing uranium (U), with some thorium processing occurring at various times. In the early years, uranium ore was processed, and the waste materials were stored in drums and silos onsite. These waste materials are a source of radon and its decay products. Consequently, this report focuses primarily on emissions of uranium, and radon and its decay products. Some uranium was recycled, which is uranium that had been returned to the FMPC from other weapons material processing facilities. As a result, other radionuclides were also released at the site. Thus, release estimates are given for thorium, and selected activation products (plutonium-238, plutonium-239,240, neptunium-237), fission products (strontium-90, technetium-99, ruthenium-106, cesium-137), and decay products of uranium (radium-226) and thorium (radium-228). Table ES-1 summarizes the most important (uranium and radon) source term estimates and their uncertainties for 1951-1988.

Airborne waste streams were typically treated prior to release to the environment using either dust collectors (filters) or scrubbers (treatment systems employing liquids to remove particulate matter from gaseous waste streams). The efficiency of both of these methods varied greatly with the state of the technology at the time, maintenance of the system, and plant throughput. For dust collectors, our estimates accounted for anisokinetic sampling and sample line losses. Anisokinetic sampling occurs when the sampling probe in the dust collector stack does not record the stack exhaust gas velocity accurately. Losses of particles in the sampling line before they are detected at the sampler can significantly affect estimates of releases from stacks at the plant. These factors were not considered in previous studies.

Release Point	Median Release Estimate	5th–95th Percentile Range
Uranium to atmosphere		· · · · ·
Dust collectors	140,000	120,000-170,000
Plant 2/3 scrubbers	66,000	56,000-78,000
Plant 8 scrubbers	81,000	56,000-130,000
Miscellaneous Sources <sup>b</sup>	16,000	9300-28,000
Total: airborne sources	310,000	270,000-360,000
· · · · · · · · · · · · · · · · · · ·		
Uranium to surface water		
Manhole 175	82,000	71,000-94,000
Paddy's Run	17,000	14,000-20,000
Total: surface water	99,000	85,000-120,000
	· · · · · · · · · · · · · · · · · · ·	
Radon to Atmosphere		
K-65 Silos		
Kadon	170,000 Ci	110,000–230,000 Ci
Radon decay products <sup>c</sup>	130,000 Ci	87,000–190,000 Ci

## Table ES-1. Summary of Median Uranium and Radon Releases Estimates From the FMPC for 1951–1988 With Uncertainty Bounds<sup>a</sup>

<sup>a</sup> Values are in kg of uranium, except for releases from the K-65 Silos which are reported in units of activity, called curies, Ci.

<sup>b</sup> Unmonitored and accidental releases.

<sup>c</sup> The release quantities for radon and its decay products are given in units of activity, curies (Ci); quantities of each of the short-lived decay products, polonium-218, lead-218, bismuth 214, and polonium-214.

Estimates of releases from the denitration processes scrubbers in Plant 2/3 (refinery) and from the scrubbers in Plant 8 (scrap recovery) were made considering uncertainty and variability in parameters that affect scrubber performance. Relevant site-specific data were used as much as possible. Monte Carlo techniques allowed us to sample the parameter uncertainty distributions to make the release estimates. The distributions represent uncertainties associated with these individual parameters and can be combined to form a distribution that characterizes the overall range of potential scrubber releases, in contrast to the point estimates of previous studies. Our estimates of releases from Plant 8 scrubbers relied heavily on data reporting monthly amounts of uranium found in the scrubber liquid residue (called scrub liquor) and measurements of scrubber penetration of uranium. The Plant 8 scrubbers dominated the uranium releases in the 1960s, with approximately 47,000 kg U released in that decade, compared to 21,000 and 19,000 kg U for the dust collectors and Plant 2/3 scrubbers, respectively. In the 1970s, the Plant 2/3 scrubbers were relatively more important. In the 1950s and 1980s, the dust collectors contributed most to the total uranium releases, although the magnitude of all releases in the 1980s was significantly less than in the 1950s.

....

. .

ÿ.,

**1** 

P. Antonio Contentionen de la co

81

ie-z-

Page xiii

A thorough evaluation of atmospheric releases of uranium from unmonitored sources (incinerators, building ventilation, lab hoods, unmonitored process emissions and waste pits) and accidental releases (fires, spills and episodic releases) indicates that these were relatively minor compared to the three primary sources of atmospheric emissions (dust collectors, Plant 8 and Plant 2/3 scrubbers). However, the detailed assessments of these sources provide thorough documentation of their magnitude with uncertainties. These release estimates are included as part of the total atmospheric source term.

Radon releases were calculated for the K-65 silos, located near the west side of the site, and for drummed K-65 material temporarily stored on the Plant 1 Pad in the early 1950s. The silos contained K-65 material, a waste from the extraction processing of uranium ore. This material contains high concentrations of radium-226, and thus, acts as a continuous source of radon-222, a highly mobile radioactive inert gas. Release estimates were complicated by a lack of data describing characteristics of the material in the silos, and by structural changes that occurred over the years. Our estimates of radon and radon decay product releases were derived from measurements found in the historical records and from previous studies. The rate of radon release from the K-65 Silos for 1959–1979 is greater than for other periods, and significantly greater than for later periods. Radon releases from the Plant 1 Pad drums were insignificant contributors to the total radon releases for the period 1951–1988, but were important contributors for 1951 and 1952.

Radioactive material left the site in liquid effluents at two key points: through Manhole 175 (MH 175), a final junction point for major effluent streams onsite to the Great Miami River, and, periodically, through the storm sewer outfall to Paddy's Run. Effluent concentrations and volumes were measured regularly at both locations, and records were used to reconstruct these source terms. More uncertainty is encountered with the release estimates to Paddy's Run because the frequency of sampling was less than at MH 175, and there were discharges to the stream that were not monitored. Nevertheless, estimates of releases of uranium in liquid discharges are relatively well known, and uncertainties are generally smaller than with releases to air.

An evaluation of the groundwater plumes underlying the FMPC indicated that, at the present time, three offsite wells are contaminated, and only a small number of people would have potentially received radiation doses from contaminated groundwater. Consequently, a simple model is used to estimate concentrations of uranium in the contaminated plume, based on recent measurements in the three offsite wells and on quantities of uranium released to the storm sewer outfall ditch and to Paddy's Run since the 1950s. Based on this simple model, it is likely that uranium contamination in the groundwater would not have reached the offsite wells prior to 1968.

There have been several previous assessments of uranium releases from the FMPC. Previous estimates of uranium discharged in liquid effluent fall within the uncertainty range of our estimates. Source terms from previous studies of airborne uranium releases have all fallen outside our uncertainty range except for one study. Exhaustive comparisons have not been made; however, reasons for our higher estimates include:

- the time to conduct a comprehensive review of historical documents, in particular original records, related to the FMPC operations;
- the use of a distribution of scrubber efficiencies for Plant 8 scrubbers;

. . . . . .

. . . .

•

; ;

1

August

. . . . .

. . . .

·

• • • • • 3. . A

and the star mon warts to

27.20

Area to par

Construction of the second

and a state of the second

esteration autoritation tomat THE TREE STORAGES

States & Real Provide Land State B.

and the second second

13710

1. 19 1.

1.5

· .

1.11 4

. . . 3

<u>.</u>,

.....

- accounting for uranium losses from miscellaneous unmonitored sources and • accidents; ۰.,-
- accounting for biases from sample line losses and o her sampling deviations in the calculation of dust collector losses.

Our results report not only best estimates of releases (as a median value) but also associated uncertainties that were calculated as an integral part of the estimates. This approach represents a significant improvement in the state-of-the-art of source term analysis. This depth of analysis was not undertaken in earlier estimates of releases. These source term estimates will be used in Task 6 to calculate radiation doses to people who live near the FMPC. •• A. 15 .

1 3 1 1 1 1 V

e la conves co

135 -

. . . . .

#### TASKS 2 AND 3

#### RADIONUCLIDE SOURCE TERMS AND ASSOCIATED UNCERTAINTIES FOR 1951–1988

#### INTRODUCTION AND OVERVIEW

· · ·

.

The purpose of the Fernald Dose Reconstruction Project (FDRP) is to estimate radiation doses to people who lived near the Fernald (Ohio) Feed Materials Production Center (FMPC) during its years of operation from 1951 to 1988 (Figure 1). Exposures resulted from both planned and unplanned releases of radionuclides to the environment. The study was conducted for the Centers for Disease Control and Prevention.

The project was divided into seven tasks. The goal of Task 2 is to determine the radionuclide source term for the facility; that is, to determine both the amounts of radioactive material released to the environment and the variability of release rates. This information is fundamental to the assessment of radiation doses to persons in the vicinity of the site. The Task 3 objective was to determine the uncertainties associated with those past releases.

An interim Task 2/3 report (Voillequé et al. 1991) initially determined the source term for the years 1960, 1961 and 1962. This shorter time period was selected because environmental samples and records were available and there was a relatively consistent level of emissions. The pilot study tested and presented our methods for estimating the amounts of radioactive materials released and for assessing the uncertainties associated with those estimates. Based on the methods described in the interim Task 2/3 report, we estimated the amounts of radioactive materials released to air, surface water and in groundwater throughout the history of the Fernald plant's operation. Those results were presented in a draft report (Voillequé 1993). The draft report was reviewed, and comments were received from a number of people and organizations, including the CDC, members of the public, current employees at the FEMP, and former employees of NLO. All comments were considered in finalizing this current report, which reflects those changes and represents the final Task 2/3 report for this project. In addition to minor editorial changes, the main revisions to this report from the draft version include:

- Annexes listing the types of documents found in Central Files at the FMPC and of the boxes of contaminated documents that were examined in the Plant 4 storage area (Appendix A)
- Revised screening calculations using updated NCRP screening factors (Appendix D)
- Re-evaluation of the attachment fraction of particles in the calculation of sampling line losses for dust collector releases (Appendix G and E).
- Recalculation of discharges from the Plant 2/3 denitration operations using additional scrub liquor concentration data; determination of effect of alternative calculation of the outage fraction on Plant 2/3 scrubber releases (Appendix H)
- Two alternative calculations of releases from the Plant 8 scrubbers to test the effect of different modeling choices on the results. (Appendix I, page I-37)

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

Č,

X. () . . .



Figure 1. Location of the Fernald Feed Materials Production Center.

- An alternative calculation of radon and radon daughter product releases from the K-65 silos using a conventional methodology of radon releases from bulk quantities of <sup>226</sup>Ra-bearing materials (Appendix J, page J-73).
- Revision of fugitive emissions calculations for the waste pits using an improved model (Appendix K).
- Use of an empirical model to estimate uranium concentrations in offsite contaminated wells for years when no measurements were made; the model uses available uranium measurements in well water and considers the uranium released to Paddy's Run and the storm sewer outfall ditch (Appendix M).

This report is divided into this summary and 13 appendices. Each appendix is in bold type when it first appears in the discussion of that appendix. The appendices are:

- Appendix A Sources of Information
- Appendix B Plant Processes and Wastes

Appendix C FMPC Production Information

Appendix D Other Radionuclide Releases

Appendix E Effluents from Dust Collector Exhausts

Appendix F Fitting Particle Size Distributions for FMPC Dust Collectors

Appendix G Estimates of Bias in Effluent Sampling for Particles

Appendix H Discharges from Plant 2/3 Denitration Operations

Appendix I Releases from Plant 8 Scrubber Systems

Appendix J Releases of Radon, Radon Decay Products and Gamma Radiation from the K-65 Silos

Appendix K Other Sources and Episodic Releases to the Atmosphere

Page 2

Appendix L Surface Water Discharges

Appendix M Groundwater Contamination Outside the FMPC

The goal of this report is to provide the reader with a clear picture of the FMPC operations from 1951 through 1988. It explains the generation of effluents from those operations, and estimates effluent releases using relevant measurements and related information.

#### PLANT PROCESSES AND WASTES

12.00

1

The FMPC is a government-owned, contractor-operated facility whose primary purpose was to convert uranium (U) feed stocks to uranium metal ingots for machining or for extrusion into tubular form. Production reactor fuel cores and target elements were fabricated. Figure 2 gives an overview of the main features of the FMPC area. An aerial photograph shows the environs of the FMPC in 1965 (Figure 3).



Figure 2. Overall view of the FMPC facility. The width of the production area is about 700 meters from east to west (inner fence).

The Fernald Dosimetry Reconstruction Project <u>Tasks</u> 2 and 3, Source Terms and Uncertainties

Low City



Page 4

Figure 3. Aerial photograph taken from the southeast of the Feed Materials Production Center in 1965, showing the production area and general land features (digitized from DOE 1965). The area within 5 miles (8 km) from the center of the FMPC is populated with farm houses, small communities, and the small town of Ross, Ohio, with land use being primarily grazing and farming.

Appendix B describes the plant functions in some detail by following the flow of uranium through the various facilities as it was converted from raw material to finished products. Although uranium was the primary product at the FMPC, lesser amounts of thorium were produced intermittently during the mid-1950s, and from 1964 through 1980. In addition, the FMPC began processing materials recycled from other stages of the nuclear fuel cycle in 1962.

Figure 4 is a material flow diagram which shows the movement of incoming raw and recycled material (called feed materials) into the FMPC at Plant 1, the Sampling Plant, and their passage through various chemical and physical processes before leaving the site as finished products. Historic records and discussions with plant staff revealed that the same basic processing scheme was employed throughout all years of operation.

From Plant 1, the materials passed to Plant 2/3, the Refinery, where the uranium in the various feed materials was converted to uranium trioxide  $(UO_3, called orange oxide because of its color)$ . The UO<sub>3</sub> was converted to uranium tetrafluoride  $(UF_4, called green salt)$  in Plant 4, and then sent to Plant 5, Metals Production. There the UF<sub>4</sub> was converted to uranium metal derbies or ingots. From Plant 5 the ingots were shipped offsite, or were sent to either Plant 6 (where the metal was fabricated into finished products) or to Plant 9 (where special products were machined).



The Fernald Dosimetry Reconstruction Project
Tasks 2 and 3, Source Terms and Uncertainties

2

In Plant 8, the Scrap Recovery Plant, waste materials and metal scraps from the production processes were heated to remove impurities before being sent back through the Refinery (Plant 2/3) and the production process. The Pilot Plant was used for the direct conversion of incoming enriched  $UF_6$  (uranium hexafluoride) to  $UF_4$  (green salt).

Much of the thorium production activity at the FMPC took place in the Pilot Plant, beginning in 1954. Plant 7 operated only from 1954–1956 in converting UF<sub>6</sub> to UF<sub>4</sub>. Waste materials from these processes were treated in various ways at the FMPC depending upon their physical form. The K-65 Storage Silos, large concrete tank-like structures, store residues from the extraction of uranium from ores that were processed during the early years of FMPC operations. Liquid effluents were collected and treated at the general sump before being discarded to the waste disposal pits. Liquids from the clearwell portion of the waste pit, along with the storm sewer runoff and sewage treatment plant effluent were piped to the Great Miami River from Manhole 175 on the eastern boundary of the site. Solid waste materials were sent directly to the waste pits, or they were burned in the incinerator located near the eastern edge of the facility or in the burn pit near the waste pits. The FMPC also operated a graphite burner from 1965 to 1984, an oil burner from 1962 until 1979, and an incinerator for liquid organic wastes that was installed in 1983. Releases from these latter facilities are described in Appendix K.

#### **FMPC PRODUCTION INFORMATION**

Page 6

Production information provides a guide to the magnitude of FMPC activities over the years. In the absence of other data, it can be used to help estimate releases from the facility to the environment. Appendix C contains details of the receipts and shipments of uranium at FMPC along with specific production data for each plant for the time period 1951–1988.

These records of shipment and receipts, and plant production provide several key pieces of information. First, they specify the level of *"enrichment"* of processed uranium, which relates to the concentration of uranium-235 (<sup>235</sup>U) relative to uranium-238 (<sup>238</sup>U).

- "Natural" uranium contains 0.72% <sup>235</sup>U.
- "Depleted" uranium contains less <sup>235</sup>U; typically 0.14–0.20% at FMPC.
- "Enriched" uranium contains more <sup>235</sup>U; typically, 0.95-1.25% at FMPC.

While most of the enriched uranium was in the above range, some processing of 2% enriched uranium occurred in the 1960s. The capability to digest 5% enriched uranium was added to Plant 1 in 1970.

Second, records of receipts of material by FMPC and shipments from FMPC provide a rough indication of production rates. Comparisons of the data on receipts and shipments indicate that material was received, processing occurred, and products were shipped on a fairly regular schedule during much of the time. During fiscal year (FY) 1952 through 1980, the FMPC received about 362,000 metric tons (MT; 1 MT = 1,000 kg = 2,200 pounds) of uranium and shipped about 358,000 MT to offsite locations (Audia 1977; FMPC 1988). Approximately 54% of the receipts and shipments were natural uranium, about 20% were enriched uranium, and some 26% were depleted uranium. Uranium shipments tended to follow the pattern of receipts during most of the years of operation.

Third, plant-specific production rates are useful for estimating releases of radioactive materials from specific facilities. Processing rates in each plant were increased or reduced because of changes in the demand for intermediate materials and finished metal products. Figure 5 summarizes the total production quantities in metric tons of uranium (MTU) for 1951 to 1988. In some plants, there was no production during certain years. For example, there was no production of UF<sub>4</sub> from UF<sub>6</sub> in the Pilot Plant from 1968 to 1984. Data on the enrichment categories of products are presented in Appendix C.

Thorium production at the FMPC was estimated to have been only about 0.4% of the uranium production. Processing was limited to a few facilities and to specific time periods. Some of the uranium received at the FMPC was recycled, that is, it had other radionuclides as contaminants in the uranium.

#### OTHER RADIONUCLIDE RELEASES

Radioactive decay of uranium and thorium isotopes produces series of other radionuclides that are collectively referred to as *decay or daughter products*. In most of the feeds received by the FMPC, the uranium had previously been separated chemically from the other decay products. As a result, the facility's effluents consisted primarily of uranium. Other radionuclides were generally present in small quantities. Early processing campaigns treated ores that contained nearly equilibrium amounts of the decay products. The wastes from that early processing were placed in the K-65 Storage Silos. Releases from the silos are discussed in Appendix J.



Figure 5. FMPC plant production for 1952 through 1988. Each plant produced a different product: uranium trioxide in Plant 2/3, uranium tetrafluoride in Plant 4, metal derbies (dark bar) and ingots (light bar) in Plant 5, machined (dark) or rolled products (light) in Plant 6, uranium ingots (light) and machined products(dark) in Plant 9, uranium recovered from scrap materials in Plant 8, and uranium tetrafluoride in the Pilot Plant.

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

è

-

÷.

Because recycled feed materials were sometimes used, small amounts of other radionuclides called fission and activation products were also introduced into the process stream and later released. Recycled uranium was not processed at the FMPC prior to October 1962, so releases of fission and activation products did not occur prior to that time. Measurements of the amounts of these radionuclides, relative to uranium, were not performed until years later. These products were measured from airborne effluents (in scrub liquor or dust collectors) at only one time in 1985.

Appendix D provides the measurement data of fission and activation products in particulate materials done at that time. The concentration of fission products— strontium-90, technetium-99 and cesium-137—were highly variable. The transuranic nuclides neptunium-237, plutonium-238, and plutonium-239,240 were detected in all of the samples analyzed, but the observed concentrations varied over a wide range within the plants and from plant to plant. Only the short-lived decay products of uranium-238 were found in consistent concentrations. The concentrations of thorium isotopes and their radium decay products were found to be consistent in samples from some plants but not from others. In some plants, the concentrations of transuranic nuclides (TRU) were clearly affected by the processing of material containing unusually high concentrations of TRU between 1980 and 1985.

Measurements of radionuclides other than uranium in liquid effluents are available for a longer time period than for airborne effluents. There was no processing of thorium during the time periods 1952–1953, 1958–1963, or since 1980. Relative concentrations of thorium with respect to uranium were measured in the mid-1950s, and again beginning in 1967. Beginning in 1976, the concentrations of plutonium, neptunium, radium and the fission products, cesium-137, ruthenium-rhodium-106, technetium-99, and strontium-90, were measured relative to uranium. The concentrations of these other radionuclides in liquid effluents are shown in Appendix D. Estimates of the amounts discharged in liquid effluents are presented in **Appendix L**.

The relative importance of various radionuclides as potential contributors to offsite radiation doses was assessed using a methodology developed by the NCRP (National Council on Radiation Protection and Measurements) (NCRP 1989). These calculations show that releases of uranium are by far the most important contributors to the potential doses from releases to the atmosphere at the FMPC. For liquid releases, the radium isotopes were found to be of primary importance, depending upon the pathway considered.

#### FMPC RELEASES TO THE ENVIRONMENT: FACTORS TO CONSIDER

te unique est est. A unique com

e la factore estador e po

Several factors regarding source term estimates were considered at the outset of the project. These included the initial period of study, characteristics of radionuclide releases, the uncertainties involved in making source term estimates, and the sources of information that would be used for this process. To apply resources most efficiently, it was necessary to assign priorities to the three source terms — airborne effluents, liquid waste discharges, and inputs to the groundwater — according to their importance. The greatest emphasis was given to those releases that had the largest potential impact on the population residing in the vicinity of the FMPC. All the evidence, which will be documented throughout the report, indicates that airborne releases deserve the greatest attention. That conclusion influenced the level of detail of the investigations and the corresponding reports in this series.

#### **Period of Time Studied**

.

1

Although radionuclide source terms are reported here for the entire operating history of the FMPC (1951–1988), our initial effort focused on a shorter time period (Voillequé et al. 1991). Originally, we considered examining 1955, the year of the highest reported releases to the atmosphere (Boback et al. 1987). During a September 1990 site visit, it was confirmed that the installation of effluent sampling equipment was not complete during 1955. The quality and variability of results from an operational effluent sampling system are needed to estimate source term uncertainty, needed for Task 3.

Other factors indicated that a time period in the early 1960s was the best focal point for the initial work on source terms and their uncertainties. These included the availability of environmental samples and records along with a level of emissions which make uncertainty analysis workable. We were also able to locate other documentation that was needed to derive source term estimates.

Analysis of data from a period of relatively consistent operation (1960, 1961 and 1962) has provided a basis for estimating source terms for other periods when fewer measurements were made and when there were more unmonitored release points. The interim draft Task 2/3 report addressed releases to the atmosphere, to surface water and to groundwater by the FMPC for the period 1960–1962. In the current report, we use the same methods of investigation to derive annual source term estimates for uranium and other radionuclides released in air, surface water and ground water from the FMPC for the entire period 1951–1988.

#### **Characteristics of Radionuclide Releases**

Initially, it is important to identify specific attributes of the radionuclide release, or source term, to be documented. The most important parameters that are common to all releases include:

- \_ nature of release: Was it routine or episodic?
- magnitude or size of the release
- radionuclides released

For the surface water source term, the discharged radionuclides in waste water were either in solution or in suspension as finely divided particles. In either case, the radioactivity was carried from the FMPC site via a pipeline to the Great Miami River or in the storm sewer overflow via Paddy's Run, a small stream at the west boundary of the site. Paddy's Run joins the Great Miami River approximately 3 kilometers south of the FMPC (Figure 2).

Radioactivity reached the groundwater by infiltration in a form similar to that in liquid discharges. The radiation doses from consumption of water from either source depend on the amounts released and upon the dilution in the river or the aquifer before withdrawal for human use.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page 9

Page 10	
---------	--

.

.

でんごと

Diane

5

2

For radionuclide releases to the atmosphere, there are two other factors, besides release rate and dispersion, that are important determinants of the radiation doses to members of the public. These are:

the chemical form of the discharge e -.

• its physical characteristics, primarily the size distribution of the released particles

Human metabolism of radionuclides that have been inhaled is dependent upon the chemical form of the radionuclides. Soluble compounds are readily taken up into the blood stream and are rapidly distributed throughout the body. Chemical forms that are insoluble in body fluids tend to be retained in the lung for a longer time and are only gradually transported to other tissues. The chemical form of the discharges are presented in the appendices describing atmospheric releases.

The particle-size distribution is important for calculating the amounts of radioactive material that were deposited on the ground following release. Particle size is also important. for estimating the radiation dose from inhalation of the particles.

#### Uncertainties in Estimating Releases

Results of scientific investigations are, by their nature, uncertain, and it is a common practice for investigators to provide some estimate of uncertainties that affect their estimates. Estimating the uncertainties associated with the source term estimates (Task 3) is, therefore, an important part of this work. The absence of uncertainty estimates is a weakness in the previous source term information.

Knowledge of several parameters, or numbers, is required to define a radionuclide release. None of them is known exactly, and most are contributors to the overall uncertainty associated with the release estimate. Two types of parameter uncertainty affect the overall source term uncertainty (Hofer and Hoffman 1987). The first is due to random variations in sampling, measurement, and operational procedures. For example, estimates of uranium releases to the atmosphere are based upon analytical measurements of the sample mass, the percent of the collected mass that is uranium, the flow rate through the sampler, the flow rate through the stack, etc. The physical dimensions of the sampling probe and the exhaust duct are also factors. Although the latter two quantities are fixed and relatively well known, each of the other measurements is rather more uncertain, for various reasons. This uncertainty contributes to the overall uncertainty of a particular release estimate.

A second type of uncertainty occurs because of a lack of knowledge about particular parameters. This may occur because the parameters were not measured during part or, in some cases, most of the period of facility operation. Examples of this type are periods when the stack sampler flow rate was not measured, and periods when the stack flow rate was not measured. In these cases, estimates of the values of those parameters during the periods between measurements will be necessary. In the absence of definitive information, subjective judgment of experts can be used to estimate the range and distribution of values for the unknown parameters during such periods.

The technique of using a computer to draw many random samples from the parameter distributions and combining these sample releases to obtain information about the

Radion	uclide So	urce Terms		
and As	sociated I	<b>Uncertainties</b>	for	1951-1988

÷.,

्

distribution of the releases is an example of what is called a Monte Carlo procedure. Figure 6 illustrates this process.



Figure 6. Schematic presentation of Monte Carlo methods for propagating a parametric uncertainty distribution through a model to its results. In this simplified illustration, A is an input parameter to the model, and Y is the result, or output, corresponding to A. For each specific value of A, the model produces a unique output Y. Such an application of the model is deterministic, because A determines Y. But A may not be known with certainty. If uncertainty about A is represented by a distribution, such as the triangular one in the figure, repeatedly sampling the distribution at random ad applying the model to each of the sample input values  $A_I$ ,  $A_2$ ... gives a set of outputs  $Y_I, Y_2,...$ , which can be arranged into a distribution for Y. The distribution of Y is then our estimate of the uncertainty in Y that is attributable to uncertainty in A. This is a stochastic, or Monte Carlo application of the model.

Our use of a Monte Carlo procedure to estimate releases explicitly recognizes that those estimates are uncertain because of variability or lack of knowledge of the parameters upon which the estimates depend. This procedure applies our best estimates of the distributions of parameter values to produce a distribution of results. Our approach contrasts with one in

Page 12	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3, Source Terms and Uncertainties

which a calculation is based upon point estimates of the various parameters and yields a single result. The Monte Carlo calculation carries the underlying uncertainty in the parameters forward and displays it in the breadth of the distribution of results.

This process was illustrated in the interim Task 2 and 3 report (Voillequé et al. 1991) by examining the distributions involved in the calculation of releases from the Plant 8 scrubbers for May 1961, and for that entire year. The estimated release from those scrubbers depends upon two parameters: the amount of uranium collected in the scrub liquor and the penetration of uranium through the scrubbers. The Monte Carlo procedure for estimating the Plant 8 scrubber releases involves independent selection of values of the two parameters and the use of the selected values to compute an estimate of the release. This procedure was performed repetitively (5000 times in the current example) and yielded a distribution of results.

S.

4.445

53650

2.17.1

X

6

Just as these source term estimates reflect the underlying variability and lack of knowledge about individual parameters, the radiation dose calculations, performed in a subsequent task (Task 6), will consider the range of source term values for a given year. They will also incorporate uncertainties about meteorological dispersion, particle deposition, and other parameters to produce distributions of estimated doses to people residing near the FMPC.

#### Sources of Information

A major effort in the Fernald Dosimetry Reconstruction Project has been searching for, and reviewing, hundreds of documents related to the operation of the Feed Materials Production Center since operations began in 1951. It has been our practice to trace the information back to original sources whenever possible. In the Task 1 report, issued in January 1991 (RAC 1991), we outlined the general approaches that we have taken to obtain this information. These five methods, which have formed the foundation for the project in providing the technical data for this study, are:

- site visits to the FMPC facility;
- investigation of records and scientific literature pertaining to the FMPC;
- retrieval and review of documents from NLO, Inc. using their computer database of document titles;
- --examination of engineering diagrams, site blueprints, historic photographs and maps; and
- discussions with current and former longtime employees.

Because we realized the importance of retrieving documents from a wide range of sources, considerable time has been spent identifying types and locations of reports and records pertinent to the completion of this project. We visited a number of locations around the country to review documents that might provide background information on FMPC operations (Figure 7). Generally, this documentation of FMPC operations and releases comes from two broad areas: (a) from National Lead Company of Ohio, Inc. (NLO), the former operator of the site, the Westinghouse Materials Company of Ohio (WMCO), the site operator from January 1, 1986 through 1992, and the Department of Energy (DOE); and (b) from FMPC-independent sources. Appendix A provides a detailed look at the sources and locations of documents used for the project.

Radionuclide Source Terms	
and Associated Uncertainties for 1951-1988	

While not all the original records are still available, many original documents remain in the files at the FMPC facility, in the library of the NLO offices, and in storage facilities utilized by WMCO. Many hours have been spent examining original plant documents, particularly those related to effluent discharge measurements and procedures. The information sources can be categorized as follows:

- processes descriptions for the various facilities
- plant operating procedures
- effluent sampling procedures
- daily and monthly reports of liquid effluent discharges
- monthly reports of airborne effluent discharges
- original analytical data sheets recording sample concentrations
- plant operating process logbooks
- nuclear materials control reports
- daily sump discharge logbooks
- topical reports related to effluent characteristics

reports of ventilation system tests and evaluations

incident reports

- invéstigation reports
- letter reports of operational problems
- production records for specific processes



**Figure 7.** Locations visited in obtaining FMPC-related documentation and information.

Discussions with long-time employees and retirees from the FMPC provided another source of information for the project (RAC 1991). Their recollections on processes and procedures that routinely occurred since facility start-up served to identify sources and

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page 13

<b>D</b> .	. 14
Par	re 14

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

With the la

÷

locations of documentation. Documents used in the construction of the source terms are referenced in the appropriate section of the text, with the references listed at the end of the appendix or section. In addition, we have maintained a collection of all documentation that we have reviewed since the Fernald Dosimetry Reconstruction project began in 1990. Appendix A lists all documents that have been added to the RAC Document Repository up to this time.

In general, data from original records used in this study are reported in the same units that appeared in the source documents. For example, the uranium concentrations in liquid effluents and volume measurements, compiled in Appendix L, are reported in mg  $L^{-1}$  and gallons, respectively. In contrast to some of the original sources of information, our final release estimates and results of other calculations are reported to only two significant figures.

#### ATMOSPHERIC RELEASES FROM DUST COLLECTORS

Atmospheric releases from FMPC operations came from buildings where uranium processing took place and from outside areas such as the waste pits and incinerators. Appendix K reviews estimates of emissions of uranium from miscellaneous unmonitored processes, non-routine events, and episodic releases. Some airborne effluents were treated with one of the two treatment systems used at the FMPC: scrubbers or dust collectors. These treatment systems are discussed in **Appendix B**. Dust collectors employed bag filters to remove airborne particulates from an exhaust stream. Information on effluents from dust collectors is presented in **Appendix E**. The key points of the dust collector operation and our estimates are presented here.

#### **Dust Collector Operation**

Process area ventilation air was ducted to dust collectors where airborne particulate material was removed before discharge through the stack to the outside. The dust collectors recovered valuable uranium that would otherwise be lost and reduced worker exposure in the process area. When operating as designed, the dust collector systems could be quite efficient (Drinker and Hatch 1956, Ross and Boback 1971).

The sampling systems installed in the dust collector stacks were simple in concept. A schematic diagram of the sampling system is drawn in Figure 8. Air was drawn from the exhaust stack through a sampling line to a pleated cellulose filter for collection of particulate material in the sample of discharged air. The filters were periodically changed and submitted for analysis. Details of the design and operation of these systems and of the sample analysis and data reporting are given in Appendix E.

Distribution to all the plants of an initial stack sampling procedure seems to have occurred in February 1956 (Starkey 1956). Later that year a formalized procedure was developed (Boone 1956). Initial sampling frequencies were weekly, biweekly, or monthly depending on the magnitude of the previous effluent measurements. Monthly reports of releases were made to plant management by the Industrial Hygiene and Radiation (IH&R) group.

The sequence of reports itself documents the onset and growth of the dust collector effluent sampling program. Periodic sampling of some stacks was performed as early as

•

1.14

1953; however, the continuous sampling program did not begin until April 1955. Initiated in seven stacks in Plant 4 and 5, the sampling program grew fairly rapidly to encompass thirty stacks six months later. There were increases in the 1950s to a maximum of 50 sampling systems in May 1958.



Figure 8. A schematic diagram of the dust collector stack sampling system.

At the start of 1960, there was a decline to 44 samplers for dust collector exhaust due to shutdown of systems in Plant 1 and in the Pilot Plant. At that time, the most common sampling interval was one month, although a few stacks were sampled more frequently. In the 1960s, sampling intervals were occasionally as long as six weeks for discharge points that were minor contributors to plant uranium releases. In later years, both plant production and staff were reduced. Intervals between sample analyses were greater and routine reports contained less detail. Filters were no longer changed and analyzed regularly. Filter changes and analysis occurred primarily when the filter had collected a visually detectable amount of particulate material.

#### Current Estimates of Release From FMPC Dust Collectors

Estimates of releases from individual dust collectors at the FMPC were tabulated from original records, which were usually monthly reports of the measurements. Review of the reported results revealed periods when samplers were not in operation and other times when the releases were too low to be detected. Estimates were made for these periods based on other sampling results and information about the sampling and analysis procedures.

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page 15

#### Page 16

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

3

Ï.

•

.

ż

ì

Ç

Estimates were also made for years before monitoring was established as a routine procedure. These estimates were based either upon normalized release rates soon after routine monitoring was established or representative measurements during the mid- to late-1950s. In some cases, evaluations of unmonitored effluents led to significant increases over previous release estimates.

There are two major deficiencies in the tabulations of reported releases in the monthly reports. The first is that the release estimates were incomplete. Release estimates were not provided for sampling periods when samplers were not installed or were not operational for the entire period. The second deficiency in the tabulations is the failure to properly account for undetected releases. If no material was detected on the filter from a dust collector exhaust sample, the reported release was shown as zero. There were entire months when either no samples were collected or no releases were detected in the dust collector exhausts because the total reported releases from some of the plants were zero. To develop a better estimate of the releases for this report, it was necessary to estimate the unmonitored and undetected releases by determining the maximum release that could have occurred when none was detected. The details of this method are given in Appendix E.

In addition to correcting for unmonitored and undetected releases, the initial releases estimates are subject to further revision to account for biases in the effluent measurements themselves. While the design of the sampling systems was generally well conceived, three types of deviations from ideal sampling conditions may have biased the dust collector discharge estimates.

Nonrepresentative sampling may have occurred when particles were not uniformly mixed in the exhaust at the location of the sampler. This is more likely to happen when the exhaust ducts are greater than 15 cm in diameter. The ANSI (1969) guide recommends multiple sample withdrawal points for ducts greater than 15 cm in diameter. The reason for multiple probes is to provide assurance that the samples will not be biased because of a nonuniform distribution of the contaminant in the stack. The sample extracted from the center of a dust collector exhaust stack would be representative if the particles were uniformly mixed in the exhaust or if the concentration on the centerline happened to be equal to the average concentration in the stack. When this is not the case, the sample is not representative of the material being discharged. The bias introduced may be positive or negative. A qualitative assessment of nonrepresentative sampling in presented in **Appendix G**.

Anisokinetic sampling may have occurred. This occurs when there is a mismatch between the fluid velocity in the probe and that in the stack. If the velocities are not the same, over- or under-sampling of particles of various sizes could occur. The possible effects of anisokinetic sampling conditions were calculated using the methods described in Appendix G. That appendix contains example calculations and the basis for parameters used in Monte Carlo calculations of bias due to anisokinetic sampling.

Losses of particles in the sampling line can occur when particles are deposited on the walls of the line, or when they are impacted due to the presence of bends in the lines between the probe and the collection filter. Neither topic has been addressed in 10.3

.

**م**ر.

previous analyses of the uranium release data. It should be emphasized that sample line losses lead only to underestimates of the effluent releases. The magnitudes of such losses depend upon particle size and density (**Appendix F**), the configuration of the sampling line, and the operating conditions for the line. These relationships are described in Appendix G.

A Monte Carlo procedure was used to estimate the sampling biases and their uncertainties. The calculations considered the three sources of bias identified above to obtain a measure of overall sampling bias. Major contributors to the uncertainty were the velocity of air in the sampling probe and in the duct, the bias due to nonrepresentative sampling, and a parameter used in computation of the attachment fractions. There is no simple way to reduce the largest uncertainties, which principally reflect the absence of information about conditions of past operations and sampling. Corrections for these biases are applied in estimating the dust collector uranium losses in **Appendix E**.

Once released from the stack, the physical and chemical characteristics of the uranium are important in the transport and deposition of released uranium and in the estimation of the radiation dose due to uranium inhalation.

Particle size distributions were measured for some of the effluent streams in 1985. Those data and information about other uranium processing facilities have been used to estimate particle size distributions for the dust collector exhausts in this report (See Appendix F and Appendix E). Particle-size distributions for the stack emissions measured in 1985 are included as a part of the source-term characterization for stacks for all years because the plant processes served by the stacks have not changed significantly since the start of FMPC operations. Appendix F contains information on the reported measurements done in 1985. The distributions cover wide ranges of particle sizes and are not truly lognormal. The ranges of particle sizes have been subdivided into intervals and representative sizes are used in the calculations. Average particle-size distributions for both the inlet and the outlet ducts for stacks emitting  $UF_4$  and  $U_3O_8$  were derived from the data in Appendix F. The average distributions and distributions obtained from similar facilities are used for FMPC exhausts for which particle size measurements were not made. In spite of some substantial variations from stack to stack, the particles were relatively large.

• The chemical form of the materials discharged from the dust collectors affects the particle density, the transport and deposition of released uranium, and the estimation of the radiation dose due to uranium inhalation. The predominant uranium species emitted from each stack was identified from FMPC reports and engineering drawings of process equipment. About three-fourths of the releases from the dust collectors were in the form of uranium oxides.

The process of developing revised estimates of releases from the FMPC dust collectors is complex. Reported releases were incomplete because sampling was not initiated when production began. The reported releases do not include estimates of releases that were

いたいい

undetected by the analytical procedure or because a sampling system was temporarily out of service. The three sources of possible bias in the reported results, discussed above, have been estimated as part of this effort.

The first step in the approach adopted was to return whenever possible to the original release reports that were prepared routinely by the IH&R department. In the early years of full operation of the effluent sampling program, these reports contained a great deal of information about sample collection and about operational problems in all the plants. These detailed reports made it possible to estimate the magnitudes of undetected releases. Later reports of results, when production rates and releases were lower, were not as detailed and were much less helpful in this regard. In general, inclusion of undetected releases does not have a large effect on the estimates for early years when releases were large. In plants whose releases were relatively small (tens of kilograms of uranium per year) the relative contribution of estimates of releases that had gone undetected was greater.

Overall, corrections for unmeasured releases and for sampling bias led to revised release estimates that were about 50% higher than previous estimates of dust collector releases. Table 1 shows that the median estimate of total releases from the FMPC dust collectors from 1951 to 1988 was about 140,000 kg uranium. Most releases occurred during the 1950s. Principal contributors to the releases during that decade were Plants 4, 7, and 5. Plant 8 also contributed significantly to the total, but most of those releases occurred over a longer period of time. Although releases from the other facilities were not small, those releases were not major fractions of the total release. However, some of the releases from plants that were lesser contributors to the total were important in individual years.

•	Best estimate of release	Other percentiles in distribution of release estimates (kg U)			
Period	(kg U)	5th percentile	25th percentile	75th percentile	95th percentile
1950s	120,000	96,000	110,000	130,000	150,000
1960s	21,000	18,000	19,000	22,000	24,000
1970s	3,100	2,500	2,800	3,400	3,800
: 1980s <sup>-</sup>	2,100	1,700	1,900	2,400	2,700
	and a star and a star a sta				· • · · · •
1988	140,000	120,000	130,000	160,000	170,000

#### Table 1. Summary Release Estimates for FMPC Dust Collectors

#### **DISCHARGES FROM PLANT 2/3 DENITRATION OPERATIONS**

The air emitted from release points not equipped with dust collectors was cleaned through scrubbers. Scrubbers used either acid or caustic solutions to scavenge particles from the air stream being discharged to the atmosphere. Most of the particles are scavenged by mist droplets, which, for the most part, are collected by mist-eliminating devices and recycled to the liquid reservoir. This liquid (*scrub liquor*) is changed periodically. The uranium-containing droplets accumulate on the mist-eliminators, and some of the liquid is agglomerated into larger droplets and escapes back into the exhaust gas stream in a process called *reentrainment*. Figure 9 illustrates these processes. In this manner, the scrubbers of Plant 2/3 and Plant 8 emitted liquid droplets of reentrained scrub liquor of varying uranium concentration.



5





Figure 9. Scrubber schematic. Exhaust gas entering the scrubber is forced through a liquid spray into a Venturi tube. The gas then passes through a separator chamber and into the outlet duct. The spray entrains most particles into liquid droplets. Most of the liquid (or scrub liquor) is collected in the separator chamber and returns to a reservoir from which it is recycled. The scrub liquor of the Plant 2/3 and Plant 8 scrubbers was changed periodically and uranium was recovered from it. To inhibit the escape of the uranium-containing droplets various mist-eliminating systems were used. The figure indicates a wire mesh mist eliminator in the outlet duct (as in Plant 2/3), which would trap most droplets. But some of the trapped liquid was reentrained into the gas stream as large agglomerates and escaped to the atmosphere. Evaporation of the liquid produced relatively large solid particles.

After 1956, exhausts from the *denitration* process in Plant 2/3 were treated by a wet scrubber prior to discharge to the atmosphere. In the denitration process, nitrates were removed from uranyl nitrate hexahydrate (UNH) to produce uranium trioxide (UO<sub>3</sub>, or orange oxide). Fumes of oxides of nitrogen that were produced during denitration were routed to the scrubber system. In a second process, orange oxide from the denitration pots was transferred by vacuum or "gulping" to a storage hopper. The releases of uranium from the scrubber exhausts were not sampled, even periodically, until recently. In June 1988, an investigation of higher than expected environmental radioactivity measurements led to the

Page 20

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

conclusion that releases from Plant 2/3 processing activities were the source of the observed higher offsite air concentrations (Investigation Board 1988). Appendix H provides details of the scrubber exhaust system, our current approach to estimating releases from the Plant 2/3 scrubbers, and previous release estimates. Because information is lacking on early operations with dust collectors, releases for those years are estimated using the same model used for years when the scrubbers were in operation.

Current release estimates are based upon a review of the following:

previous release estimates (Semones and Sverdrup 1988);

plant operating data from 1969, 1970 and 1973;

the Shift Foremen's Logs for 1956-1962 and 1967; and

uranium trioxide production data.

The log sheets and logbooks contained information on parameters important for the calculation of releases due to gulping operations. Uranium released from the Plant 2/3 scrubbers is composed of releases due to scrub liquor entrainment and to particles of UO3 in the air stream that pass through the scrubber. Independent estimates of releases from the Plant 2/3 scrubber system were performed using models of scrubber penetration by particles and mist reentrainment that were based upon the recent effluent measurements. Monte Carlo techniques were then used to sample the parameter distributions and the randomly selected parameter values were used to make the release estimates. The parameters considered in calculating the releases estimates are:

•	scrubber outage fraction		and the second second
•	scrub liquor concentration		
•	entrainment release factor	·· ·	
•	amount of UO <sub>3</sub> in a pot		
۰	gulping time		
•	gulping release factor.		

Estimates of Plant 2/3 scrubber releases obtained from the Monte Carlo calculations are shown in Table 2 by decade. Median estimates of releases during three of the four decades of operation are comparable, about 20,000 kg, while the value for the 1980s was much lower. The median release estimate for the entire period of operation was 66,000 kg uranium. This estimate was bounded by 5th and 95th percentile values of 56,000 and 78,000 kg uranium, respectively. The highest annual releases were estimated for the period 1957–1961.

. ,	Best Estimate of Release	Other percentiles in distril	oution of release e	stimate (kg U)
Period	(kg U)		75th	
1950s	24,000	18,000 21,000	26,000	32,000
1960s	19,000	14,000 17,000	21,000	25,000
1970s	. 22,000	17,000	25,000	29,000
1980s	980	730	1,100	1,600
1953-1988	66,000	56,000 - 62,000	71,000	78,000

a. É 5 1954 -

1

5

ŝ,

About 25% of the release is estimated to have been small particles of UO<sub>3</sub> that penetrated through the scrubber. The larger fraction (~75%) would have been uranyl nitrate hexahydrate (UNH). The estimated size range for these particles is 19-100  $\mu$ m. An alternative calculation of releases from the Plant 2/3 denitration operations, based on a change in the outage fraction, is described in Appendix H.

#### **RELEASES FROM PLANT 8 SCRUBBERS**

.

Descriptions of Plant 8 operations, scrubber efficiency measurements, and the basis for both previous and current release estimates are given in Appendix I of this report and in the Task 4 report (Killough et al. 1993). Ten air scrubbing systems in Plant 8 cleansed, or scrubbed, the exhaust air by contact with droplets of caustic liquid. Six of the scrubbers the rotary kiln, oxidation #1, the caustic or primary calciner, uranium ammonium phosphate (UAP) furnace, the oxidation #2 or NPR, and the green salt reverter—handled hot exhaust gases from the kiln and furnaces. The other four scrubbers—old digester, new digester, the ammonium diuranate (ADU), and the leach tank—treated ventilation air collected above the digestion and other process tanks. Some of the key findings that affect the current release estimates are:

• The exhausts from these systems were not sampled on a regular basis. Periodic measurements of discharge concentrations and of scrubber efficiencies were performed by the Industrial Hygiene and Radiation Department. A number of their measurements for the caustic, kiln, UAP, and NPR scrubbers were made during the early 1960s, a period of substantial concern about releases of uranium from these systems. In the early 1980s, when Plant 8 production was lower, measurements were made to determine emission factors for the Plant 8 scrubber discharges.

There were no reported measurements of the sizes of the particles or liquid droplets released to the atmosphere from the Plant 8 scrubbers. A theoretical analysis of Plant 8 scrubber operations was conducted to estimate these particle size distributions [see Appendix D of the Task 4 report (Killough et al. 1993)]. About 30% of the total uranium emitted from the Plant 8 scrubbers included solid particles of  $U_3O_8$  of less than 10 micrometers in diameter. The remainder of the released uranium from the scrubbers escaped as large droplets (80 to 180 µm in diameter) of reentrained scrub liquor. Evaporation of the liquid produced relatively large solid particles.

Previous estimates of releases from the Plant 8 scrubber systems were reviewed. An important difficulty with previous estimates of the Plant 8 scrubber releases was the assumption of a constant scrubber efficiency. Just as with these previous estimates, current estimates require knowledge of scrubber efficiencies and uranium concentrations in the scrubber liquor. Plant records were found in storage that provided data on the amounts of uranium scrubbed from the airborne effluents during periods ranging from one month to one year. Plant 8 production (uranium recovery) data were compiled to indicate the changing scale of plant operations. Memoranda and analytical data sheets were located that
described measurements of scrubber efficiencies performed in Plant 8, primarily during 1961-1965. These data were compiled for each scrubber for use in calculations of releases from 1953 through 1981. Data collected in the 1980s on short-term measurements of release rates from the various stacks were also compiled and used for calculations for this later period.

For the years 1953–1981, annual uranium releases from the Plant 8 scrubbers and the uncertainties associated with them were estimated by applying a simple model to each scrubber. The calculations used the following plant-specific data:

- Plant 8 production (uranium recovery) data;
- amounts of uranium found in scrub liquor; -
- the amount of uranium in scrub liquor per unit production;
- the use and performance of the scrubbers serving the calciner, rotary kiln, UAP furnace and the two oxidation furnaces.

For the latter years of FMPC operation (1982–1988), release estimates were based upon the operating times for the various scrubbers and release rate measurements that had been made during scrubber operation. For both time periods, simple models of releases were applied to individual scrubbers. When information on scrub liquor collections was not available, the 6- to 12-month average ratio of plant production to the amount of uranium collected in scrub liquor was found to be a reasonable link between production data and scrubber operations.

Monte Carlo calculations were performed to estimate uranium releases from the Plant 8 scrubbers. The ranges of all of the parameters used in calculations were relatively broad, owing both to variability and to limited historic data. Table 3 contains summary release estimates by decade and for the entire period from 1953 through 1988. The table illustrates the importance of the releases during the 1960s when plant production was highest. The median estimate for the 1950s was second highest, about 60% of that for the following full decade of operation. Alternative calculations of releases from the Plant 8 scrubbers, performed to test the effect of different modeling choices on the results, are described in Appendix I. The first alternative used correlations between scrubber penetration and the accumulation of uranium in the scrub liquor for the calculation. The second alternative approach was based on ratios of release to production for the early 1960s, when the scrubbers were studied most intensively. These ratios were applied to the entire period of operation.

The release estimates for the Plant 8 scrubbers that are summarized in the table are higher than previous FMPC estimates. The fundamental reason for the difference is that the present calculations consider ranges of individual scrubber performance that are broader than the single collection efficiency of 83 percent that had been assumed for all of the scrubbers.

Analysis of the Plant 8 scrubber releases suggests that two distinct types of particles were present in the emissions. The first type consisted of solid particles of  $U_3O_8$  of less than 10 micrometers in diameter which penetrated the scrubber systems. The second type was droplets of entrained scrub liquor that contained suspended uranium particles. During the first two decades, when releases were highest, it is estimated that about 25% of the releases were of small particles of  $U_3O_8$  and that the remainder were the result of entrainment of contaminated scrub liquor containing suspensions of uranium compounds Radionuclide Source Terms and Associated Uncertainties for 1951-1988 Table 3. Summary Release Estimates for Plant 8 Scrubbers Best Estimate

	of Release	Other percent	<u>tiles in distribut</u>	<u>cion of release e</u>	stimate (kg
Period	(kg U)	<u>5th</u>	25th	<u>75th</u>	95th
1950s	29,000	17,000	23,000	37,000	53,000
1960sª	47,000	30,000	39,000	57,000	78,000
1970s	1,700	1,000	1,400	2,100	2,700
1980s.	1,400	980	1,200	1,600	2,000
1953-1988	81,000	56,000	69,000	95,000	130,000

Page 23 -

To put these atmospheric releases into perspective, Figure 10 compares the uranium released annually from the dust collectors, the Plant 8 scrubbers, and the Plant 2/3 denitration processes. The dust collectors dominated the releases in the 1950s with 120,000 kg of uranium released, with a maximum of 54,000 kg of uranium released from them in 1955 alone. In the 1960s, the Plant 8 scrubbers dominated the releases, with approximately 47,000 kg uranium released during that decade, compared to 21,000 and 19,000 kg U for the dust collectors and Plant 2/3 scrubbers, respectively. In the 1970s, the Plant 2/3 scrubbers were relatively more important, discharging 22,000 kg U, compared to 3,100 and 1,700 kg U, respectively for the dust collectors and Plant 8 scrubbers. Again in the 1980s, the dust collectors contributed most to the total uranium releases, although the magnitude of all releases in the 1980s was significantly less than at any other time.



Figure 10. The best estimates of annual releases of uranium to the atmosphere from the Plant 8 scrubbers (square), the dust collectors (triangle) and the Plant 2/3 scrubbers (circle). The relative importance of each of these sources to the total atmospheric uranium release changes with each decade.

Radiological Assessments Corporation "Setting the standard in environmental health"

•

13

 $\tilde{\mathcal{A}}^{(n)}$ 

Page 24

2

# OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE

**Appendix** K addresses other miscellaneous unmonitored sources and accidental releases to the atmosphere. The unmonitored sources include emissions from:

- five waste incinerators,
- building exhaust and lab hood ventilation,
- miscellaneous unmonitored process emissions, and
- the waste pits.

Accidental releases include:

- non-routine events, and
- episodic releases.

Episodic releases are actual accidental releases which occurred in the past, and which were large enough to be given special treatment in terms of environmental transport and dose assessment. In addition to actual episodic releases, non-routine releases from other events, such as spills, fires and leaks of gaseous uranium hexafluoride and uranyl nitrate, were estimated in a generic way based on the frequency of occurrence of such events. Table 4 presents the total release estimates from the miscellaneous unmonitored sources. In addition, the table illustrates the difference between our reconstructed source terms and those previously developed by the FMPC contractor. In contrast to previous estimates, the reconstructed source terms all carry some estimate of uncertainty and are well documented.

Releases from these sources were more thoroughly examined than they had been in the interim source term report (Voillequé et al. 1991). There, only a few revised source term estimates were developed. Although releases from these sources were believed to be relatively minor compared with the dust collectors and scrubber emissions, the documentation to support that conclusion was lacking in most cases, and some of the previous methods used to estimate releases needed improvement. The detailed assessments in Appendix K provide thorough documentation of the magnitude of these sources, with uncertainties.

**Miscellaneous Unmonitored Emissions** 

The agreement between past and revised release estimates is good for the incinerators. Of all incinerators at the FMPC, the old solid waste incinerator had the highest total release of uranium, with a median estimate of 2200 kg. The reconstructed median release estimate from building ventilation or exhausts (4100 kg U) is over ten times higher than the previous estimate, due to two main reasons:

(1) the use of lower dilution factor for building make-up air, and

(2) the use of higher in-plant airborne contamination levels, measured in the 1950s, to make a forward projection through 1970.

The median release estimate for non-routine releases (1300 kg U) is less than that previously calculated by Vaaler and Nuhfer (1988), although the 5th and 95th percentile range encompasses the previous estimate. The median estimate of releases from the waste

#### Radionuclide Source Terms and Associated Uncertainties for 1951–1988

ينبغ الم

pits (3000 kg U) was about twice as high as previous results, because we used a model (i.e., the resuspension algorithms found in MILDOS) that was highly sensitive to soil particle size which varied greatly among the pits.

		Total Relea	ase Estimate (kg U)	<u> </u>
			5th-95th	Previous
Source	Inclusive Dates	Median	Percentile Range	Estimate <sup>a</sup> -
Miscellaneous Unmoni	tored Releases			•
Old Solid Waste Incinerator	1954–1979	2200	1600-2900	2471
Oil Burner	1962-1979	370	270-470	467
Graphite Burner	1965–1984	230	61–730	129
New Solid Waste Incinerator	1979–1986	8	0.6–90	14
Liquid Waste Incinerator	1983–1986	4	0.9–9	12 <sup>d</sup>
Building Ventilation	1954-1987	4100	970–15,000	390
Unmonitored Process Emissions	1953–1988	b	110-970°	′ 324
Lab Hoods	1953-1987	b	20-200°	66.5
Waste Pits	1953-1988	<b>3000</b> Car	900-12,000	1560
Accidental Releases			.•	
Non-routine Releases <sup>e</sup>	1952–1988	1300	780–2900	2784
Episodic Releases <sup>f</sup>	1953, 1960, 1966, 1978, 1979, 1983	1700 <sup>f</sup>	1300–2100 <sup>r</sup>	Not defined previously

# Table 4. Summary of Total Estimated Releases of Uranium from Miscellaneous Unmonitored and Accidental Sources at the FMPC

<sup>a</sup> From FMPC operating contractor. See individual sections of Appendix K for sources of information.

<sup>b</sup> Not reconstructed; estimate developed previously by the FMPC contractor.

<sup>c</sup> Subjective uncertainty of a factor of 3 applied to previous estimate.

<sup>d</sup> Based on maximum processing rate.

<sup>e</sup> Includes fires, spills, and leaks of uranium hexafluoride and uranyl nitrate.

<sup>f</sup> Does not include the November 1960 episodic release from the Pilot Plant dust collectors, which is included in the total dust collector source term. Does include two accidental releases of uranium hexafluoride and three releases (unknown sources) identified from ambient air monitoring.

Page 25

H. . .

÷.,

5.4

1 1

Sec. 18

MARY 14

. .

5

### **Accidental Releases**

Accidental releases are frequently characterized as increases in the effluent discharge rates due to unplanned and non-routine events. In previous historic reports, typical events included spills, fires, and cleanup system failures. However, when the frequency of the unusual events is high, one questions whether the adjective "accidental" is correct. Similarly, when a large release is the result of a conscious operational decision, it hardly qualifies as unplanned. Such situations complicate the definition of the term accidental releases; so the term "episodic releases" has been defined and used in the Fernald Dose Reconstruction Project. Criteria for an episodic release, discussed fully in **Appendix K**, that were used to determine whether special evaluation of a release from a particular event is warranted include:

- the event under consideration caused the composite release rate of the FMPC to increase by a factor of ten or more above the value that would otherwise have been observed, and
- the duration of the high release rate caused by the particular event was less than 10 days.

Six incidents involving releases of uranium were identified which met our criteria for special treatment as episodic releases. It should be emphasized that all known releases are included in the total source term estimates, but only a small number are truly episodic releases, by our definition. Three episodes, documented in incident reports, occurred on November 7, 1953, in November 1960, and on February 14, 1966. The remaining three episodes were identified by air monitoring data, although documentation could not be found to identify the sources. These events occurred sometime during the weeks ending on September 28, 1978, February 8, 1979, and September 20, 1983. In terms of total quantity of uranium released, the dust loss episode in November 1960 had the most impact. However, the episode on February 14, 1966 had the largest release rate, releasing 750 kg U in one hour. A release of about 30 Ci of radon occurred on April 25, 1986, from unauthorized venting of the K-65 silos. This source term may also be treated separately as an episodic release.

Figure 11 compares the relative importance of the various unmonitored sources with releases from the dust collectors, the Plant 2/3 denitration operations and the Plant 8 scrubbers. It is clear that the magnitude of uranium releases from the miscellaneous unmonitored sources is minor relative to the three major sources of atmospheric emissions from the FMPC (Figure 10). When all of the miscellaneous sources investigated in Appendix K are combined, using appropriate statistical measures, the grand total of the releases is 16,000 kg (median estimate), with a 5th-95th percentile range of 9,300 to 28,000 kg. This total does not include the November 1960 dust loss from the Pilot Plant, which is included with the total dust collector source term.

Class of the Pro-

Page 26



.....

.

5



**Figure 11.** Relative importance of miscellaneous unmonitored sources of atmospheric releases of uranium compared with releases through scrubbers and dust collectors. The 50% point represents the median (best estimate). The 5% and 95% points encompass a 90% probability range on the total estimates. Figure 11a is plotted on a logarithmic scale, so that the uncertainty distributions can be seen more clearly, while Figure 11b is plotted using a linear scale, which more accurately illustrates the true relative magnitude of these sources.

#### Page 28

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

2

にんりいとう

1.44.4.22

1

Sec. Starie

44, U-

ť,

N 1274

1

#### RADON AND DECAY PRODUCT RELEASES FROM K-65 SILOS AND MATERIALS

The main source of radon-222 release from the FMPC is material stored in the K-65 silos, which contain residue, called K-65 material, from the extraction of uranium from pitchblende or other uranium ores. Originally, the waste residues from the processing, including the K-65 material, were to be returned to the supplier, the African Metals Corporation. On an "interim" basis, the wastes were stored at processing facilities, where they remain. The K-65 material contains very high concentrations of radium-226, and consequently, is a significant source of radon-222 emissions.

The K-65 material at the FMPC has primarily been stored in large concrete storage tanks, called the K-65 Silos, located in the waste storage area of the site. Figure 2 shows the location of the K-65 Silos, as well as two other waste storage silos. Silo 3, the Metal Oxide Silo, contains the metal oxide waste material, another waste residue from the extraction processing of uranium ores. The metal oxide material is also contaminated with radioactivity, but the concentration of radium-226 is much lower than in the K-65 material. Silo 4 has never been used, and contains only a small quantity of water with very low levels of radioactive and chemical contaminants. The Metal Oxide Silo and Silo 4 are not considered significant sources of radon-222 releases. Belgian Congo uranium ores were also processed at the Mallinckrodt Chemical Works (MCW) facility in St. Louis. Due to insufficient storage capacity at MCW, K-65 material from MCW was shipped to the FMPC, beginning in 1951, before construction of the K-65 Silos was complete. That K-65 material was stored in 55-gallon drums on the storage pad around Plant 1.

Appendix J contains the detailed descriptions of the radon-222 and radon daughter release estimates, including more information about the K-65 and metal oxide materials and storage silos; a summary of previous estimates of radon releases, by others; a discussion of potential radon sources at the FMPC; descriptions of our calculational strategies for current estimates of releases; models and calculated releases for the different time periods assessed; and a discussion of an alternative calculation, for comparison with current estimates. The following sections provide some information about the history of K-65 materials at the FMPC, and our estimates of radon-222 and radon decay releases from the site.

## History of K-65 Silos and K-65 Material at the FMPC

The K-65 Silos were constructed in August 1951 through July 1952 for storage of K-65 materials. However, MCW began shipping K-65 material to the FMPC before construction of the FMPC silos was complete. By the end of July 1952, about 13,000 55-gallon drums of K-65 material (equal to about half the capacity of one Silo) had been received at the FMPC. Before disposal in the Silos began, the drummed K-65 material was stored on the concrete ore storage pad around Plant 1, the Sampling Plant, for the period September 1951-mid-June 1953. The K-65 material was added to the Silos from July 1952 through September 1958. We thus calculate radon-222 and radon decay product releases from:

• the K-65 Silos, and

• stored drums of K-65 material on the storage pad near Plant 1 for 1951–1953.

The K-65 Silos have had problems of deterioration, almost since the time of construction. Significant cracking in the walls and seepage of the contents was noted from the 1950s (Wunder 1954; Martin 1957). Because of these problems, repairs and improvements to the

#### Radionuclide Source Terms and Associated Uncertainties for 1951–1988

Page 29

Silos occurred from the 1960s through the 1980s. Not all of the changes to the Silos would have had a significant effect on the releases of radon. The most important change, for radon emissions, was the sealing of penetrations of the Silo domes in 1979. This action would have significantly reduced the ventilation of the silo air spaces, and thus also reduced the radon releases from the Silos. The addition of an exterior foam layer on the silo domes in 1987 may have further reduced the emissions of radon. Earthen berms were built around the Silos in 1964. However, at that time the radon releases occurred primarily through openings in the silo domes, so the addition of the berms would not have altered the releases.

Based on these changes to the K-65 Silos and on the operational periods of them, we estimate radon and radon daughter releases from the silos separately for each of the following periods:

- mid-July 1952 to mid-June 1953 (operational period for Silo 1)
- mid-June 1953 to mid-September 1958 (operational period of Silo 2)
- mid-September 1958 to June 1979 (both silos inactive; prior to sealing penetrations),
- July 1979-to December 1987 (both silos inactive; after sealing penetrations), and
- 1988 (1988 is the last year of concern for this project).

#### **Current Estimates of Radon Releases**

. .

2

For some other releases at the FMPC, extensive data sets of direct measurements of release quantities are available. However, for radon and radon decay product releases there are no direct measurements of release quantities. In addition, until the 1980s there were very few measurements of parameters that can be used indirectly to calculate radon releases. Because of this limited availability of data, we use models to estimate radon release quantities.

The traditional model used to estimate radon releases from radium-226-bearing material, such as uranium mill tailings, involves calculations of the quantity of radon formed in the material, and the subsequent diffusion of the radon through the material to the outside air. For the K-65 materials, measurements have not been made of the radon diffusion coefficient and radon emanation fraction, which are two key parameters in this traditional calculation. Literature values can be obtained for these parameters, but without site-specific values, the uncertainty ranges are extremely large. To reduce the uncertainties in our results, we have used different models, which we believe make the best use of the limited data that are available. Appendix J describes the available, useful information; the information lacking, that would be useful to improve estimates; and the general approach to estimating radon releases. The methods used for 1980–1987 are generally similar to those used in previous release estimates (Borak 1985; IT 1989; Grumski 1987; Boback et al. 1987), though additional data have been obtained and used.

There are no direct data available for estimating releases of radon decay products. Thus, radon decay product releases are calculated to be equal to radon releases multiplied by two correction factors. The first correction factor accounts for the expected ratio of radon decay product concentrations in the silo air to the radon concentration (equilibrium fraction). The second is a fractional release factor, that accounts for deposition of radon decay products along the release path (such as cracks in the silo domes, or penetrations in the domes), which reduces the quantities of decay products released.

30	The Fornald Designatry Reconstruction Project
~~	The Fernald Dosinietry Reconstruction Froject
	Tasks 2 and 3 Source Terms and Uncertainties
	rashs 2 and 0, bounce rennis and Oncertainties

Page

As for other releases, we use Monte Carlo methods to perform the calculations of radon and radon decay product releases, so that uncertainties are calculated along with best estimates. The estimated release rates from the K-65 Silos are plotted versus time in Figure .12. The cumulative quantity of radon released from the K-65 Silos for 1959–1979 is larger than for other periods, due to the length of this period and the higher release rate for the period. Releases for this period may also be important in terms of potential doses to offsite people. The predicted radon release rate from the K-65 Silos remained elevated through most of the 1970s, while uranium releases to air generally decreased through the 1970s compared to the 1960s (see Figure 10 and Table 11).

The predicted total quantities of radon released from the FMPC for 1951-1988, are summarized in Table 5. From this summary, it can be seen that radon releases from the drummed K-65 material stored on the Plant 1 pad are relatively insignificant contributors to the total radon releases for the period 1951-1988. However, the radon releases from the drummed K-65 material occurred when operations at the FMPC were just beginning and releases of uranium were relatively small. Consequently, radon releases from the drummed K-65 material may be significant contributors to site-wide releases of all radionuclides from 1951-1953.

. 1772 .



Figure 12. Estimated radon-222 release rates from the K-65 Silos as a function of time. The periods indicated are only the nominal periods; the more precise dates are given in Appendix J.

and the second sec

مېر.

1

-

1

 $\mathbf{\hat{z}}_{i}$ 

Table 5. S	Summary of	Predicted 1	Fotal Radon	and Radon	Decay	Product	Release
	Quantiti	es (Ci) from	the FMPC f	or the Perio	d 1951-	-1988	

	Ra	don releas	ed	Decay	products r	eleased <sup>a</sup>
Source of releases	5th	median	95th	 5th	median	95th
K-65 Silos	110,000	170,000	230,000	87,000	130,000	190,000
Drummed K-65 material stored on Plant 1 pad	54	720	3,400	4.5	130	880
Both sources	. 110,000	170,000	230,000	87,000	130,000	190,000

short-lived decay products, polonium-218, lead-214, bismuth-214, and polonium-214.

Table 6 presents a comparison of our results with previous estimates of the emissions of radon from the K-65 Silos. The other studies did not report uncertainties associated with the release rate estimates. However, results of the other studies generally fall within, or close to, our 90% probability interval (5th to 95th percentile) of release rates.

Table 6. Comparisons of Current Estimates of Radon Release Rates (Ci y<sup>-1</sup>) from K-65 Silos to Release Rates from Other Studies

	Percentiles of our estimates		timates	Resu	ılts of other studies
Period, release pathway	5th	median	 95th	Value	Reference
1980–1987, diffusion	72	130	· 240	60 <sup>a</sup> ·	Borak 1985; IT 1989 <sup>b</sup>
1980–1987, air exchange	230	810	1600	1023 <sup>a</sup>	IT 1989 <sup>b</sup>
1980–1987, total	360	950	1700	1083 <sup>a</sup>	IT 1989 <sup>b</sup>
1988, total	120	540	1300	1150 <sup>b</sup> .	Hamilton et al. 1993

<sup>a</sup> These results were considered by IT (1989b) to apply to the complete period 1953-1984, but we believe that the conditions and parameters used to develop the estimates were only valid for the period July 1979-1987.

<sup>h</sup> This result was the average release rate calculated for 1989–1990. We compare it to our results for 1988 because we believe conditions of the Silos were unchanged for 1988–1991.

We did an alternative calculation of radon releases using more conventional methods. This method estimates radon releases that would exist if the Silo domes did not cover the K-65 material. The results of the alternative method are generally consistent with, but not as satisfactory as the current methodology because of very large uncertainties and the apparent underprediction of the radon releases.

#### DIRECT EXPOSURES FROM GAMMA RADIATION FROM THE SILOS

Radium-226 and other radionuclides in the materials stored in the K-65 and Metal Oxide Silos produce emissions of gamma radiation, which may have exposed people outside the FMPC. In our Task 4 Report (Killough et al. 1993), we described the methodology to be

Ś

なるため

.....

used to calculate exposures and doses due to this direct radiation. Exposure rates will be calculated using the MicroShield 4 computer software (Negin and Worku 1992). In Appendix J, we provide additional information, necessary to complete the exposure calculations that will be reported in the Task 6 report.

The two K-65 (Silos 1 and 2) and the Metal Oxide (Silo 3) Silos are the only significant sources of direct radiation exposures to people outside the FMPC boundary. This conclusion is based on the results of aerial radiation surveys of the FMPC site and surrounding area, and results of penetrating radiation monitoring performed by the FMPC along the site boundary. Additional information is used for direct exposure calculations, including:

concentrations of radionuclides in the Silos 1,2 and 3,

concentrations of radionuclides in the air space of the K-65 Silos,

densities and moisture content of the materials stored in the Silos, and

information about the time-history of filling of the K-65 Silos.

#### LIQUID WASTE DISCHARGES FROM FMPC

Liquid wastes that are generated at the FMPC come from three main sources: process water via the clearwell portion of the waste pit, sanitary sewage, and storm water. Figure 2 shows that liquid effluent streams from FMPC are released to the offsite environment at two locations. These are (1) the combined sewer outfall which discharges through Manhole 175 into the Great Miami River at a point almost directly east of the plant site, about three miles upstream from New Baltimore and (2) the storm sewer outfall which discharges into a branch of Paddy's Run onsite. Appendix L provides more detailed descriptions of the principal contributors to liquid discharges from the FMPC and the types of documentation used to tabulate the discharges.

#### Releases of Uranium in Liquid Effluents from the FMPC

To the Great Miami River. Manhole 175, located on the eastern side of the facility, is the discharge point for waste water leaving the site through the main effluent line to the Great Miami River. It is the final junction point of the major waste effluent streams from the facility. The discharge flow to the Miami River was continuously measured. A composite sample was collected and analyzed for uranium on a daily basis. These daily uranium measurements were found for most years in the 1950s and 1960s. Daily flow rate measurements were located for 1958-1964, and monthly totals were available for later years. When specific information was not located for a particular month, an average value, based on the other months in the same year, was used.

The quantity of uranium released to the river is the product of the uranium concentration multiplied by the flow volume. Sources of uncertainty for these estimates of uranium losses through Manhole 175 to the Great Miami River come primarily from the analytical errors in measuring effluent flow, and in sampling and measuring uranium concentrations in the water.

To Paddy's Run. Runoff water collected in the storm sewer system passed through the storm sewer lift station before release through Manhole 175 to the river. Since the storm sewer lift station was not connected to any process, all the uranium lost through it was assumed to be from leaks and spills (Ross, 1972). When the capacity of the storm sewer lift station was reached, water overflowed through the storm sewer outfall to Paddy's Run. The volume of storm water that overflowed the storm sewer lift station was related to rainfall amounts and patterns.

Estimates of uranium losses from the storm sewer outfall to Paddy's Run were based upon analytical data sheets and monthly reports which listed the individual outfall events occurring during that month. There are three major components of uncertainty associated with estimation of uranium losses to Paddy's Run:

- the analytical errors associated with determining uranium concentration and water flow before discharge to Paddy's Run.
- time periods when rainfall, and consequently runoff, were quite high and the capacity of the storm sewer lift station flow meter and v-notch weir at Paddy's Run was exceeded.
- unmeasured losses from the site above the point where the storm sewer outfall enters Paddy's Run (where the measured losses were recorded).

Figure 13 shows the annual uranium release estimates to the Great Miami River and to Paddy's Run for all years. The magnitude of the uranium releases to the river peaked in 1961 with  $7300 \pm 140$  kg uranium. From 1974 onward, the annual releases were below 1000 kg. The uranium losses to Paddy's Run show much more month-to-month variation than do the uranium losses to Manhole 175 (MH 175). However, the average quantity of 500 kg uranium discharged through Manhole 175 to the Great Miami River each month during the early 1960s was roughly five times greater than the average quantity of 100 kg of uranium lost to Paddy's Run during that same time.

#### Other Radionuclides Released in Liquid Effluents

Release estimates for thorium, radium-226, radium-228, and fission and activation products are based on correlations between the total annual releases of uranium and those of the other radionuclides. These ratios of releases, computed for years when measurements were made, provide a basis for estimating the release of the other radionuclides for years when they were not measured. This methodology is described in Appendix D in the present report, and in Appendix C of Task 4 (Killough et al. 1993). Ratios of the annual average activity of a radionuclide (or quantity of thorium) to the annual uranium quantity were calculated for years when data were available. The measured concentrations at MH 175 reported in analytical data sheets were used to calculate the ratio for some years. Annual average concentrations of radium, thorium and the fission and activation products in liquid effluents were reported by the FMPC in historic release reports (Boback et al. 1987), and in annual environmental monitoring reports beginning in 1976. The variability of the release ratio from year to year was considered in deriving the uncertainty associated with the estimated releases of these other radionuclides. The release estimates and uncertainty analysis were computed using Monte Carlo techniques in the Crystal Ball® program (Decisioneering 1993).



Figure 13. Uranium losses to the Great Miami River via Manhole 175 and to Paddy's Run from the FMPC from 1952–1988. The uncertainty of each estimate is described by the 95th percentile (top, broken line), and the 5th percentile (lower, dotted line).

Table 7 summarizes our estimates for releases of materials in liquid effluents from the FMPC for all years of operation. Our best estimate of uranium released to the Great Miami River for all years is 82,000 kg. The 5th to 95th percentile uncertainty range is 71,000 to 94,000 kg of uranium. Some estimates of uranium in liquid wastes have been made by others on an annual basis (Boback 1971), or, in summary reports evaluating the past discharge history of the facility (Rathgens 1974, Boback et al., 1985). These estimates of uranium to surface water from 1951 through 1984 range from 74,000 to 77,000 kg (Boback et al., 1987, Galper 1988) and fall within the uncertainty range of our estimates. Revisions to historic discharge reports generally focused on amending estimates of uranium loss to airborne effluents, and did not include updated figures for liquid effluents (Boback et al. 1985, Boback et al. 1987).

The total release estimate for uranium to Paddy's Run via the storm sewer outfall ditch and runoff is 17,000 kg of uranium. The 5th to 95th percentile uncertainty range is 14,000 to 20,000 kg of uranium. Losses to Paddy's Run show much more month to month variation than do the uranium loss estimates to the Great Miami River. The highest annual releases of uranium occurred from 1960 to 1964, when the average quantity of uranium discharged through MH 175 to the river was approximately 500 kg each month, about 3 to 4 times greater than the average quantity of uranium lost to Paddy's Run each month.

The other materials released at various times over the years include decay, fission and activation products of uranium, thorium and recycled uranium. Recycled uranium was not processed at the site until late 1962, so releases of fission and activation products would not have begun until that time. Releases of thorium, and one of its decay products, radium-228, occurred when thorium was processed at the site in 1954–1957, and 1964–1988. Releases of radium-226 occurred throughout the history of the site; and the total release is estimated at

Ņ

うちょうぞく

ę.

ġ

Ċ

ŝ.

Ĕ.

#### Radionuclide Source Terms and Associated Uncertainties for 1951–1988

÷.,

÷ -

18,000 mCi or 18 Ci, with an uncertainty range of 15 to 22 Ci. These values will be used to calculate radiation doses to the population in the vicinity of the FMPC in our final task report.

Material Released to Great		Uncertainty Range
Miami River	Median Value	(5th %ile to 95th %ile)
	Quantity (kg)	Quantity (kg)
Uranium	82,000	71,000 to 94,000
Uranium (To Paddy's Run)	17,000	14,000 to 20,000
Thorium	5,800	3800 to 9400
, a	Activity (Ci)	Activity (Ci)
Radium-228	2.7	0.33 to 20
Radium-226	18	15 to 22
Plutonium-239,240	0.0088	0.0019 to 0.033
Plutonium-238	0.00028	0.00016 to 0.0034
Neptunium-237	0.0044	0.0011 to 0.018
Cesium-137	0.54	0.14 to 1.9
Ruthenium-106	0.056	0.014 to 0.22
Technetium-99	300	110 to 800
Strontium-90	6.0	1.5 to 24

# Table 7. Summary of Total Estimates of Radioactive Materials Released From theFMPC in Liquid Effluents For All Years of Operation

The chemical form of uranium in liquid effluents is not known with certainty, but several uranium species of both the +4 and +6 oxidation states may have been present in solution in liquid waste streams during this period. The ratios of these various ionic species in the process waste streams, in Paddy's Run, or in the main effluent pipeline to the river, would be a function of the pH of the water. The presence of suspended solids in the liquid wastes is considered in assessing the relative solubility of uranium in liquid releases. Daily measurements of total suspended solids (TSS) were made on 24-hour composite effluent samples at MH 175 beginning in 1956 (NLCO 1956). Among the suspended solids may have been very small particulates of the insoluble  $U_3O_8$  and  $UO_2$ . Not all the suspended solids measured on a daily basis were uranium, but the average monthly values may provide an upper bound, or conservative estimate, for the amount of insoluble uranium that was released in liquid effluent. Furthermore, some uranium-containing suspended solids that were released into the waste streams might have dissolved during dilution downstream from the FMPC.

#### URANIUM CONTAMINATION IN GROUNDWATER OUTSIDE THE FMPC

Contamination of the groundwater could occur either by direct discharge of waste waters to it or by infiltration of contaminated water through the soil. No evidence of direct discharges to the groundwater from the facility has been found in review of historic documents. Concern about the infiltration pathway has been evident in FMPC documents

	•	
Page 36		The Fernald Dosimetry Reconstruction Project
		Tasks 2 and 3 Source Terms and Uncertainties

since the late 1950s, and a variety of studies and analyses have been conducted from that time to the present day (Eye 1961, Dove and Norris 1951, Hartsock 1960, Spieker and Norris 1962). Recent reports describe the measured contamination levels in groundwater, primarily to the south and southwest of the FMPC that have resulted from infiltration of water bearing uranium to the aquifer (GeoTrans 1985, ASI-IT 1990). Uranium contamination of groundwater outside the FMPC has been known since late 1981, when the first samples of water from private wells were analyzed. The significant offsite uranium contamination in groundwater is south of the site, and is now called the "South Plume." There are additional known areas of groundwater contamination on the FMPC site, but only the South Plume area extends outside the site boundary. Since this dose reconstruction project is concerned with past doses to people around the site, the groundwater contamination under consideration here is limited to the South Plume. Figure 14 shows the estimated area of the South Plume contamination, as of 1991. Also shown are the locations of the private wells sampled by the FMPC monitoring program.

In our Task 4 report (Killough et al. 1993), we examined the potential importance of the groundwater contamination for doses to people around the FMPC. It was shown that only three of the private wells monitored, numbers 12, 15, and 17, have had measured uranium concentrations above the range of background. Although well 26 is within the area of groundwater contamination, it is installed deeper in the aquifer, and the uranium concentrations are at background levels. We concluded that because of the limited area of the South Plume, only a small number of people would have potentially received radiation doses from contaminated groundwater. Toward the main objective of this project, the determination of the feasibility of an epidemiological study, doses to these people would be less significant to the collective population dose than doses through other pathways. For this reason, we further concluded that a detailed assessment of the groundwater transport of radionuclides, and detailed assessments of doses to individuals potentially exposed through groundwater pathways, are not warranted. For other project objectives, it is still important to estimate potential doses through the groundwater pathway, so instead we use simple methods to estimate concentrations of uranium in the three contaminated wells. Appendix M contains details of our groundwater assessments.

2

# Potential Sources of Groundwater Contamination

The status of groundwater contamination in the vicinity of the FMPC has been investigated. Appendix M describes a special study that was conducted to determine the primary transport pathway for uranium deposited on soil around the FMPC. The study compared uranium migration due to infiltration, surface soil erosion, and surface water runoff. Results of the study show that uranium deposited on soils is primarily transported by infiltration and that soil erosion transports the least amount of uranium. There are two potential sources of groundwater contamination originating on the FMPC site (see Figure 14): (1) historical releases of uranium-contaminated water to Paddy's Run and to the Storm Sewer Outfall Ditch (SSOD), and (2) possible releases from the solid and liquid waste pits in the waste storage area.

Of these two potential sources, the principal source of uranium contamination in the South Plume has been determined to be the historical releases to Paddy's Run and the SSOD (DOE 1990). The bottom sediments of Paddy's Run and the SSOD are very permeable

#### Radionuclide Source Terms and Associated Uncertainties for 1951–1988

· · ·

, · ·

in the area north and west of the South Plume, so these areas are recharge areas for the regional aquifer. Thus, uranium contamination in Paddy's Run and the SSOD percolates downward through the permeable sediments to ultimately reach the groundwater.



Figure 14. Approximate area of uranium contamination in the South Plume at the end of 1991, and locations of the private wells around the FMPC sampled in the FMPC routine monitoring program. Sampling point W7 is a location for sampling the surface water in Paddy's Run, at the Willey Road bridge.

#### Estimated Uranium Concentrations in Private Wells

A preliminary investigation of the movement of contaminated groundwater was performed, to determine the transport times required for uranium contamination to move from the source (waters in Paddy's Run and the SSOD) to offsite locations. The study is described more fully in Appendix M. Based on results of this preliminary assessment, we concluded that the South Plume would not have reached the offsite private wells in the South Plume area until after 1962. Thus, exposures of people using wells in the South Plume might have occurred from 1963 onward.

Monitoring of the three contaminated wells (wells 12, 15 and 17) was initiated in late 1981. Routine monitoring of these wells, as well as other private wells, has been performed by the FMPC since 1982. We obtained results of monthly measurements of uranium

ç :

Sec. 15

1

CONTRACT.

concentration in well water for the three contaminated wells for late 1981 through 1992. Annual average uranium concentrations are shown in Table 8. The annual average concentrations for 1982-1988 will be used as the basis of dosimetry calculations for these years.

For the period 1963-1981, for which well monitoring was not performed, we used models to estimate concentrations of uranium that might have existed in well water of the South Plume. We first developed an estimated upper bound on the annual average uranium concentration that could have existed in wells 12, 15, and 17. As mentioned above, the primary source of uranium contamination of the South Plume has been determined to be uranium-bearing waters released into Paddy's Run and the SSOD. Thus, uranium concentrations in the groundwater are expected to be at the most, equal to concentrations in Paddy's Run and the SSOD. Uranium concentration data for Paddy's Run and the SSOD were obtained and compiled in Appendices L and M. Uranium concentrations were higher in the SSOD than in Paddy's Run. In the SSOD, the maximum concentration of uranium was  $8,300 \text{ pCi L}^{-1}$ , for the year 1960. Thus, this value is used as the upper bound of the annual average uranium concentration that might have existed in the contaminated wells during 1963-1981.

We recognize that this upper bound is an extremely conservative estimate (that is, the estimated value is too high) of the uranium concentrations in the three contaminated wells for 1963–1981. The conservatism results because: (1) the maximum annual average concentration was used to represent the concentrations for the complete period, (2) dilution of the uranium with water from Paddy's Run (with lower concentrations than that of the SSOD) was ignored, and (3) dilution in the groundwater (from other groundwater sources) was also ignored. For the dosimetry calculations, we believe the use of the upper bound uranium concentration of 8,300 pCi  $L^{-1}$ , to represent concentrations in private wells of the South Plume area for 1963–1981, is unrealistically conservative.

Year	Well 12	Well 15	Well 17
. 1982	170	320	45
1983	180	<b>290</b>	39
1984	170	220	36
1985	···· 140	200	31
1986	150	.190	31
. 1987	200	200	40
1988	170	190	38
1989	170	<sup>the</sup> • <b>190</b>	27
1990	<b>130</b>	180	<b>30</b>
1991	100	170	27
1992	e eff de 100 gebuch	150	25

### Table 8. Annual Avérage Concentrations of Jranium (pCi L<sup>-1</sup>) in the Three Contaminated Wells<sup>a</sup>

<sup>a</sup> The range of long-term average, background concentrations of total uranium in private well water around the FMPC is 0.09 to  $1.3 \text{ pCi L}^{-1}$  (Shleien et al. 1993).

Radionuclide Source Terms and Associated Uncertainties for 1951–1988

÷.,

.....

Thus, we developed an empirical model to estimate uranium concentrations in the contaminated wells. An empirical model is one based primarily on measurement data, rather than on theory, to explain the particular conditions. In this case, the data we used are the annual average measured uranium concentrations in the contaminated wells for 1982-1992, and the calculated quantities of uranium released to Paddy's Run and the SSOD for 1952-1988 (these releases are discussed in Appendix L). Details of the model are described in Appendix M. We think that the use of this model provides more realistic, though still somewhat conservative, estimates of uranium concentrations that might have existed in the contaminated wells for 1963-1981.

Table 9 summarizes the uranium concentrations in well water from the South Plume, that will be used for the dosimetry calculations (Task 6). The values for 1963–1981 are based on the empirical model. Based on the empirical model calculations, it is likely that uranium contamination in the groundwater would not have reached the offsite wells prior to 1968 (estimated concentrations are zero prior to 1968). The values for 1982–1988 are the annual averages based on measurements for well 15. Concentrations from well 15 are used in this assessment because they are the highest concentrations of the three contaminated wells.

Year	Concentration	Year	Concentration	Year	Concentration
1951-1967ª	. 0	1975	490	1983	290
1968	180	1976	580	1984	220
1969	230	1977	620	1985	200
1970	230	1978	620	1986	190
1971	230	1979	570	1987	200
1972	240	1980	510	1988	190
1973	290	1981	460		
1974	370	1982	320		

#### Table 9. Values of Uranium Concentration (pCi L<sup>-1</sup>) Used to Represent Annual Average Concentrations in Contaminated Wells of the South Plume Area

#### TASK 2 AND 3 SUMMARY AND CONCLUSIONS

The purpose of the Fernald Dosimetry Reconstruction Project is to estimate doses to the public who lived near the Feed Materials Production Center near Fernald, Ohio from the radionuclides released to the environment during operation of the facility. This report describes our best estimates of releases to the atmosphere and to surface water from FMPC operations, and from the K-65 Silos, during the period 1951–1988. Table 10 provides a summary of our best estimates these results.

Figure 15 shows the relative contributions of uranium released from the major sources at the FMPC facilities during the period. These major sources are uranium released to the atmosphere, uranium released in liquid effluents, and releases of radon gas and its decay products. They are shown in three main sections separated by vertical lines. Numerical values of the best estimate of release are shown next to the heavy bars that represent them.

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page 39

The methods used to determine these release estimates are described carefully and fully in the accompanying appendices.

## Table 10. Summary of Median Uranium and Radon Release Estimates From the FMPC for 1951–1988 With Uncertainty Bounds<sup>a</sup>

	Median release	111 E 111	
Source	estimate	5th percentile	95th percentile
U to Atmosphere	ар ал Риварица II	· · ·	
Dust Collectors	140,000	120,000	170,000
Plant 2/3 Scrubbers	66,000	56,000	78,000
Plant 8 Scrubbers	81,000	56,000	130,000
Miscellaneous Sources <sup>h</sup>	16,000	9,300	28,000
Total: airborne sources	310,000	270,000 · · "	360,000
U to Surface Water To the Great Miami River To Paddy's Run Total: surface water	82,000 17,000 	71,000 14,000 85,000	94,000 20,000 120,000
Radon to Atmosphere K-65 Silos Radon-222 Radon-222 decay products <sup>c</sup>	170,000 Ci 130,000 Ci	110,000 Ci 87,000 Ci	230,000 Ci 190,000 Ci

<sup>4</sup> Values are in kg of uranium, except for releases from the K-65 silos which are reported in units of activity, called curie, Ci. Median estimates of releases from the various sources cannot be directly added to obtain a corresponding total median release estimate for all sources because medians do not have the additive properties that are associated with arithmetic means. See discussion on uncertainty in release estimates on page 10.

<sup>b</sup> These estimates do not include the November 1960 release from the Pilot Plant which is included in the dust collector releases.

<sup>c</sup> The release quantities for decay products are quantities of <u>each</u> of the short-lived decay <u>products</u>, <u>polonium-218</u>, lead-214, bismuth-214, and <u>polonium-214</u>.

It should be noted that uncertainties associated with the parameters used to determine these values vary considerably. In some cases, detailed measurements had been made and were located. An example is the uranium discharged in liquid effluent to the Great Miami River. In other cases, however, measurements of uranium losses were not made, and current release estimates are based on other information (for example, the Plant 8 scrubber releases). The median release estimates do not stand alone. The statistical parameters reported with these values in the appendices are an integral part of the release estimates; they should always be reported with them. The table and figure include ranges of estimates as well as the *best* estimates to provide a general comparative overview of annual release estimates for these years.

For the operational period of the FMPC, the total releases from atmospheric sources (dust collectors, Plant 2/3 scrubbers, Plant 8 scrubbers and miscellaneous sources) are 310,000 kg uranium, with the 5th to 95th percentile range of 270,000 to 360,000 kg. The predicted total quantities of radon and radon decay products released from the FMPC

#### Radionuclide Source Terms and Associated Uncertainties for 1951–1988

• ). <del>-</del>3

through 1988 are 170,000 Ci (5th to 95th percentile range of 110,000 to 230,000 Ci), and 130,000 Ci (5th to 95th percentile range of 87,000 to 190,000 Ci). For releases of uranium in liquid effluents, the median release estimate to the Great Miami River during this time period, is 82,000 kg (5th to 95th percentile range of 71,000 to 94,000 kg), while that to Paddy's Run is 17,000 kg, with the 5th to 95th percentile range of 14,000 to 20,000 kg.

It is important to realize that median estimates of releases from various sources may not be directly added to obtain a corresponding median estimate of the annual total release for all sources. The reason is that the medians do not have the additive properties that are familiar to most people from dealing with (arithmetic) means. We have chosen to use median estimates because they represent the 50th percentile of their distributions. For nonsymmetric distributions such as those encountered in this work (principally lognormal or approximately so), the mean is larger than the median by an amount that increases with the weight of extremely large values. For this reason, the median is considered a more stable measure of the central tendency of the distribution, and it is generally used in this study to represent best estimates of uncertain quantities.



Figure 15. Summary of release estimates from the FMPC for the years 1951–1988. Releases are divided into three main sections which are separated by vertical lines. The center square represents the median or *best* estimate. The dark square on top represents the 95th percentile value, while the lower diamond represents the 5th percentile value. Ninety percent of the estimates lie within the range defined by top and bottom values that surround the best estimate.

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page 41

Our work strongly supports the conclusion that atmospheric releases account for the greatest fraction of uranium released from the FMPC facility. Table 11 summarizes the grand medians and percentile values for the releases by decade for the three primary sources—the dust collectors, the Plant 8 scrubbers, and the Plant 2/3 scrubbers. The total releases estimate for 1951-1084 is a summary for all release points, including the unmonitored and accidental releases. The unmonitored releases are relatively minor compared to the three major sources, contributing only 16,000 kg uranium over the 47-year time span (Figure 15). Uranium releases to the atmosphere were highest in the 1950s with 175,000 kg uranium released from the three primary sources, and declined to almost half that in the 1960s. Total release estimates for the 1970s and 1980s are significantly less at 30,000 and 4,400 kg, respectively.

Best Estimate			
Period	(kg U) a		
1950s	175,000		
1960s	90,000		
1970s	30,000		
1980s	4,400		

There have been several previous attempts at determination of uranium releases from the FMPC. Estimates of uranium discharged in liquid effluent were have been made by others on an annual basis (Boback 1971), or in summary reports evaluating the past discharge history of the facility (Rathgens 1974, Boback et al., 1985). These estimates of uranium to surface water from 1951 through 1984 range from 74,000 to 77,000 kg (Boback et al. 1987, Galper 1988) and fall within the uncertainty range of our estimates. Revisions to historic discharge reports generally focused on amending estimates of uranium loss to airborne effluents, and did not include updated figures for liquid effluents (Boback et al. 1985, Boback et al. 1987).

Previous reports of airborne uranium releases which have been used to estimate radiation doses in the offsite population around the FMPC have been reviewed for this project (Shleien 1991). Table 12 summarizes estimates of atmospheric releases of uranium which have been presented by others previously. These previous studies to determine the releases of radionuclides from the FMPC have yielded source terms which are less than our median or best estimates described in the present report. Our uncertainty ranges do not encompass these estimates except for that of the IEER. Exhaustive comparisons have not been made; however, reasons for our higher estimates include:

• the time to examine numerous documents, in particular original records, related to the FMPC operations;

• the use of a distribution of scrubber efficiencies for Plant 8 scrubbers;

#### Radionuclide Source Terms and Associated Uncertainties for 1951-1988

- accounting for uranium losses from miscellaneous unmonitored sources and accidents;
- accounting for biases from sample line losses and other sampling deviations in the calculation of dust collector losses.

Table 12. Summary of Previous Atmospheric Uranium Release Estimates			
Years (inclusive) Uranium (kg)		Reference	
1953-1984	96,000	Data for EPA estimate <sup>a</sup>	
1951-1985	135,000	FMPC-2082 report <sup>b</sup>	
1951-1987	179,000	Addendum to FMPC-2082 Report; IT report <sup>c</sup>	
1951-1985	390,000	Reports prepared by Institute for Energy and	
		Environmental Research for litigation involving the US DOE <sup>d</sup>	

<sup>a</sup> From Kennedy 1985 and Meyers, no date; no specific documentation for estimate is provided.

h From Boback et al. 1985; report estimated airborne uranium releases from plant operations only. <sup>c</sup> From Clark et al. 1989 and IT 1989; addendum also included uranium releases from Plant 2/3

scrubber operations, unmonitored releases and accidental releases. The IT report used the source term from the Addendum to the 2082 report.

<sup>d</sup> From Makhijani and Franke 1989; this estimate from their "alternative #2" calculations included additional scrubber losses from Plant 8 based on 70% efficiency for scrubbers instead of 85%.

Our methodology represents a significant improvement in the state-of-the-art of source terms analysis over previously reported data. It involves estimating a median, or best estimate of the releases in addition to a formal uncertainty analysis of parameters associated with these estimates. The Monte Carlo procedure uses our best estimates of the distributions of parameter values to produce a distribution of results. This process has resulted in obtaining a distribution of release estimates, instead of determining a single point estimate of the various parameters, with a single result. As a result, the source term has been characterized by a distribution of uncertainty for each year's releases.

#### REFERENCES

•

- ASI-IT (Advanced Sciences, Inc. International Technology Corporation). Engineering evaluation/cost analysis south plume Feed Materials Production Center Fernald, Ohio, Cincinnati, OH: Advance Sciences, Inc., International Technology Corporation; 1990.
- Audia, S. F. Over-all accountability analyses report, startup through September 30, 1976, Letter to H.D. Fletcher, ERDA. Cincinnati, OH: National Lead Company of Ohio; 31 August 1977.
- Boback, M. W. Radioactivity in airborne and liquid effluents calendar 1970. Cincinnati, OH: National Lead Company of Ohio. 21 June 1971.
- Boback, M. W.; D. A. Fleming; T. A. Dugan; R. W. Keys; R. B. Grant. History of FMPC radionuclide discharges. Cincinnati, OH: National Lead Company of Ohio; NLCO-2039; November 1985.

The Fernald Dosimetry Reconstruction Project
Tasks 2 and 3, Source Terms and Uncertainties

- Boback, M. W.; T. A. Dugan; D. A. Fleming; R. B. Grant; R. W. Keys. History of FMPC Radionuclide Discharges Cincinnati, OH: Westinghouse Materials Company of Ohio; Document Number FMPC-2082 (Revision to FMPC-2058). 1987.
- Boone, F.W. Stack sampling procedure. Fernald, OH: National Lead Company of Ohio; 5 September 1956.

Borak, T. B. Calculation of radon emission, dispersion and dosimetry from K65 Storage Tanks at the Feed Materials Production Center. In: Boback, M. W.; Dugan, T. A.;
Fleming, D. A.; Grant, R. B.; Keys, R. W. 1987. History of FMPC Radionuclide Discharges. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; FMPC-2082. October 1985.

Clark, T. E.; Elikan, L.; Hill, C. A.; Speicher, B. L. Addendum to FMPC-2082, history of FMPC radionuclide discharges; revised estimates of uranium and thorium air emissions from 1951-1987. Cincinnati, OH: Westinghouse Materials Company of Ohio; March 1989.

- Decisioneering. 1993. Crystal Ball<sup>®</sup> Version 3.0 for Windows. User's Manual. Decisioneering, Inc., Denver, Colorado.
- DOE (U.S. Department of Energy). Aerial photograph of the Feed Materials Production Center, taken from the southeast. Oak Ridge, TN: Oak Ridge Operations, U.S. Department of Energy; 1965.
- DOE (U.S. Department of Energy). Engineering evaluation/cost analysis, south plume, Feed Materials Production Center, Fernald, Ohio. Oak Ridge Operations Office, U.S. Department of Energy; Rep. FMPC-0003-6; November 1990.
- Dove, G.G. and S. E. Norris. Conditions Governing the Occurrence of Ground Water in the Fernald Area, Ohio, With Reference to the Possibilities of contamination by Disposal of Chemical Wastes, U.S. Geological Survey, Ground Water Branch, Columbus Ohio. September 1951.

Drinker. P. and Hatch, T. Industrial dust. New York: McGraw-Hill Book Company; 1956.

- Eye J.D. Report on the Ground Water Pollution Potential in the Feed Materials Production Center Operated by the National Lead Company of Ohio. 23 January 1961.
- FMPC. FMPC uranium inventory records. Cincinnati, OH: Westinghouse Materials Company of Ohio; 1988.
- Galper, M. Tabulation of data on historical emissions from FMPC, Memorandum to B. Speicher and L. Elikan. Cincinnati, OH: National Lead Company of Ohio; 27 October 1988.

GeoTrans. Preliminary characterization of the groundwater flow system near the Feed Materials Production Center, Great Miami River Valley - fill aquifer Fernald, Ohio, Report prepared for the Ohio Environmental Protection Agency, 1985; p. 57.

- Grumski, J. T. Feasibility investigation for control of radon emission from the K-65 Silos. Revision 1. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; 30 July 1987.
- Hamilton, L.D.; Meinhold, A.F.; Baxter, S.L.; Holtzman, S; Morris, S.C.; Pardi, R.; Rowe, M.D.; Sun, C. Pilot study of risk assessment for selected problems at the Fernald Environmental Management Project (FEMP). Upton, NY: Brookhaven National Laboratory; rep. BNL-48777, revised; May 1993.

Hartsock, J.K. Geological Considerations of Waste Control at FMPC. TID-12297. US Atomic Energy Commission. 15 February 1960. Radionuclide Source Terms and Associated Uncertainties for 1951–1988

.

2

÷.,

- Hofer, E; and F. O Hoffman. Selected examples of practical approaches for the assessment of model reliability-parameter uncertainty analysis. In: Proceedings of an IAEA workshop on uncertainty analysis for performance assessments of radioactive waste disposal systems. Paris: Organization for Economic Co-Operation and Development; 1987.
- Investigation Board. Investigation report on Plant 2/3 gulping emission at the Feed Materials Production Center, June 1988. Oak Ridge, TN: U.S. Department of Energy; Document DOE-ORO-897; November 1988.
- IT (IT Corporation). Appendix F, Radon dose and risk assessment for the Feed Materials Production Center Fernald, Ohio. In: Assessment of radiation dose and cancer risk for emissions from 1951 through 1984. Oak Ridge, TN: IT Corporation; Project 303063; August 1989.
- Kennedy, W.E. Ad Hoc assistance Lung dose estimates for FMPC from 1953 Through 1984, Letter to S.P. Mather. Radiological Sciences Department, Department of Energy; 25 March 1985.
- Killough, G.G.; M.J. Case, K.R. Meyer, R.E. Moore, J.F. Rogers, S.K. Rope, D.W. Schmidt, B. Shleien, J.E. Till, P.G. Voillequé. The Fernald Dosimetry Reconstruction Project, Task 4: Environmental Pathways Analysis — Models and Validation. Draft interim report for comment. Neeses, SC: Radiological Assessments Corporation; Rep. CDC-3; February 1993.
- Makhijani, A. and B. Franke. Addendum to the Report "Release Estimates of Radioactive and Non-radioactive Materials to the Environment by the Feed Materials Production Center 1951-1985. Takoma Park, MD: Institute for Energy and Environmental Research; May 1989.
- Martin, H.K-65 storage tanks. Internal memorandum to A. Stewart. Cincinnati, Ohio: National Lead Company of Ohio; 8 November 1957.
- Meyers, S. Letter to L. Weiss (c/o) Senator John Glenn), U.S. Environmental Protection Agency, no date.
- NCRP. "Screening Techniques for Determining Compliance with Environmental Standards, Releases of Radionuclides to the Atmosphere," NCRP Commentary No. 3. Washington, DC: National Council on Radiation Protection and Measurements. 1989.
- Negin, C. A.; Worku, G. MicroShield, version 4, user's manual. Rockville, Maryland 20850: Grove Engineering, Inc., 15215 Shady Grove Road, Suite 200; Rep. Grove 92-2; 1992.
- NLCO (National Lead Company of Ohio). Analytical data sheets of uranium concentration of daily Manhole 175 water samples, Health and Safety Division, Analytical Department. Cincinnati, OH: National Lead Company of Ohio; 1956.
- RAC (Radiological Assessments Corporation). Task 1: Identification of Release points, the Fernald Dosimetry Reconstruction Project. Neeses, SC: Radiological Assessments Corporation; 22 January 1991.
- Rathgens, L. H & S Request, Tabulation of volume and uranium quantities to MH 175 and Paddy's Run prior to CY 1963. Inter-office memorandum to M. Boback. Cincinnati, OH: National Lead Company of Ohio; 19 April 1974.
- Ross, K. N.; Boback, M.W. The control and sampling of airborne contaminants from uranium production. Cincinnati, OH: National lead Company of Ohio; Document NLCO-1087; 15 November 1971.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page 45

٠,

- Ross, K.N. Uranium losses in the storm sewer system, Memorandum to M. W. Boback. Cincinnati, OH: National Lead of Ohio; 5 January 1972.
- Semones, T.R. and Sverdrup, E.F. Uranium emissions from gulping of uranium trioxide. Document FMPC/Sub-019. Cincinnati, OH: Westinghouse Materials Company of Ohio. December 1988.
- Shleien, B. Summary and analysis of previous studies applicable to dose reconstruction at the Feed Materials Production Center, prepared for Radiological Assessments Corporation. Silver Spring, MD: Scinta, Inc. March 1991 (1991).
- Shleien, B., S. K. Rope, .M. J Case, G. G Killough, K. R. Meyer, R. E. Moore, D. W. Schmidt, J. E. Till, P. G. Voillequé. The Fernald Dosimetry Reconstruction Project, Task 5: Review of Historic Data and Assessments for the FMPC. Draft report for comment. Neeses, South Carolina: Radiological Assessments Corporation; Rep. CDC-4; November 1993.
- Spieker, A.M. and S.E. Norris. Ground-water movement and contamination at the AEC Feed Materials Production Center Located near Fernald, Ohio, U.S. Geological Survey, Professional paper 605-c. 1962.

Starkey, R.H. Cincinnati, OH: National Lead Company of Ohio; 1956.

- Vaaler, S.C.; Nuhfer, K.R. Airborne emission from historical non-routine events. Internal memorandum to B.L. Speicher. Cincinnati, OH: Westinghouse Materials Company of Ohio; 9 March 1989.
- Voillequé, P.G.; Meyer, K. R.; Schmidt, D.W.; Killough G.G.; Moore, R.E., Ichimura, V.I., Rope, S.K.; Shleien, B.; Till, J.E.. The Fernald Dosimetry Reconstruction Project Tasks 2 and 3 Radionuclide Source Terms and Uncertainties —1960–1962. Neeses, S.C.: Radiological Assessments Corporation. December 1991.

Wunder, G.W. Preload concrete storage tanks. Letter to C. L. Karl, U.S. Atomic Energy Commission. Cincinnati, Ohio: National Lead Company of Ohio; 23 August 1954.

> of constants Later - dr Constants Constants Constants Constants Constants Constants

> > an a ( a + 1) a ra **(6**€ 7)

> > > . . . . . .

. . .

÷.,

#### APPENDIX A

## SOURCES OF INFORMATION FOR THE FERNALD DOSIMETRY RECONSTRUCTION PROJECT

A major effort in the Fernald Dosimetry Reconstruction Project has been searching for, and reviewing thousands of documents related to the operation of the Feed Materials Production Center (FMPC) since the facility opened in 1951. It has been our practice to trace the information back to original sources whenever possible. In the Task 1 report, issued in January 1991 (RAC 1991), we outlined the general approaches that we have taken to obtain this information. These five methods, which have formed the foundation for the project in providing the technical data for this study, include site visits to the FMPC facility; investigation of records and scientific literature pertaining to the FMPC; the retrieval and review of documents from NLO, Inc. using their computer database of document titles; examination of engineering diagrams, site blueprints, historic photographs and maps; and discussions with current and former longtime employees. The employees' recollections on plant processes, and procedures that routinely occurred since facility start-up served to identify sources and locations of documentation. Many of these individuals had been at the facility since the early fifties and sixties, and had served in various capacities, including maintenance, engineering, production, and plant management.

Because we realized the importance of retrieving documents from a wide range of sources, considerable time has been spent identifying types and locations of reports and records pertinent to the completion of this project. Generally, this documentation of FMPC operations and releases comes from two broad areas: (a) those produced by National Lead Company of Ohio, Inc. (NLCO), the former operator of the site, the Westinghouse Materials Company of Ohio (WMCO), the site operator from January 1, 1986 through 1992, and the Department of Energy (DOE); and (b) those issued by FMPC-independent sources.

The purpose of this appendix is to outline these sources of information and the types of documents that were found. For each source or location of documents, we have described the broad types and dates of documents, and have maintained detailed records of the reports and records that we have obtained at each location. In addition, *RAC* has maintained a detailed bibliography of all documents that we have gathered for the project. The documents in the *RAC* Document Repository are organized by topic and listed in Annex C of this appendix. All documents in the *RAC* Document Repository have been kept at a single location throughout the active phase of this project, but will be transferred to CDC at the conclusion of the project. Table A-1 lists the general sources of documents, dates, and comments. Each category or location is described briefly.

#### **FMPC SITE**

1.1

Many official monthly and annual FMPC reports, analytical data sheets, records, logbooks, and personal notes and diaries for most years of operation still exist. These various types of records at the FMPC site are found in the main records storage area

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

5

. .

ά,

2

11 July 12

7

(Central Files), the Library, and individual plants or buildings. The great majority of documents in the Central Files area have been tabulated in the FMPC Records Storage Inventory list of documents. Although individual documents are not listed, most records are grouped together by department, individual's personal records, plant processes or building location. The documents on the list are distributed among four locations: in the Central Files vault at the FMPC site, at the Federal Storage Center in Dayton, in local storage in Cincinnati, or in the process area (Plant 9 or Plant 4) where contaminated records are stored. There is an index card for each file folder of records which indicates its location, date, and box number holding the documents.

Records and documents in the Central Files and Vault at FMPC are listed in the WMCO FMPC Records Storage Inventory list. The list is organized by topic or document type under a particular department. The actual record related to each topic may be located in a single folder in a box (about 13" x 16"), or may require many boxes, each with records related to the main topic.

We used the WMCO FMPC Records Storage Inventory list to select documents of interest. In the following table, document topics or types are listed in the first column with the box number following. The topics are arranged by department similar to the FMPC Records Storage Inventory list from which we were working. Each topic or document type is listed by box number, if known, and outcome or status. The "not useful" comment indicates that the information was not helpful to us at the time. Other comments were added when available. All copied documents are part of the RAC document repository. Annex A of this appendix lists the types and status of documents that we reviewed from the Central Files storage area.

The Library is a source of logbooks kept by individuals or as a record for various processes or departments, and some classified documents. All documents are listed in a card catalogue, and stored in a secure vault there. The library has an index, and copies of all FMPC Quarterly and Topical Reports published since operations began. Although many logbooks and diaries are descriptive in nature, a few also provide quantitative data on operation times and duration, production amounts, or concentrations and volumes of materials released. Many of these have been reviewed and copied.

The card file of classified documents was examined. Many of the classified documents were compilations of abstracts of classified research that had been performed over the years by the AEC. During construction of a new building, the Library vault was closed temporarily. During that time, the plant logbooks were sent to Central Files, to storage offsite, or to 4 onsite if the logbooks were contaminated with low-level radioactivity. RAC has compiled a list of all FMPC logbooks that have been examined up to this time.

The repository for contaminated documents and logbooks is located on the third floor of Plant 4. Over the course of the project we spent ample time examining the documents that were sent there from other areas onsite, and noted records of interest. Annex B to this appendix lists the box numbers, dates and the types and status of the documents in the contaminated box repository at the FMPC.

> an<u>tak</u>ay Kerdikata

# Appendix A Sources of Information

•

. .

....

Source and Location	Dates of	
of Documents	Documents	Comments
FMPC Site		······································
Central Files	All	WMCO provided list of all document categories. RAC checked hundreds of documents in dozens of boxes; a listing of all files/boxes examined has been kept.
Library	All	FMPC quarterly and topical reports, logbooks and diaries. Classified document card file examined; no significant content. Listing of logbooks examined here and in Plant 9.
Plant 4	All	Contaminated logbooks and documents in boxes from Central Files and Library.
Plant 6	All	Seven 4-drawer file cabinets with files from "metal" and "chemical" plants. Most files related to process testing and Test Authorizations since FMPC startup, their status, and final report, if done. List is available.
FMPC Public Affairs Reading Room	1980s and 1990s	Hundreds of documents on environmental procedures, investigation reports, safety, hazardous materials and waste, and general information about FMPC.
National Lead Company of Ohio, Inc., Cincinnafi.	All	Over 200,000 documents gathered by NLO, Inc. for litigation purposes. Using a computer database file of document titles, RAC has requested and received hundreds of documents from this source.
DOE Oak Ridge Operations (ORO) and Office of Scientific and Technical Information (OSTI), Oak Ridge, TN.	1970s and 1980s	DOE Oak Ridge Records Retention Center has documents grouped by shipment number. Environmental Division records checked. Some classified documents reviewed; requested declassification. OSTI has a computer listing of all FMPC-related documents.
National Archives and Record Center, Atlanta, GA.	1940s and 1950s	Listing of documents in two shipments from DOE/ORO reviewed; one shipment of 28 boxes from 1947 to 1954, the other shipment of 84 boxes from 1943 to 1964.
Ohio State Health Department, Columbus, OH.	Various	Found a few boxes of reports related to FMPC discharges; follow-up visit showed FMPC information is not easy to locate.

Table A-1. Sources and Locations of Documentation for the

Radiological Assessments Corporation

"Setting the standard in environmental health"

11\_

#### Page A-4

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

È,

.

Table A-1. Sources a	and Locations of Documentation for the
Fernald Dosime	try Reconstruction Project (cont'd)
Source and Location Dates of of Documents Document	s Comments
U.S. Geological Survey 1951–1985 (USGS)	Reports in early 1950s, 1962, 1968, and 1985 on groundwater movement and stormwater collection onsite.
Open scientific literature	nt Database systems used to search for FMPC-related reports include HP QUEST, GRATEFUL MED, and Toxline.
FMPC Area Residents; Various FRESH	RAC and CDC have asked for leads in finding sources of documents.
Offices of Waite, All Schneider, Bayless & Chesley, Cincinnati, OH	Documents related to FMPC discharge history; generally the same as those at the NLO, Inc. offices.
GAP (Government Accountability Project), Washington, D.C.	Non-profit organization representing FMPC workers' interests. Have 5 boxes of documents related to FMPC.
IEER (Institute for All Energy and Environmental Research, Tacoma Park, MD	Performed release and dose estimates for Waite, Schneider, Bayless & Chesley; have documents related to FMPC operations.
Universities 1960–1990	Reports by professors from University of Cincinnati, Miami University, Colorado State University, and University of Rochester.
Private Companies 1970–1990	PEDCo Environmental, Cincinnati; EG&G L. Lehman & Associates, Inc.; Roy F. Weston, Inc.; West Chester, PA and others have studied and reported on the FMPC site and vicinity.

NLO, INC.

Over 200,000 documents pertaining to the FMPC operations were gathered by NLO, Inc. for litigation purposes. These documents are stored at the NLO office in Cincinnati, and each has been assigned a unique identifying inventory control number (ICN). For each of the 200,000 documents, NLO has listed the ICN, the title, the author(s), and the date in a computer database file. RAC received a computer database file of these documents through the Centers for Disease Control and Prevention (CDC) at the beginning of the project in

i ai

i prima an trans Tana si trans

Stratt
 Hard Schert

``

### Appendix A Sources of Information

÷.

Page A-5

1990, and an update to the database in January 1993. We have used the database in several ways to identify and sort documents that pertain to the dose reconstruction project. Several thousand documents have been retrieved and reviewed for their relevance to the project. We have obtained copies of many of these documents for the RAC Document Repository.

#### OAK RIDGE: DOE ORO and OSTI

The Department of Energy Oak Ridge Operations Office (DOE/ORO) in Oak Ridge, Tennessee oversees the operations of the Fernald facility, and documents have been sent from FMPC to DOE/ORO over the years. The DOE/ORO Records Retention Center (RRC) lists boxes of documents by shipment number only so there is currently no timely or logical method for searching for FMPC-related documents. Nevertheless, inventory files in the RRC were reviewed by year and division in an attempt to locate Fernald related documents. Environmental Division records were studied more closely than others. Ultimately, documents from the DOE Records Retention Center in Oak Ridge are sent to the Federal Archives in Atlanta for permanent storage.

The Office of Scientific and Technical Information (OSTI) is the national center for scientific and technical information for DOE. OSTI encompasses not only DOE-originated information but also worldwide literature on scientific and technical energy-related matters, and maintains computerized energy-information databases that can be accessed through computer retrieval systems. At OSTI, a computer listing was available for all documents related to Fernald. These documents were reviewed relative to their usefulness to the project and important documents were copied.

#### **FMPC-INDEPENDENT SOURCES**

Locating independent sources of documents has been particularly important in verifying the data and records from the FMPC site. All avenues were explored to find pertinent monitoring data on environmental releases that may have been gathered by individuals or organizations not directly involved with FMPC operations. In the following discussion, examples of this work are cited and referenced. The listing is not comprehensive.

The Ohio State Health Department had some historical records and environmental monitoring data to substantiate information we had gathered previously. In addition, CDC has kept the Ohio State Health Department informed of our activities at FMPC for the Fernald Dosimetry Reconstruction Project.

Among the earliest independent studies were those conducted by the U.S. Geological Survey (USGS). Reports on ground water conditions in the Fernald area were prepared in the early fifties (Dove & Norris 1951) and sixties (Spieker & Norris 1962, Spieker 1968). The Ohio Division of Water has also performed hydrologic studies (Dove 1961).

Searches for publications related to the FMPC in the open scientific literature were performed using the bibliographic computer database systems, HP QUEST, GRATEFUL MED, and Toxline. The database HP QUEST includes publications devoted to radiation protection, while GRATEFUL MED is the National Medical Library search system. Various

....

ļ

.

ŝ

2.11.11

search criteria and keywords were employed to locate FMPC-related documents, specifically those from independent sources. A number of useful documents were found in this way.

Over the years of FMPC operation, professors at several universities around the country have completed a diversity of projects at FMPC. For example, in the early 1960s, Professor J. D. Eye, in the Department of Civil Engineering at the University of Cincinnati reviewed the potential of groundwater pollution at FMPC in several research reports (for example: Eye 1961a, 1961b). In 1985, T. B. Borak from Colorado State University studied the emission of radon from the K-65 silos (Borak 1985). Several private companies have also prepared various reports on the status of FMPC from the 1970s to the present. In 1976, 1977, and 1985, EG&G completed aerial radiological surveys of FMPC and surrounding areas (Feimster 1979; Shipman 1985). In 1988, L. Lehman & Associates, Inc. of Minneapolis reviewed literature pertaining to FMPC, and proposed a mechanism for groundwater contamination near FMPC (Lehman and Hansen 1988).

Efforts to find FMPC-related documentation have led to numerous meetings and phone conversations with knowledgeable individuals, such as Mr. Van Clay, the Assistant Attorney General for the State of Ohio, and Professor Roy Eckert of the University of Cincinnati. In addition, we talked with former employees and retirees from the FMPC. RAC has visited the attorneys in the office of Waite, Schneider, Bayless & Chesley in Cincinnati, who have assembled hundreds of documents for litigation related to the discharge history and past practices of FMPC. Although much of the documentation is similar to that retrieved from NLCO offices, some documents relevant to the dose reconstruction project were identified and copied.

We also visited the Government Accountability Project (GAP) office in Washington, DC on two occasions to review documents which they had obtained from FMPC personnel, and from DOE and WMCO through Freedom of Information Act requests. The GAP is a nonprofit organization with the stated purpose of representing workers' interests. The five boxes of documents related to FMPC were checked for their application to this study.

Finally, we met with Arjun Makhijani of the Institute for Energy and Environmental Research, in Takoma Park, Maryland regarding studies on release estimates and radiation doses that they had completed in 1988 and 1989 (Franke 1988, Makhijani 1988, Makhijani and Franke 1989). They have a large number of documents similar to those found in offices of Waite, Schneider, Bayless & Chesley.

In summary, RAC has determined that there still exist a large number of reports, production records, and monitoring data related to FMPC operations. Although the record of operations is more complete for the seventies and eighties, a large number of analytical data sheets, monthly reports, letters, memoranda, photographs and drawings have been located for the fifties and sixties. Original logbooks have been useful; however, not all plant processes were documented in detail in logbooks.

RAC has gathered thousands of these documents for careful review in the preparation of the all project-related task reports. We are maintaining an ongoing list of the documents we have gathered in the *RAC* Document Repository. This documentation process will continue throughout the entire dose reconstruction project, with the final collection of *RAC* documents stored at CDC.

#### Appendix A Sources of Information

#### REFERENCES

4

- Borak, T. B. Calculation of radon emission, dispersion, and dosimetry from K-65 storage tanks at the Feed Materials Production Center. Appendix A of History of FMPC radionuclide discharges. Document Number FMPC-2082. Cincinnati, OH: Westinghouse Materials Company of Ohio; 1987.
- Dove, G.G.; Norris, S. E. Conditions governing the occurrence of ground water in the Fernald area, Ohio, with reference to the possibilities of contamination by disposal of chemical wastes. Columbus OH: U.S. Geological Survey, Ground Water Branch; 1951.
- Dove, G.D. A hydrologic study of the valley-fill deposits in the Venice area, Ohio. Columbus, OH: Ohio Division of Water, Technical Report 4; 1961.
- Eye, J.D. Report on the ground water pollution potential in the Feed Materials Production Center operated by the National Lead Company of Ohio. Cincinnati, OH: University of Cincinnati; 1961a.
- Eye, J.D. Contamination of Paddy's Run by process chemicals used in the Feed Materials Production Center. Cincinnati, OH: University of Cincinnati; 1961b.
- Feimster, E. L. An aerial radiological survey of the area surrounding the Feed Materials Production Center, Fernald, Ohio in August 1976 and May-June 1977. Las Vegas, NV: EG&G Energy Measurements Group; Document Number EGG-1183-1680; 1979.
- Franke, B. Preliminary assessment of radiation exposures associated with releases of radioactive materials from FMPC--1951 to 1984. Takoma Park, MD: Institute for Energy and Environmental Research; 1988.
- Lehman, L.; Hansen, E. Final report: review of existing literature on Feed Materials Production Center. Prepared for Waite, Schneider, Bayless & Chesley. Burnsville, MN: L. Lehman and Associates, Inc.; 1988.
- Makhijani, A. Release estimates of radioactive and nonradioactive materials to the environment by the Feed Materials Production Center, 1951-1985. Takoma Park, MD: Institute for Energy and Environmental Research; 1988.
- Makhijani, A.; Franke, B. Addendum to the report, Release estimates of radioactive and non-radioactive materials to the environment by the Feed Material Production Center 1951-1985. Takoma Park, MD: Institute for Energy and Environmental Research; 1989.
- RAC (Radiological Assessments Corporation). Task 1: Identification of release points at the Feed Materials Production Center. Prepared for the Fernald Dosimetry Reconstruction Project. Neeses, SC: Radiological Assessments Corporation; 22 January 1991.
- Shipman, G. R. An aerial radiological survey of the Feed Materials Production Center and surrounding area, Fernald, Ohio. Date of Survey, April 1985. Las Vegas, NV: EG&G Energy Measurements Group; Document Number EGG-10282-1084; 1985.
- Spieker, A.M. Ground-water hydrology and geology of the Lower Great Miami River Valley, Ohio. Columbus, OH: U.S. Geological Survey; Professional paper 605-A; 1968.
- Spieker, A.M.; Norris, S. E.. Ground-water movement and contamination at the AEC Feed Materials Production Center Located near Fernald, Ohio. Columbus, OH: U.S. Geological Survey; Professional paper 605-c; 1962.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page A-7

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

2

.

. .

-

# ANNEX A TO APPENDIX A

# TYPES OF DOCUMENTS IN THE CENTRAL FILE STORAGE AREA AT THE FEED MATERIAL PRODUCTION CENTER

TOPIC	BOX NO.	STATUS	
ANALYTICAL			
Report of chem. analysis-Plant 1	40618	Not useful; lab data	
(1/81-12/87)		sheets with no report	
and the state of the second		or sample key	
Report of Isotopic analysis - :.	••		
all areas (1983)	41029	Not useful; raw data	
Sector A state of the sector of the		without report or	
		sample key	
EMERGENCY PREPAREDNESS			
Emergency, prepare, records	45212	Not useful	
and correspondence	45103	Not useful	
	46096	Not useful	•
ENGINEERING SERVICES	-10000	The aberai	
Dominants from REECO databases			
air water emissions infe all	16591	Some Conied	
hove ICN # and request the set MI O	40041	ot Control Filer	
have 1014 #-can request through NLO;	40023	at Central Flies;	
total of 12 boxes-looked all	46524	some copied at NLO;	
INDUSTRIAL HVCIENE	• • • • •	· · · · · · ·	•
K Ross - Follout, River	and the second sec		
Gross/Soil Air Boundary Somaling	AAEQA		
Grassison, Air Boundary Sampling	44004	Useful, copy later	
K. Ross - Stack Sampling Newsletter	44584	Not useful	
al distanting the second second	•		
Miami Valley Water Quality	•		
Committee Correspondence	A43540	Not useful	
Insident Observation Personts		Not model. Joiler lo-	
incluent Observation Reports	A23014	Not useful; daily log	
	÷, (, ,	of technician.	•
Report of Fume Release (50-65)	A17936	Not useful small accident	
		renorte - no	
amounts given:			
Health/Safety narrative of			
arcidents			
Plant Reports (1961)-		· · · · · · · · · · · · · · · · · · ·	
accurational arm studios Diante 1.9	· · · · · · · · · · · · · · · · · · ·	Not ucoful	
occupational. exp. studies riants 1-0	WT 1920	not aserui	
Plant reports/ Radiation and			
effluent - Jan-Jun monthly			
· reports: MH 175 & storm source	A 17026	Conind	
i oporto, mili i to de Storini Sewer	WT1220	Copieu	
Major Incident Investigations	24796	Copied	
manual ruendente rus ezel Bations	04/00		

2

Sources of Information	·		
MAINTENANCE			
Job Orders - 1985 ->		A45214	Conjed
- 1988-89		Δ.46758	Not useful:
PMS - Work Orders		A40750	Not useful: canceled jobs
This - work orders.	, *	A40702	Not useful, canceled Jobs
MATERIALS CONTROL & ACCO	DUNTABI	LITY	•• .
Nuclear Materials Mngmnt Reports			FY62-FY87: very good mtrl
			rec'd, beg. & ending inven, by
			month & vr. 1961 available.
Physical Inventories/WIP			Inventories & mtrl. balance
• .			dif. (9/77-FY88) with details on
			losses & inventory; nuclear mtrl.
•			production reports for 9/77-FY88.
•			
SS Receiving Log A-Z (1965-75)	· ·· · . ·	•	Examined
NMC Files - Bernie Gessiness		38577	Has file on Plt 8 loss back to 60's t
			80s: efforts to control losses: mans
			of all manholes & connections.
Routine Operating Losses -		•	· · ·
By type discard (52-72)		A41492	Copied
•			•
Diant 9 reference diagonal (59.77)			Conieda process information
Flant 2 reinery discard (55-77)	A41494		from 1064 to 74 invent (akin inf
			from 1964 to 74; invent./snip. inf.
			some early ous & tus, much 1977
		• •	information.
Routine Operating Losses (81-82)	A41492		Copied: records prior to 1965
			destroyed but 1960-63 at NLO all
•			copied
· · · · · · · · · · · · · · · · · · ·			-
ROL's VVB (wet & dry pits)	A41492		Copied (52-72)
Discards by plants (64-77)	A41492		Copied
B-PIDS (Book-Physical Inventory			
differences - 7/61_7/69)	A41409		Tables I-V in front Conied. others
anterences - 1101-1104)	41 <b>7</b> 17 <i>34</i>	•	ranied
· ·		4	
Write-off Correspondence	A41492		Copied Notes on
-			Plt. 8 Trailer Cake
	A41492		Copied; discharge & losses from
,	•		Plant 8 in 70's.
PLANT 1			
SS Material Receiving Report			Destroyed prior to 65; (1965-75)
• • • • •			Checked- type of mtrls, date rec'd.
			Alternational and the Manual
	•		snipped, mailed, account #: Many

Radiological Assessments Corporation "Setting the standard in environmental health"

. .

÷.,

.

•

. .

Page A-10

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

#### NUCLEAR & SYSTEM SAFETY **Enriched Material Incident**

PRESIDENT'S OFFICE Historical Reports (1964-1985)

Production Supplies (1962 -84)

#### PROPERTY ACCOUNTING

**409A-Special Reactor Materials** 

### PERFORMANCE ASSESSMENT Mike Boback's Misc. Files

Historical Discharge report -notes and data re: solubility--Tom Borak reply to comments -Letter re: raincaps -PO for analyses of dust coll. -Inf. re: Rn meas. near K-65

Historical discharge Report(F2) -Misc. re: 2082 report -UO<sub>2</sub> gulping operations

Historical discharge Report (F-3) -Boback review of NLO dbase doc. -MC&A comments on 2082

FMPC-2082 - Misc. material -Data on Th & Ra in feed mtrl -Particle size of U compounds -Memo Koch to Herman, 17 Apr 1985 particle size distribution dust collector material

#### FMPC-2082 Tables 13, 14, 88

-Letter to Spenceley, 16 Jul 85,

-Letter to Reafsnyder, 16 Jul 85,

-Data sheets of annual composites of boundary air dust samples

dose estimates

1982-84.

Northern Ky - dust collector efficiency

Major Emission Stacks -Letter to Reafsnyder, 20 Sep 85 data compilation for historical

data for 15 major emission stacks and the state of the

partial data for major emission. stacks.

6 - . . Ge - 1 **'47225** 法教育方法

a diseas.

47225

47225 ί.

47225

47225

47225

-1

47225

. . à.

Copied

2

ş

i.

Copied

•......

#### Copied

Checked list of docs-not useful

Checked; (4/61 - 8/64) enr. mtrl. incident reports beginning Apr 61

Offsite at BIS

Checked: Inventory (12/59-6/62) cost of inven/no wt., no U costs; has Be, Y, some Ra. ٠.

Copied (1951-1985)

Copied

Copied

Copied

Copied

Appendix A Sources of Information Page A-11

Epidemiology Study -Self-absorp. fac./air fltr	47225	Copied
NLCO-1093-Re: graphite and		
oil incinerator	47225	Copied
DOE-ORO Sites Discharge Reports -Report on historic U releases	47225	Copied
from current DOE ORO facility.,		
RADIOLOGICAL SAFELL	•	
DOL Misc. Correspondence	1.0510	
(6/63-7/79)	A43540	Copied
DOE Annual Reports 2/5/71 ->	A43540	. Copied
Accounting: Loss of Material		
2/8/71 -> 12/80	A43540	Copied
DOE Misc Soils 1970-71	A43540	Copied
Equipment & Mtrl. Pass July 81->	A43540	Not useful
Daily Monitoring Records		
(Vehicle) 8/2/82->	A43540	Not useful
Stack sampler flow rate and		
stack loss conversion	45539	Copied

#### RADIOLOGICAL SAFETY (DOSIMETRY AND INSTRUMENTATION)

Incident Investigation Reports	37
--------------------------------	----

**Analytical Data Sheets** 

1

140

(1954-68, 1970-86)

[There is a box for each year with air and water data: estimated stack losses for each plant, offsite air dust, misc. file, daily or weekly water samples for sewage plant, storm sewers, Manhole 175, Miami River at Venice & New Baltimore Bridges, fluoride pit, Paddy's Run water treatment. Data sheets grouped Jan-Jun, and Jul-Dec in separate folders for each location.]

Data sheets for 1961

0-000-535-291

188

Data Sheets for 1960

0-000535-292 0-000-535-290 .0-000-535-290 0-000-535-289 water treat; Fluoride pit, sewage plant; storm sewer, river copied at NLO Carbon copies of Box 0-000-535-291 MH 175, Paddy's Run Copied Offsite air dust copied Carbon copies of Box 0-000-535-290

Copied Paddy's Run, MH175,

Copied most

Box No. 17936

Industrial Hygiene Chronological File - Radiation and Effluent Control (1/58-6/58 only) Contains miscellaneous memos, letters, reports and monthly reports from the Radiation and Effluent Control section. Mostly not useful, but all sorts of things are in these files, occasionally something useful. Only had 1958 in this location.
.

Ś;

7

# 75<sup>1</sup>1401 + Box No. 17936 Chronological File - Engineering and Special Problems Section (1/58-6/58 and 7/58-12/58) See above comment. Box No. 17936 Chronological File - Survey Section (1/58-6/58 and 7/58-12/58) See above comment. Box No. 17936 936.16 Report of Fume Release Previously reviewed by others, nothing useful found. Box No. 17936 Investigation of Injury Nothing useful. Box No. 44584 EPA Method 5 Stack Sampling - Power Plant and Kelley Waste Incinerator - K. Ross . . . . Nothing useful on the incinerator. Box No. 44584 Files containing rainfall sampling data - K. Ross Rainfall measurements and analysis results for radioactivity in the rainfall, for mid-1960s? Copied some typical documents for Kathleen Meyer. ۰. Box No. 37188 Drawings of PERMs Not useful. Box No. 37188 River sample summaries Not useful. Box No. 37188 Technical Lab and Lab Machine Shop 1954-1969 Surveys, miscellaneous. Not useful. Box No. 37188 Miscellaneous Surveys 1964-1968 Not useful. 1 GJ 10 44 Box No. 37188 Plant 2/3 Surveys, miscellaneous. Not useful. Box No. 37188 Pilot Plant Surveys, miscellaneous. Copied 2. Box No. 37188

Page A-13

Radiation Exposure Investigations 1964-1965 Not useful. Plant 9

Box No. 37188 Surveys, miscellaneous. Not useful.

Box No. 37188 Plant 6 Survey results and miscellaneous. Copied one document regarding samples taken during a chip fire.

Box No. 37188 Incident Investigations 1959-1969

Box No. 37188 Services for Offsite Work to 1961 Survey results and other reports. Not useful.

Box No. 37188 Knoxville Iron Company Reports about work and surveys for Knoxville Iron. Not useful.

Box No. 37188 Plant 8 Contains some documents about the Plant 8 scrubbers. None were copied; believe we

already have copies of same documents.

Box No. 37188 AEC Audits Not useful.

÷.

Box No. 37188 Plant 4 1962-1969 Various survey activities for Plant 4, copied one document.

Box No. 37188 Plant 5 Air Dust Surveys

Box No. 37188 Disposals to Waste Pit 1964-1968 Contains information about material sent to the burning pit. None copied at this time.

Box No. 37188 Three reports of exposure studies in Plants 5 and 8 for 1967 and 1968 Not useful.

Box No. 21936 IH & R Monthly Reports 1963

Page A-14

3.

S. 12. V

5

These are potentially useful. Monthly progress reports for Survey section, Engineering and Special Problems section, Radiation and Effluent Control section, and for IH & R department. All available copied.

Box No. 21936 Stack Loss Reports 1963 Set of stack loss reports for 1963, except does not include December. All copied.

Box No. 21936 Daily Monitoring Records Completed forms for radiation surveys of shipments.

Box No. 21936 Inspection and Service Reports 1963 Records of inspections of radiation detection alarms (RDAs). Not useful.

Box No. 21936 Radiation Monitoring Records 1963 Records of surveys of equipment, presumably before release. Not useful.

Box No. 21936 Equipment and Material Passes Tags to apply to equipment to show survey results and recommendations. Not useful.

Box No. 21936 Miscellaneous Correspondence 1957, 1958, 1959, 1961, 1962, and 1963 Various memos, letters, and reports. Found useful K-65 silos survey with Rn concentration measurements.

Box No. 23814 Trip Reports for 1964 and 1965 Not useful.

Box No. 23814 Reports of Fume Releases - NLO-H&S-1538 - 1964 and 1965 Records of investigations of fume releases relative to worker protection - mostly chemical, some radioactivity releases. Not useful.

and the second second second

Alexander Older Barry and Alexander

Box No. 23814

Reports of Injury and Ambulance Service 1964 and 1965 Not useful.

Box No. 23814 Report of Plant Fires

Box No. 23814 Equipment and Material Passes Not useful.

Box No. 23814 Inspection and Service Reports 1964 and 1965

n an ann an Anna an Ann

Page A-15

Records of inspections of RDAs and nuclear accident dosimeters. Not useful.

Box No. 23814 Correspondence on Fume and Dust Control Committee 1962 through 1964. Not useful.

Box No. 23814 Monthly Reports for 1964 Reports for the three sections in IH & R. Copied

Box No. 23814 Daily Monitoring Records 1964 See earlier comment. Not useful.

Box No. 23814 Estimated Stack Loss Reports 1964

Box No. 23814 Notice of Contamination Source 1959 through 1963 Not useful.

Box No. 23814 Radiation Monitoring Records 1964 and 1965 See earlier comment.

Box No. 23814

Miscellaneous Correspondence 1962, 1963, 1964, 1965 Could be useful. Memos, letters, reports from IH & R department. Various pieces were copied.

Box No. 44583 RDA Test Evaluation This file relates to test evacuations. Not useful.

Box No. 43207 Radiological Safety (Dosimetry and Instrumentation) Historical Radiation Reports 1953-1983 Compilation of radiation exposures to personnel. Not useful.

Box No. 46404 Beta and Gamma Exposure Readings 1959 Film badge records for 1960 and part of 1959. Not useful.

Box No. 37192,... etc.

Radiological Safety

Radiation Monitoring Record 1961-1962. Contains routine survey records: Daily Monitoring Record, Radiation Monitoring Records (equipment after decon), Reports of Fume Release, Inspection and Service Reports (RDAs), and IH & R form 492 (equipment for disposal). There are other boxes (not reviewed) with similar files, for various years in the 1960s, 1970s, and 1980s. Not useful.

2

1.12.20

2

č.

#### Box No. 45539

Miscellaneous monitoring files for: ERMT Class, Contamination Surveys, Environmental Rad. Man. Qual. Check, Plant 5, K-65, Tank Farm, D & D Facility, Stack Sampler Flow Rates & Stack Loss, Stack - Jan. and March, Stack - April and June, Report of Chemical Analysis, SRPD Logs, Stack Results 1986, Smears, K-65 Paddy's Run.

Mostly not useful. The K-65 Paddy's Run files contain records of external gamma radiation surveys performed along Paddy's Run Road, at points closest to the K-65 silos. These may be useful for calculating gamma doses due to the silos. Copied a representative sample of these files.

### Box No. 45539

#### Sample Result Correspondence 1986

This file not useful. Similar files exist for earlier years - from 1956, which could have useful information.

#### Box No. 46573

Miscellaneous routine survey and other routine records for: K-65 Area, Lab HFM Survey, Laundry, Locker Room, Maint #107, Medical Emergency, Men's Locker Room, N.A.D. Inspection, Outgoing Vehicles, Paddy's Run Road, P.P. Office, Radon/Thoron Samples, R.S. Trailer, Respirator Trailer, RIMIA, Rust Building 3045, Radiation Work Permit, RDA, Personnel Contamination, RGM #2 Operational Checks, and Radiation Monitoring Record. Mostly not useful. There was additional data from the Paddy's Run Road gamma survey program, which could be useful. None copied.

•

. 1959 19

Page A-17

# ANNEX B TO APPENDIX A

# BOXES OF CONTAMINATED DOCUMENTS FROM CENTRAL FILES AND LIBRARY AT THE FMPC EXAMINED BY RAC

Box No.	Plant	File	Date	Status
A 36715		Fire and safety work permits	no date	Rev. by F. Rogers, CDC, 6/2/94: no interest
A44099		Chemical analysis reports	1984-85	Reviewed by F Rogers CDC 6/2/94
		Chemical analysis reports (	1001-00	
B 39374	Plant 8	Work Records Plt. 8	Jul 56 - Sep 57	No-list of nersonnel and job assignments
		Foreman's Log-Chin Furnace-Plt 8	Feb - Oct 1953	
		Area Foreman's Notes to Foremen-Plt 8	Aug 53 - May 56	Conjed Feb Mar Jun Jul Aug 53
4	· ·	Area Poreman's Nows to Porement it. 0	ring oo - may oo	(oner summary): 30 stano
<b>、</b>		• • • • • • • • • • • • • • • • • • • •	4 	notebooks ning folders with notes
				some reference to scrubbers
39408	Prod\ Pit 8	Work Record-Plt 8 NLO-PRO-1868		INo conjes, nergonnel and
			;	ish assignments
÷	1	Daily dust cal shack Plt 8 NI O. PRO. 1868	May 68, San 68	Conied four de beg configuration for
		Daily dust con thete1 it. 8 1410-1 10-1008	may uo-bep uo	copied lew, de bag configuration for
			Feb 67- Jul 67	tea plant, notes on operation of bag landre
***		Work Proved Project Johan Deal H&S 1015	Feb 62 Dec 62	No. list of normannal and ich agaignments
		Work Record - Project labor 1 001-114-0-1010	Dec 67 May 69	into- list of personnel and job assignments
	i	Work Proved NLO DEP: 1567 Lounday	1062	No list of personnel ish sesimerate
00075		Work Record NLO-PER 1507-Laundry	1903	No annian 1052 local dissignments
39370	Planto	r oreman's nandwritten notes-wet Area-rit. o	040 07-140V 07	ino copies, 1955 logs,
		Paulanaula Landumittan natas Duu Aron Dit. 9	May 56 Oct 57	requires time and effort to read all notes.
	<u>,</u> 3	Area Foreman's rates to shift foreman. Dit 9	May 50 - Oct 57	
00070		Werk Poreman's notes to shift forement -r it. o	May 50- Sep 57	No contaga list of neurophal
39379	Flanco	Work Record-flocs 1013-Fit. 8	00007-00109	and ich agaigments
		Handweitten shift foroman's lag/notes Plt 8	Oat 57 Dag 59	land job assignments
00.000		Maluwritten smit foreman's lognoles-Fit. o	Son Dec 50	No
39403	Plt. 5 ,0, 8	Work Record-Pit.o-riao-1015	Sep - Dec 60	
		Work Record-Pit 9-rias	Jan - Dec ou	110
		Poreman's Log Sneet-Pit. 9	May 09 - Jan 60	
	· .	Daily dust collector check sheets-Pit.9	Oct-Dec 59	ino; separate form with dc and
				Dag configuration for each plant;
••		The stand of the stand of the standard of the	NICER D. FO	notes on operation or dag failure
•		Daily dust collector check sheets-Pit.8	Nov 57-Dec 58	
		Daily dust collector check sheets-Pit.8	(Uct 55 - May 56	· · · · · · · · · · · · · · · · · · ·

.

.

· · ·

.

•

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

\*\*\*

÷.

. .

Sec. 184

10000

··· ··

...

1 80

-----. 3

.

• • •

ì

•

•

÷

.

۰.

•

•

.

.

•••••••

•	14. 4.8.	

· · ·

.

.

Box	No.	Plant	File	Date	Status	N N
394	403	Plt. 5 ,6, 8	Daily dust collector check sheets-Plt.5	Jan - Dec 62	19 98	Ĕ
		Plt. 7	Plant 7 notebooks: Vaporizer; Refrigeration;	Dec 55- May 56	No	ces
			Plant 7 notebooks: Leaderman's Log	Mar - May 56	Copied; small binder with norm & depl	of,
	ļ		· ·		quantities on shift by shift basis;	In
				]	may be useful for Plt 7 production.	lor l
A 45	5875	Pilot /Plt. 7	Misc. records & correspondence	1951 - 1968	Copied: loss of materials; dc bags &	ma
	[				filter types; enr. UF4 prod. Aug56-Apr 57;	tio
					dc loading & efficiency tests;	17
			• • •		fume release in 1955.	ł.
393	342	Plant 2&3	Leaderman's Log-Extraction Area-Ore Ref.	Jan-Jun57	No	`
			Shift Foreman's Log -Plt 3-Recovery	Jan-Jun 57	No	
			Shift Foreman's Log-Ore Ref Denitration	Jan- Jun 57	Copied-"gulping" operations-3 shifts/day	ł
			Operator's Shift Log-Ore RefDenitration	Jul-Dec 57	Copied-"gulping" operations-3 shifts/day	1
•			Work Record & Shift Foreman's	Jul-Dec 57	No	ł
			Log-PRO-664			1.
			Shift Log-Denitration Area	Aug-Oct 57	Copied-"gulping" operations log -3 shifts/day	ŀ
			Shift Foreman's Log Recovery Area-Ore Ref.	Nov, Dec 57	No	
		•	Denitration Operators Shift Log	Jan-Dec 57	Copied Apr to Sep -"gulping" operations	ľ
393	46	Plant 2&3	Shift Foreman's Log-Denit. Operators Log	Jun 58-Mar 59	Copied-"gulping" operations-3 shifts/day	
			"On-stream Factor Report"	Jun 58-Mar 59	Copied-summary of all operational logs:	
					shift foreman's extraction, dinitration, sump	
					technician's log, nitric acid recovery	
393	45	Plant 2&3	Sump Technician's Log-PRO-1039-Ore Ref.	Jan-Dec 58	Copied-Daily discharges to general	
					sump &MH 175	
	. (		Shift Foreman's Log-Denit. & Recovery Area	Jul-Nov 58	Copied-"gulping" operations- 3 shifts per day	1.
	· 1		Operators Shift Log-Denit. Area-PRO-1175	Jul-Dec 58	Copied-"gulping" operations log-3 shifts/day	1
A48	689		Hydrolysis UNO3 test log 903 1955-56;	1955-61	No; reviewed by F. Rogers, CDC, 6/2/94	
			U techniques			
A 47	394		Chemical analysis cards, water	1989	No; reviewed by F. Rogers, CDC, 6/2/94	
A48	700	Notebooks	Log book 2853, gulping amounts	1975-76	Reviewed by F. Rogers, CDC, 6/2/94	
<u></u>	· •	•	7 day/shift 1975-76			
<sup>1</sup> .		• •• •	Log book 2855; gulping oper. 1975-76	1975-76	Reviewed by Felix Rogers, 6/2/94	

٠

.

Box No.	Plant	File	Date	Status
A48696	Notebooks:	625: Metallurgy Dept.; cost comparison	N	
•	handwritten	PP & Plt. 4 products; 30x and 500 x photos.	1954 - 55	
	from library	627: Solvent extrac U nitrate; purification		
		of thorium in cellulose column.	1953 - 55	•
		692: Development of moving bed reac UF4	Oct-Nov 54	
		699: U metal quality; photos of slugs 100x	. <b>1954 - 59</b>	
		700: Pilot Plant - Furnace operation	1954	No; nothing on releases
		705: Plant 4, UO3 processing	1954 - 55	
		708: Salt heat treating of U; diff. therm. ana	1954 - 57	
	÷ 1	3087: Pilot Plt operations & procedures	1978	No; nothing on releases
	· . •	3088: Pilot Plt operations & procedures	1978 - 79	No; nothing on releases
A48696	Notebooks:	3100: Refinery; boil down operations	1981 - 82	No copies
	handwritten	3102: Supervisor's instructions, refinery	1981 - 85	No copies
	from library	3099: Ray Bauer's notebook; mold specs.	1978 - 84	No copies
	· · · ·	3105: Pilot Plt-procedures and operations	1979	No; nothing on releases
	i trans	3108: Pilot Plt-procedures and operations	1979	No; nothing on releases
		3109: Pilot Plt-procedures and operations	1979	No; nothing on releases
		3113: Pilot Plt-procedures and operations	1979	No; nothing on releases
	• • • •	3118: Pilot Plt-procedures and operations	1979	No; nothing on releases
	•	3117: Plant 1-operations & daily log	1979 - 80	No copies
	•	3119: Plant 4	· 1979	No; nothing on releases
		3120: Plant 4-operations & procedures	1979-80	No; nothing on releases
	-	3105: Pilot Plt-operations	Jan-Apr 79	No; nothing on releases
	•	3108: Pilot Plt-shift & activities log	Apr-79	No; nothing on releases
		3109: Pilot Plt-shift & activities log	May-79	No; nothing on releases
	<i>·</i> · ·	3118: Plant 4-shift log ·	Nov-79	No; nothing on releases
A42673	Plant 6	Environmental Safety & Health-MC&A daily		
		production reports-Plant 6	1974 - 84	No copies
B39213		Daily time sheets	19598	No; reviewed by F. Rogers, CDC, 6/2/94
54200		Purchase Orders	1985	No; reviewed by F. Rogers, CDC, 6/2/94
39219	Metals area	Shift Foreman's Daily Log Sheets-Plt. 9-	Oct - Dec 58	No copies
	•	2nd and 3rd shifts	Apr 59-Aug 60	
		Foreman's Daily Log-PRO-909-Plt. 6	Jun 59-May 60	

· · · .

\$ 34.5

27.00

61°-2-22

10,035

449800

100. 15

N 0

·· •.

۰.

411

۰ .

÷,

Page A-20

,

• .

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

· •,

• 31

• -

•

3

· · · ·

.

•

Box No.	· Plant	File	Date	Status
39219	Metals area	Daily time sheets-PRO 909-Plt. 9	Apr 59-Jun 60	10
B 39341	Plant 2/3	Foreman's Log-Ore Refinery		
		Foreman's Log-Denit /Acid Recovery	Jan-Dec 56	Detailed shift logs for "gulping" operations;
		Digestion/Extraction Logs	1956	No
A48688	2543	Metallurgical Dept. handwritten lab books	1968-70	
	2464	, u	1968-69	
	2525	н Н	1968-69	
	433	Maurice Atwell	1953-1957	
1	2427	Metallurgical Dept. handwritten lab books	1967-68	
	2455	"	1967-70	4 <sup>4</sup>
	2485	) II	1967-69	}
1	2364	} "	1966-68	
	2322	•	1965	·
	2249		1965-66	· ·
	2246	1 u ·	1965-66	
	2250	· · ·	1965-67	
	2254	u u	1965-69	
]	2253	<b>u</b>	1966-68	
]	2266	Handwritten carbide tool development	1966-67	1
1	2333	Metallurgical Dept. handwritten lab books	1965-78	}
	2271	Metallurgical Dept. handwritten lab books	1964-77	
	2284	Project log- extraction	1964-66	
	2499	R.C. Kispert	1967	1 1
	2626		1968-69	
	2344	Plant 2/3 denitration log (# pots gulped)	May-Sep 1973	copied
	2279	C.W. Huntington	1964-66	]
	2284	Thorium extraction test log-Kispert	• 1964-66	
	2333	SS Material weight log	1965-78	
	2271	SF materials shipping log	1964-77	
B39240	Plant 2/3	Foreman's daily log sheets	Jan 59-Sep 60	copied
A48691	1936	General sump log for 1963	1963	copied
	· 3335	Operators' shift log for Plt 8; feed/prod. wt.	3/83 to 9/83	Furnace oper.; drums to furnace; clean out

Radiological Assessments Corporation "Setting the standard in environmental health"

1

.

•

Box No.	Plant	File	Date	Status
A48691	3345	Plant 8 shift log; furnace operation	6/83 to 8/83	Operator's log kiln; R.L. Gardner
	3337	R.L. Gardner; Plt 8; operators log	4/83 to 6/83	· · · · · · · · · · · · · · · · · · ·
	3350 ``	Opeators' shift log; Plant 8	4/83-6/83	
	3351	P.A. Shanks-Chemical production tech.	· · · · ·	. <b>19</b>
A44040	Plant 8	Misc. chemical analysis;notebooks		
		UO3 production for Paducah	Mar73-May77	
· · ·		Lot marking system	1968-70	
		Sample log summary	1975-77	19 B
	:	Refinery and Plt 8 analysis	May-Nov'75	Box furnace product-Plant 8
		Plant 8 analysis; trailer cake	1971	
.		UO3 analysis	1975	
	ī : í:	Plant 8 oxidation furnace product	May-Nov'75	
112		Plant 8 rotary kiln product		
:		Analysis of refinery feeds	10	
A45875	Black Start	Misc. receipts, correspondance	1951-1968	Reviewed by F. Rogers, CDC, 6/2/94
A39343	i	Foreman's logs	1958	Reviewed by F. Rogers, CDC, 6/2/94
427574		Disouted weight cards	no date	Reviewed by F. Rogers, CDC, 6/2/94
A48697	918	Lab notebook; W.E. Palmer	1955-57	
	928	Logbook	1955	· · · ·
:	934	Logbook	1955-56	· · ·
	942	Logbook	1955-56	
	944	Logbook	1955-56	
	956	Logbook	1955-57	].
- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1	970	Logbook	1955-57	· ·
	973	Ray Bauer's chemical lab notebook	1955-57	
	974	Logbook	1955-57	
	979	Logbook	1956	· ·
	2087	Logbook	1963	
	2901	Logbook	4 -	
	2903	Logbook	1973-74	
	2904	Logbook	1973-74	
	2921	Logbook	1973-74	
	2022	Calciner shift log	1974	

.

• · •.

•

. •

.. . . .

. . . .

. ·

.

~7

Page A-22

The Fernald Dosimetry Reconstruction Project

.

. •• 1999 1999 199 1.00 я ar na 6 .... • • • • 12013 A. . . . . . £ ۰.

•

.

.

Hand the Carlo and Indiana

.

Radiological Assessments Corporation
"Setting the standard in environmental health"

•

.

P

ذ.،..

SW15 57 77 63345

A CONTRACT NUMBER OF STREET

1 4.98.99

. .....

.

Box No.	Plant	File	Date	Status
	2927	Calciner shift log	1975	
	2928	Plant 9 test logbook	1974-75	
	2939		1974-78	· ·
	2979	· · ·	1975	· ·
	2978	1	1975-78	
B39226	Plts 5,6,9	Foreman's log sheets	Jan-Jun 1962	
	•	Daily time sheets	Jan 63-Jun83	
B39376	Plant 8	Shift foreman's log notes and log	Oct 57-Dec 58	
		Work record; H&S	Oct 57-Jun 59	
B39351	Plt 2/3	Work record	Jan 57-Dec 68	
B39351		Work record; shift foreman's log-	1967	Some copied
		digestion & extraction		
		Operators' shift log all areas-ore refinery	1967	Copied
		Foreman's instructions log-ore refinery	May 67-May68	
B39344	Plant 2/3	Work record; shift foreman's log-	Jan 58-Dec 59	
		digestion & extraction		
		Operators' shift log all areas-ore refinery	Jan 57-Mar 60	Copied
	• •	Area foremens' notes; cold weather shutdown	Nov 60-Dec 60	
B39340	Plant 2/3	Foreman's log-ore refinery, digestion,	Dec 53-Dec 57	Some copied
		extraction areas		
B39351			· .	
A44584	ES&H	Stack sampling newsletter	1974-78	
		Exhaust ventilation surveys	1965-67	
		Fallout, river, grass/soil, air sampling	1960-1969	Keith Ross' box; all copied
		Correspondance of Keith Ross files	1980-85	Copied
	•	River water survey at 15 locations	1960s	copied
B39217	Plt. 6	Foremans' daily log sheets; mechanical	Jun 58-Feb 59	
		dept. Daily time sheets	Jan - Dec 1959	
B39343	Plt. 2/3	Work record; shift foremans' log	Jan-Dec 1957	Copied
		for refinery, extraction		
	•	Work record; shift foremans' log	Dec 56-May 57	Copied ·
		for refinery, extraction	-	
		Work record; shift foremans' log	Jan-Jun 1958	Copied

Appendix A Sources of Information

· · · · · ·

Page A-23

.

Box No.	Plant	File	. Date	Status
68000 48693 84400		for refinery, denitration Purchase orders Misc. lab notebooks-research Purchase orders	1985 1984 1987	No; reviewed by F.Rogers, CDC, 6/2/94 Reviewed by F. Rogers, CDC, 6/2/94 Reviewed by F. Rogers, CDC, 6/2/94
38378	•	11me cards, assignment sneets	1955-60	Reviewed by F. Rogers, CDC, 6/2/94
Boxes outs	ide of Stora	ge room on 3rd floor of Bldg. 4	· ·	•
0 boxes fr	om Pilot Pla	ant; routine operations		
1	Pilot	Misc. records; 1987 investigation rpt;	1987	
	•	of HF release on Sept 29, 1987;		· ·
		study environs of P P July 3, 1987		
• •	. :		•	
2		Foremans' office; minor events;	1986-87	
: .		vessel inspections		
3		Production files		
2 boxes fr	om Plant 2/3	; unnumbered; some indications of conten	t written on to	p
	Plt 2/3	Area clock cards	1987	
		Pot control records	1987	
· · · · · · · · · · · · · · · · · · ·		Job orders	1987	
		Vacatin records		
1	•	Daily records	1984-87	
		Refinery/extraction records;	1984-87	· · · · · · ·
		slag leach data sheets; production		
	· · ·	consumption worksheets. Safety meeting	1981-1983	, · · ·
		minutes. plant test authorizations, nucelar	1981-1983	
		material custodian activities		
•	••••			
•			1	

.....

.

2

, <u>.</u>.

65

...  Pa

1.00

Land St.

Land La

\*\*\*\*

### ANNEX C TO APPENDIX A

. ,

# RAC DOCUMENT COLLECTION FOR THE FERNALD DOSIMETRY RECONSTRUCTION PROJECT

The following list identifies the documents that we have located and reviewed for the Fernald Dosimetry Reconstruction Project. All documents in the *RAC* Repository are grouped by topic and kept at a single location. Additional materials are added regularly to the collection as the project proceeds.

### TABLE OF CONTENTS

AERIAL SURVEYS / PHOTOGRAPHS / MAPS	27
AIR SAMPLING/BIOASSAY/GUMFILM	27
ANALYTICAL DATA SHEETS / CHEMICAL ANALYSIS	29
Air-Inplant Sampling	29
Air-Perimeter and Boundary Sampling	31
Air-Offsite Sampling	32
Gumfilm and Fallout Trays	33
Milk	34
Plant 2/3 "Gulping" Operations	35
Rainfall	35
Soil and Grass	35
Liquid Effluents-Manhole 175 Outfall	36
Storm Sewer	37
Surface Water-Great Miami River	38
Surface Water-Paddy's Run Creek	40
Waste Pits/Sewage and Water Treatment Plant	<b>41</b>
CP - CONSTRUCTION PROPOSALS	12
COST STATEMENTS - PRODUCTION INVENTORIES	43
DOSE /PREVIOUS ESTIMATES TO POPULATION	<b>14</b> .
DUST COLLECTORS AND BAG FILTERS	15
ENGINEERING DRAWINGS	19
Plant 1 Drawings4	19
Plant 2/3 Drawings	<b>19</b> '
Plant 4 Drawings	50
Plant 5 Drawings	52
Plant 6 Drawings	53 <sup>°</sup>
Plant 7 Drawings	53 <sup>°</sup>
Plant 8 Drawings	54
Plant 9 Drawings	54
Pilot Plant Drawings	54
K-65 and Metal Oxide Silos Drawings	55
"Old" Solid Waste Incinerator and Sewage Treatment Area Drawings	56
Other Buildings Drawings	57
FMPC General Area Drawings.	57
Miscellaneous Drawings	58

.

	ENVIRONMENTAL MONITORING REPORTS	58
	FMPC REPORTS ON FMISSIONS and SITE & SSESSMENTS	ەر رى
	FRESH (Fernald Residents Grown)	02 64
	CPOLINDWATER	
,	CROUND WATER	04 67
	CIMEN M	07
		10 
		15 76
•		10
		0/
		93
:;	K-OD SILUS AND MATERIALS/KADON	
	NDDES AND LIQUID EEELIENT DISCUADCE DEDODTS	107
	NPDES AND LIQUID EFFLUENT DISCHARGE REPORTS	102
	OPED ATING LOSSES	107
		100
:		
1.5		
	PLANT 2/3; REFINERY	
	PLANT7	
·	PROCEDURES, STANDARDS AND SOPs	
. 7	OPERATING PROCEDURES: SERIES 3C - Sops (1957-1961)	
	PROCESS DESCRIPTIONS OF PLANTS 2 & 3 - SERIES 3A (1957)	118
	PRODUCT SPECIFICATIONS/SAMPLING - SERIES 3B (1957-1959)	
	PROCESS DESCRIPTIONS OF PLANT 4 PROCESSES - SERIES 4A (1956-1961)	
	QUALITY CONTROL AND UNCERTAINTIES	
• •••	RAIN CAPS	
	RECYCLED FEEDS	
·	SCIENTIFIC BACKGROUND / FERNALD-RELATED	
	SCRUBBERS	124
	SOILS AND SEDIMENTS	
	STACK EMISSIONS	130
	STACKS - PHYSICAL FEATURES & UNMONITORED	133
	STORM SEWER AND PADDY'S RUN	
	SUMP AND SEWAGE SYSTEM	138
	THORIUM	140
	Pilot Plant Thorium Data, 1966-1968 Folder.	142
· .	Thorium Gel (Th(OH <sub>4</sub> )) Preparation 1964-1969 Folder	
(	Thorium Metal Production Pilot Plant 1969-1971 Folder	143
	Thorium Production for Bettis 1971-1976 Folder, Records Received From FMPC	144
	Pilot Plant Thorium Extractions 1964-1980 Folder	145
	Thorium Processing General Folder, Records.	145
	UNUSUAL EVENTS, MAJOR LOSSES, OSHA COMPLAINTS	147
•.	URANIUM IN MILK	151
•	WASTE PITS/LAND BURIAL	151

A Contract Brack States and States 1 and 1 And the set of an Brezila

··· · .

...

Page A-27

### AERIAL SURVEYS / PHOTOGRAPHS / MAPS

- Feimster, E. L., June 1979. An Aerial Radiological Survey of the Area Surrounding The Feed Materials Production Center, Fernald, Ohio, EGG-1183-1680. EG&G Energy Measurements Group. Date of survey: August 1976/May-June 1977.
- FMPC Series of Aerial Photographs of FMPC Site and Process Buildings in 1954, 1960, 1965, 1987 1990.
- Ross, K. Late 1950. Plan of General Area Property, Incinerator. Drawing No. 8-4001. (24 x 36 inch map that PGV copied in sections from K. Ross files in Central files. Includes sampling locations for gumpaper, fallout, soil and grass in late 50s and early 1960s). National Lead Company of Ohio.
- Shipman, G. R., October 1985. An Aerial Radiological Survey of the Feed Materials Production Center and Surrounding Area, Fernald, Ohio, EGG-10282-1084. EG&G Energy Measurements. Date of Survey, April 1985.
- Stern, R. J. Comments on Aerial Radiation Survey of the Feed Materials Production Center, Fernald, Ohio.. Report to W.A. Vaughn regarding the EG&G aerial surv ey of the FMPC. Department of Energy, Environment, Safety and Health. PE-222. ICN 2144793.

#### AIR SAMPLING/BIOASSAY/GUMFILM

- Bipes, R.L. Ventilation Survey of the Paint Spray Booth-Mechanical Shop. Memorandum to D.E. Diehl. Cincinnati, OH: National Lead Company of Ohio. 19 October 1962.
- Blase, E.F. Air dust samples in wet side of pilot plant., 3013. Memorandum to R.C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. 22 April 1952.
- Blase, E.F. Air dust survey reversing mill. Memorandum to R.C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. 26 November 1952.
- Boback, M.W. and R.C. Heatherton. 28 September 1964. Recent Bioassay Activities at National Lead Company of Ohio. NLCO-933. (Summarizes recent nonroutine problems for bioassay department including use of infrared heating, U in lung and lymph node tissue, U slivers in hand, radium isotopes from remelt operation, U in fecal samples). Prepared for presentation at the Tenth Annual Bio-assay and Analytical Chemistry Conference, Cincinnati, Ohio. October 8-9, 1964. National Lead Company of Ohio. Health & Safety Routine Reports
- Boback, M.W. Procedure for Treatment and Analysis of Gumpapers. Letter to Felix Rogers. Memo No: 94-026. Cincinnati, OH: Fernald Environmental Managment Project. 18 May 1994.
- Dodd, A.O. Monthly Progress Reports. Memorandum to R.H. Starkey. Have 1958: March, April, May, June, July, August, September, Oct. (Report film badge exposure data, special external radiation investigations, ground contamination surveys, plant liquid effluent, outplant air dust and fallout).

Page A-28

- . · .

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

....

:---

- Dodd A.O. Annual Report Radiation and Effluent Control Section. Memorandum to R.H. Starkey. (2 pages, personnel monitoring data, effluent control, air dust and fallout studies, enriched materials movement coordination, residues surveillance; nothing quantitative). Cincinnati, OH: National Lead Company of Ohio. 12 February 1958.
- Heatherton, R.C., M.W. Boback. and J.A. Quigley. A Continued Program of Analysis for Uranium in Human and Animal tissues. NLCO-895. (Comparisons are made of uranium concentrations in tissues of 16 exposed and unexposed persons). Prepared for presentation at the Ninth Annual Bioassay and Analytical Chemistry Conference, San Diego, California October 10-11, 1963. National Lead Company of Ohio. 20 September 1963.
- Held, B.J. and E. Chenault. Perimeter Air dust survey. Memorandum to R.C. Heatherton. (Results of survey on October 30 and 31, 1956 and December 27, 1956 around perimeter. Cincinnati, OH: National Lead Company of Ohio. 8 November 1956.
- Kessler, L. W. Air Contamination In Plant 8, Project No. P-23000-15, Short Order Completion Report for Production Engineering Department, NLO/ICN 2225348. (Equipment contributing to high airborne contamination in Plant 8 identified and action taken outlined; future activity reported under Project P-20000-22). 17 February 1959.
- Klein F.J. Memorandum to R.L. Fischoff. Uranium Fallout Study in Adjacent Vicinity of the Oil Burner and The Incinerator. (Lists concentration range and averages at five locations). NLO/ICN 2118894. Cincinnati, OH: National Lead Company of Ohio. 1 May 1964.
- Ross, K.N. and F.J. Klein. Monthly FMPC fallout data using variety of techniques and Abbe Observatory rainwater data for 1965. Letter to C.E. Schumann (City of Cincinnati). Cincinnati, OH: National Lead Company of Ohio. 8 February 1966.
  - Starkey, R. H. Compilation of High Air Dust Exposure Operations. Report to J. A. Quigley, P. G. DeFazio & C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio. (7 pages, compilation of air dust exposure operations for all plants in excess of 3 x MAC, and status of corrective action). 20 October 1960.
  - Starkey, R. H. Compilation of High Air Dust Exposure Operations. Report to J. A. Quigley, P. G. DeFazio, C. R. Chapman and S. Marshall. '(9 pages, compilation of air dust exposure operations for all plants in excess of 3 x MAC, and status of corrective action as of 12/13/62). Cincinnati, OH: National Lead Company of Ohio. 2 January 1963.
  - Starkey, R. H. Compilation of High Air Dust Exposure Operations. Report to J. A. Quigley, P. G. DeFazio, C. R. Chapman and S. Marshall. (8 pages, compilation of air dust exposure operations for all plants in excess of 3 x MAC, and status of corrective action as of 4/18/63). Cincinnati, OH: National Lead Company of Ohio. 24 May 1963.
  - Starkey, R.L. Correlation between two-stage air sampling data and the excretion of uranium in urine. For presentation at the American Industrial Hygiene Conference, 9 May 1963, and the health Physics Society meeting 11 June 1963. Cincinnati, OH: National Lead Company of Ohio. NLCO-869. 1963.

Twitty, B.L. and M.W. Boback. 1970. Rapid Determination of Thorium in Urine by Thermal Neutron Activation Analysis. Analytical Chimica Act20, 49: 19-24.

and the state of the

Page A-29

- Wing, J. F., K. N. Ross and R. G. Wissman, Exposure Study of Technical Laboratory personnel to Radioactive Airborne Dust. (Brief summary and discussion of existing air dust levels at Technical lab. Bldg, 10 pages). 30 November 1961.
- Wing, J. F. to H. M. Beers. Air Dust Samples From Outside Mill, Plant 8, NLO/ICN 2225349. (Results grossly in excess of MAC), 1 August 1958.
- Wing, J.F. Simultaneous Air Samples and Face Velocity Measurements. Memorandum to E.D. Leininger, R.G. Wissman and R.L. Ruhe. Cincinnati, OH: National Lead Company of Ohio. 20 January 1965.

### ANALYTICAL DATA SHEETS / CHEMICAL ANALYSIS

- Boback, M.W. 22 March 1967. Neptunium in NFS Uranium. Memorandum to J.A. Quigley. (Analyses for Np in NFS Dresden material, shipment 24 and 30). National Lead Company of Ohio.
- Boback, M.W. 17 May 1967. Neptunium in Plant Materials. Memorandum to J.A. Quigley. (4 tables contain results of Np in NFS Dresden uranyl nitrate; attempt to follow particular batch of Np-containing uranium through plant processes). National Lead Company of Ohio.
- Gustavson, S.R. NLO-NBL Assay Comparisons on NLO Inventory Samples. Letter to C.H. Weldon. (Tabulation of U assay results on various process samples incl. scrubber acid, digestor liquor, Q-11). US Atomic Energy Commission, New York Operations Office. 8 February 1954.

### Air-Inplant Sampling

- NLO (National Lead Company of Ohio). Analytical data sheet of alpha in air dust and smear samples taken in Laboratory Building collected 1/9, 1/12, 1/13, 1/14, 1/16, 1/19, 2/5, 3/4, 4/5, 3/9, 3/10, 3/11, 3/18, 3/24, 3/26, 3/31, 4/2, 4/3, 4/6, 4/14, 4/17, 4/20, 4/27, 4/28, 4/29, 5/1, 5/4, 5/6, 5/7, 5/22, 5/26, 5/27, 6/9, 6/10, 6/15, 6/17, 6/24, 7/1, 7/13, 7/14, 7/16, 7/17, 7/21, 8/2, 8/7, 8/15, 8/17, 8/20, 9/2, 9/11, 10/12, 10/19, 10/26, 11/7, 11/9, 12/15, 12/16/53. From FERMCO Box 535-279. Cincinnati, OH: National Lead Company of Ohio. 1953.
- NLO (National Lead Company of Ohio). Contamination survey sheet of various rooms in Laboratory Building collected 8/2, 8/7, 8/10, 8/19, 8/27, 9/4, 9/14, 10/19, 10/26/53. From FERMCO Box 535-279. Cincinnati, OH: National Lead Company of Ohio. 1953.
- NLO (National Lead Company of Ohio). Analytical data sheet of alpha in air dust and smear samples taken in Laboratory Building collected 1/11, 2/11, 2/15, 2/16, 3/9, 3/11, 3/15, 4/7, 4/16, 4/26, 4/28, 4/29, 4/30, 5/7, 12/10/54. From FERMCO Box 535-280. Cincinnati, OH: National Lead Company of Ohio. 1954.
- NLO (National Lead Company of Ohio). Analytical data sheet of alpha in air dust samples taken in Health and Safety Service Building collected 2/22, 2/24, 5/12, 5/13, 6/24/55. From FERMCO Box 535-283. Cincinnati, OH: National Lead Company of Ohio. 1955.
- NLO (National Lead Company of Ohio). Analytical data sheet of alpha in air dust samples taken in Health and Safety Service Building collected 2/2/56. From FERMCO Box 535-283. Cincinnati, OH: National Lead Company of Ohio. 1956.

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

NLO (National Lead Company of Ohio). Analytical data sheets of alpha in wipe samples in Laboratory Building collected 1/2, 1/21, 2/28, 3/4, 3/6, 6/17, 6/18, 6/19, 6/21, 6/23, 6/25, 6/26, 6/27, 7/1, 7/2, 7/3, 7/5, 7/8, 7/11, 7/12, 7/15, 7/16, 7/18, 7/30, 8/15, 8/19, 9/3, 10/23, 10/24, 10/29, 11/11, 11/13, 12/16/57. From FERMCO Box 535-286. Cincinnati, OH: National Lead Company of Ohio. 1957.

NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust samples from Laboratory Building collected 2/6, 2/11,2/15, 3/3, 3/5, 3/15, 12/18, 12/19, 12/23, 12/24, 12/29/58. From FERMCO Box 535-287. Cincinnati, OH: National Lead Company of Ohio. 1958.

NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust samples from Health and Safety Building collected 1/24, 8/16, 8/17, 9/30, 10/1/58. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1958.

- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust samples from Laboratory Building collected 1/13, 2/9, 3/10, 3/11, 6/19, 10/1, 10/9, 10/12, 10/13, 10/14, 10/29, 11/6,11/21/59. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1959.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust samples from Health and Safety Building collected 1/19, 1/23, 3/31/59. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1959.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust samples from machining operations at offsite locations collected in 1959. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1959.
- NLO (National Lead Company of Ohio). Analytical data sheet of alpha in air dust samples taken in Health and Safety Building collected 2/2/56. From FERMCO Box 535-283. Cincinnati, OH: National Lead Company of Ohio. 1960.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium in air dust samples from Laboratory Building collected 11/21, 11/22, 11/30, 12/23/60. From FERMCO Box 535-289. Cincinnati, OH: National Lead Company of Ohio. 1960.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust samples from Health & Safety Building collected 8/19, 9/20/61. From FERMCO Box 535-292. Cincinnati, OH: National Lead Company of Ohio. 1961.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust samples in Health and Safety Building collected 3/31/63. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1963.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust in Radiograph facility collected 5/22/63. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1963.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust in laboratory machine shop collected 6/20, 6/25/63. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1963.

5,5

Ξ.

Page A-31

- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust in inventory building collected 12/28/63. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1963.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust in Laboratory Building collected 11/29, 12/2, 12/3, 12/17, 12/26, 12/28, 12/31/63. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1963.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air dust samples from Health and Safety Building collected 11/6/64. From FERMCO Box 535-294. Cincinnati, OH: National Lead Company of Ohio. 1964.

#### Air-Perimeter and Boundary Sampling

- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air samples at various times in 1953, 1954 and 1955. From FERMCO boxes. Cincinnati, OH: National Lead Company of Ohio. 1953-1955.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air near onsite roadways at various times in 1955, 1957, 1958, 1960, 1963, 1965, 1966, 1967 and 1968. From FMPC box 51, 53, 54 and 55. Cincinnati, OH: National Lead Company of Ohio. 1955-1968.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha in air samples at various times in 1956 and 1957. From FMPC box 54. Cincinnati, OH: National Lead Company of Ohio. 1956-1957.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1958. From FMPC Box 55. Cincinnati, OH: National Lead Company of Ohio. 1958.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1959. Cincinnati, OH: National Lead Company of Ohio. 1959.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1960. From FERMCO Box 535-289. Cincinnati, OH: National Lead Company of Ohio. 1960.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1961. From FERMCO Box 535-291. Cincinnati, OH: National Lead Company of Ohio. 1961.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1962. From FMPC Box 60. Cincinnati, OH: National Lead Company of Ohio. 1962.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1963. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1963.

Page A-32

:.·'

2.1

- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1964-1965. From FERMCO Box 535-294. Cincinnati, OH: National Lead Company of Ohio. 1964-1965.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1966-1968. From FERMCO Box 37189. Cincinnati, OH: National Lead Company of Ohio. 1966-1968.

NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1969-1971. From FERMCO box. Cincinnati, OH: National Lead Company of Ohio. 1969-1971.

NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium and particulates in air samples at various times in 1972-1974. From FERMCO box. Cincinnati, OH: National Lead Company of Ohio. 1972-1974.

NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium and particulates in air samples at various times in 1975-1977. From FERMCO box. Cincinnati, OH: National Lead Company of Ohio. 1975-1977.

NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium and particulates in air samples at various times in 1978-1979. From FERMCO box. Cincinnati, OH: National Lead Company of Ohio. 1978-1979.

NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium and particulates in air samples at various times in 1980-1981. From FERMCO box. Cincinnati, OH: National Lead Company of Ohio. 1980-1981.

NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium and particulates in air samples at various times in 1980-1981. From FERMCO box. Cincinnati, OH: National Lead Company of Ohio. 1982-1983.

NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium and particulates in air samples at various times in 1984-1986. From FERMCO box. Cincinnati, OH: National Lead Company of Ohio. 1984, 1986.

- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium and particulates in air samples at various times in 1980-1981. From FERMCO box. Cincinnati, OH: National Lead Company of Ohio. 1980-1981.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium and particulates in air samples at various times in 1980-1981. From FERMCO box. Cincinnati, OH: National Lead Company of Ohio. 1980-1981.

and the state of the second states

### **Air-Offsite Sampling**

Hinnefeld, S.L. Radiological Survey at Crosby Township School. Memorandum to R.B. Weidner. NLO/ICN 2139431. Cincinnati, OH: National Lead Company of Ohio. 7 January 1985.

Keys, R.W. Air sample results from Elda Elementary School. Letter to J. Bischoff (Ross Local Schools). NLO/ICN 2154841. WMCO:EH(EC):86-0029. Cincinnati, OH: Westinghouse Materials Company of Ohio. 29 January 1986.

X

Page A-33

- Keys, R.W. Air sample results from Crosby Elementary School. Letter to E. Frank (Southwest Local School District). NLO/ICN 2154841. WMCO:EH(EC):86-0174. Cincinnati, OH: Westinghouse Materials Company of Ohio. 30 May 1986.
- Keys, R.W. Air sample results from Crosby Elementary School. Letter to E. Frank (Southwest Local School District). NLO/ICN 2154511. WMCO:EH(EC):86-0276. Cincinnati, OH: Westinghouse Materials Company of Ohio. 14 July 1986.
- Keys, R.W. Air sample results from Crosby Elementary School. Letter to E. Frank (Southwest Local School District). NLO/ICN 2154511. WMCO:EH(EC):86-0497. Cincinnati, OH: Westinghouse Materials Company of Ohio. 24 October 1986.
- Keys, R.W. Air sample results from Crosby Elementary School. Letter to E. Frank (Southwest Local School District). NLO/ICN 2154511. WMCO:EH(EC):87-0082. Cincinnati, OH: Westinghouse Materials Company of Ohio. 23 February 1987.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1956, 1957, 1958, 1960-1962. From FMPC Box 53. Cincinnati, OH: National Lead Company of Ohio. 1960-1962.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1963. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1963.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1964. From FERMCO Box 535-294. Cincinnati, OH: National Lead Company of Ohio. 1964.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1965-1966. From FERMCO Box 535-294. Cincinnati, OH: National Lead Company of Ohio. 1965-1966.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1966-1968. From FMPC Box 37189. Cincinnati, OH: National Lead Company of Ohio. 1966-1968.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in air samples at various times in 1969-1971. From FMPC Box 34737. Cincinnati, OH: National Lead Company of Ohio. 1969-1971.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta, uranium and particulates in air samples at various times in 1975-1977. From FMPC Box 36858. Cincinnati, OH: National Lead Company of Ohio. 1975-1977.
- NLO (National Lead Company of Ohio). Analytical data sheets of gross beta total uranium, spectral analysis in air samples at various times in 1985. From FMPC Box 44925. Cincinnati, OH: National Lead Company of Ohio. 1985.

**Gumfilm and Fallout Trays** 

Page A-34

....

٠٠.

Contraction and a

NLO (National Lead Company of Ohio). Analytical data sheets of alpha in fallout tray samples collected 11/23, 12/4, 12/8/53. Cincinnati, OH: National Lead Company of Ohio. 1953.

NLO (National Lead Company of Ohio). Analytical data sheets of beta on gumfilm collected 1/30, 2/21, 3/6, 3/22, 4/10, 4/27, 5/23, 5/25, 6/7, 6/19, 7/9, 8/15, 8/29, 9/17, 9/25, 10/25, 11/27, et 16 12/26/56. From FERMCO Box 535-290. Cincinnati, OH: National Lead Company of Ohio. 1956.

NLO (National Lead Company of Ohio). Analytical data sheets of beta on gumfilm collected 1/29, 2/21, 3/26, 3/27, 4/9, 4/16, 4/25, 5/4, 5/16, 5/27, 6/27, 7/15, 8/1, 8/13, 8/23, 8/30, 9/6, 9/13, 9/30, 10/31, 11/29/57. From FERMCO Box 535-290. Cincinnati, OH: National Lead Company of si topulare Ohio. 1957. . .

ATEL S SH

NLO (National Lead Company of Ohio). Analytical data sheets of beta on gumfilm collected 1/15, 2/24, 3/21, 4/22, 5/12, 5/13, 5/14, 5/15, 5/16, 5/21, 5/23, 5/26, 5/27, 5/28, 5/29, 6/2, 6/3, 6/4, 6/5, 6/6, 6/19, 7/21, 8/25, 9/24, 10/23, 11/19, 12/16, 12/22/58. From FERMCO Box 535-287. Cincinnati, OH: National Lead Company of Ohio. 1958.

NLO (National Lead Company of Ohio). Analytical data sheets of beta on gumfilm collected 1/5, 1/29, 2/2, 3/2, 4/7, 4/24, 5/6, 6/9, 7/9, 7/10, 8/11, 9/11, 10/12, 11/13, 12/14/59. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1959. 

NLO (National Lead Company of Ohio). Analytical data sheets of uranium and beta on gumfilm for special fallout study collected 3/21-3/28, 4/4-4/11, 4/12-4/18, 4/19-4/25, 4/26-5/2, 5/3-5/9, 5/17-5/23, 5/24-5/30, 5/31-6/6, 6/7-6/13, 6/14-6/20, 6/21-6/27, 6/28-7/4, 7/5-7/11, 7/12-7/18, 7/19-7/25, 7/26, 8/1, 8/2-8/8, 8/9-8/15, 8/16-8/22, 8/23-8/29, 8/30-9/5, 9/6-9/12, 9/13-9/19, 9/20-.9/26, 9/27-10/3, 10/4-10/10, 10/11-10/17, 10/18-10/24, 10/25-10/31, 11/1-11/7, 11/8-11/14, 11/15-11/21, 11/22-11/28, 11/28-12/5, 12/6-12/12, 12/13-12/19/60. From FERMCO Box 535-290. Cincinnati, OH: National Lead Company of Ohio. 1963.

and the second secon 10.131 Milk NLO (National Lead Company of Ohio). Analytical data sheets of uranium, beta, fluorides and specific gravity of milk samples collected 7/17/59, 8/12, 9/13, 10/6, 11/19,12/15/65 and 2/15,7/15/, 6/16/66, 8/8/66 from Knollman Farms. Cincinnati, OH: National Lead Company of He & Bette Collection (Children Collection)
 He will find the top in the collection of the coll Ohio. 1959, 1965-1966.

NLO (National Lead Company of Ohio). Analytical data sheet of uranium in muskrat killed near residue pond east of K-65 area on 9/3/59. Cincinnati, OH: National Lead Company of Ohio. the good tole of the state of the second state of the 1959. no Enfortes e la c

NLO (National Lead Company of Ohio). Analytical data sheets of uranium, radium-226, radium-228 and lead-210 in milk samples collected monthly from Knollman and McClanahan Farms. Cincinnati, OH: National Lead Company of Ohio. 1980. ಟಕ್ಷಾಗಿ ನಿರ್ದೇಶವರ್

NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in rain samples from FMPC and Abbe Observatory in Cincinnati at various times in 1961-1963, From FMPC Box 60. Cincinnati, OH: National Lead Company of Ohio. 1961-1963. コンチョンとと話記が出した。 だんし しとうび つけの 化てつけの物

EAL (Environmental Analysis Laboratories). 1980-1984. "Analytical results of milk samples from the FMPC." Letter to T. Dugan. EAL, Richmond, California.

÷.,

5

Appendix A

Sources of Information

Page A-35

- Nelson M.S. Activity in milk from cows grazing on AEC land. Letter dated October 14, 1966 to C.L. Karl, U.S. Atomic Energy Commission. National Lead Company of Ohio, Cincinnati, Ohio. 1966.
- Nelson M.S. Activity in milk from cows grazing on AEC land. Letter dated December 13, 1966 to C.L. Karl, U.S. Atomic Energy Commission. National Lead Company of Ohio, Cincinnati, Ohio. 1966.

### Plant 2/3 "Gulping" Operations

NLO (National Lead Company of Ohio). Operator's Shift log sheets of Plant 2/3 "gulping" operations. From Plant 4 contaminated records storage. Cincinnati, OH: National Lead Company of Ohio. 1957-1959, 1970-1972.

#### Rainfall

- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in rain samples from FMPC and Abbe Observatory in Cincinnati at various times in 1961-1963. From FMPC Box 60. Cincinnati, OH: National Lead Company of Ohio. 1961-1963.
- NLO (National Lead Company of Ohio). Analytical data sheets of alpha, beta and uranium in rain samples from FMPC and Abbe Observatory in Cincinnati at various times in 1964-1967. From FMPC Box 37190 and 535-294. Cincinnati, OH: National Lead Company of Ohio. 1964-1967.

### Soil and Grass

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, radium or beta in soil samples from K-65 or clay pit area on 3/17/54, 5/3/55. NLO/ICN 2240530. Cincinnati, OH: National Lead Company of Ohio. 1954-1955.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium in soil samples from Plant 5 area on 11/15, 12/6/60. NLO/ICN 2241624 and 2241631. Cincinnati, OH: National Lead Company of Ohio. 1960.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium in soil samples for special study by Professor Eye collected on 7/28-29/60. NLO/ICN 2241637. Cincinnati, OH: National Lead Company of Ohio. 1960.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium alpha, beta, and fluorides in soil and grass samples collected on and offsite 4/7, 4/22, 8/25, 9/11 and 9/24/58. Cincinnati, OH: National Lead Company of Ohio. 1958.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium alpha, beta, and fluorides in soil and grass samples collected on and offsite 4/7, 4/22 and 9/11/59. Cincinnati, OH: National Lead Company of Ohio. 1959.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium alpha, beta, and fluorides in soil and grass samples collected on and offsite 4/1 and 9/27/63. Cincinnati, OH: National Lead Company of Ohio. 1963.

Page A-36

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

> . .

يافزر

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium alpha, beta, and fluorides in soil and grass samples collected on and offsite 4/30 and 9/15/64. NLO/ICN 2243768. Cincinnati, OH: National Lead Company of Ohio. 1964.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium alpha, beta, and fluorides in soil and grass samples collected on and offsite 4/28 and 9/1/65. Cincinnati, OH: National Lead Company of Ohio. 1965.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium alpha, beta, and fluorides in soil and grass samples collected on and offsite 5/4 and 8/17/66. Cincinnati, OH: National Lead Company of Ohio. 1966.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium alpha, beta, and fluorides in soil and grass samples collected on and offsite 4/14 and 8/9/67. Cincinnati, OH: National Lead Company of Ohio. 1967.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium alpha, beta, and fluorides in soil and grass samples collected on and offsite 4/16, 8/16/68. NLO/ICN 2252101. Cincinnati, OH: National Lead Company of Ohio. 1968.

Liquid Effluents-Manhole 175 Outfall

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil and chlorides in water collected at various times at Manhole 175. Cincinnati, OH: National Lead Company of Ohio. 1954-1955.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175 in 1956. Cincinnati, OH: National Lead Company of Ohio. 1956.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, radium, thorium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175 in 1957. Cincinnati, OH: National Lead Company of Ohio. 1957.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175 in 1958. Cincinnati, OH: National Lead Company of Ohio. 1958.
  - NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175 in 1959. Cincinnati, OH: National Lead Company of Ohio. 1959.
  - NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175 in 1960. Cincinnati, OH: National Lead Company of Ohio. 1960.
  - NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175 in 1961. Cincinnati, OH: National Lead Company of Ohio. 1961.

Page A-37

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175 in 1962. Cincinnati, OH: National Lead Company of Ohio. 1962.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, total suspended solids and volume of effluent pumped daily from general sump to MH 175. Cincinnati, OH: National Lead Company of Ohio. 1959, 1964, 1965, 1967, Jun-Dec 1970, 1971, 1979.
- NLO (National Lead Company of Ohio). Analytical data sheets of radium-228 in MH 175 and Pit 5 water at various times in 1969-1970. Cincinnati, OH: National Lead Company of Ohio. 1969-1970.
- NLO (National Lead Company of Ohio). Analytical data sheets of radium 226 and 228 in MH 175 water at various times in 1969-1974. Cincinnati, OH: National Lead Company of Ohio. 1969-1974.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175. Cincinnati, OH: National Lead Company of Ohio. 1970
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175. Cincinnati, OH: National Lead Company of Ohio. 1971
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175. Cincinnati, OH: National Lead Company of Ohio. 1972
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175. Cincinnati, OH: National Lead Company of Ohio. 1973
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, oil, chlorides and total suspended solids in water collected daily at Manhole 175. Cincinnati, OH: National Lead Company of Ohio. 1974.

### Storm Sewer

1

8.1

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, fluorides, nitrates, oil, pH and total dissolved solids in water collected weekly in 1954 in storm sewer and catch basins. Cincinnati, OH: National Lead Company of Ohio. June-October 1954.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, fluorides, nitrates, oil and pH in 24-hr composite water samples collected semi-weekly in 1955 in storm sewer. Cincinnati, OH: National Lead Company of Ohio. 1955.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, fluorides, nitrates, chlorides, oil, pH and total dissolved solids in 24-hr composite water samples collected daily in 1956 at storm sewer lift station. Cincinnati, OH: National Lead Company of Ohio. 1956.

Page A-38

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

بأويدة

1

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, fluorides, nitrates, chlorides, oil, pH and total dissolved solids in 24-hr composite water samples collected daily in 1957 at storm sewer lift station. Cincinnati, OH: National Lead Company of Ohio. 1957.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, fluorides, nitrates, chlorides, oil, pH and total dissolved solids in 24-hr composite water samples collected daily in 1959 at storm sewer lift station. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1959.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, fluorides, nitrates, chlorides, oil, pH and total dissolved solids in water collected daily in 1960 at storm sewer lift station. Cincinnati, OH: National Lead Company of Ohio. August 1960.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, fluorides, nitrates, oil, pH and total dissolved solids in water collected daily in 1961 at storm sewer lift station. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1961.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, fluorides, nitrates, oil, pH and total dissolved solids in water collected daily in 1962 at storm sewer lift station. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1962.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, fluorides, nitrates, chlorides, oil, pH and total suspended solids in 24-hr composite water samples collected monthly in 1965 at storm sewer lift station. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1965.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, fluorides, nitrates, oil, pH and total dissolved solids in water collected daily in 1966 at storm sewer lift station. From FERMCO Box 535-293. Cincinnati, OH: National Lead Company of Ohio. 1966.

Stack Sampling

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium in stack sample collected from Plant 4, 5, 8, 9 in 1958. From FERMCO Box 535-287. Cincinnati, OH: National Lead Company of Ohio. 1958.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium in stack sample collected from Plant 4, 5, 8, 9 in 1959. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1959.

#### Surface Water-Great Miami River

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, fluorides, nitrates and pH in water collected daily and weekly upstream and downstream of discharge point in Great Miami River and Paddy's Run. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1955.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, pH and total dissolved solids in water collected daily and weekly

Carlo Ca Carlo Carl

37

Page A-39

upstream and downstream of discharge point in Great Miami River. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1956-58.

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, pH and total dissolved solids in water collected daily and weekly upstream and downstream of discharge point in Great Miami River. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1959.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly upstream and downstream of discharge point in Great Miami River. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1960.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly upstream and downstream of discharge point in Great Miami River. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1961.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly upstream and downstream of discharge point in Great Miami River. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1962.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly upstream and downstream of discharge point in Great Miami River. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1963, 1965.
- NLO (National Lead Company of Ohio). River survey- analytical data sheets of uranium, alpha, beta, fluorides, nitrates and chlorides in water collected semi-annually from 100 km upstream to the Ohio River downstream of the FMPC in Great Miami River. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1963-1967.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly upstream and downstream of discharge point in Great Miami River. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1966-1967.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly and Ra-226, Ra-228, collected periodically upstream and downstream of discharge point in Great Miami River. From Central Files Cincinnati, OH: National Lead Company of Ohio. 1970-1971.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly upstream and downstream of discharge point in Great Miami River. From Central Files Cincinnati, OH: National Lead Company of Ohio. 1972-1974.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, Ra-226, Ra-228, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly

127

e-

upstream and downstream of discharge point in Great Miami River. From Central Files Cincinnati, OH: National Lead Company of Ohio. 1978.

NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly upstream and downstream of discharge point in Great Miami River. From Central Files Cincinnati, OH: National Lead Company of Ohio. 1976.

3117 C. 3

NLO (National Lead Company of Ohio). Handwritten summaries of concentrations of uranium, alpha, beta, fluorides, nitrates, chlorides, pH and total dissolved solids in water collected weekly upstream and downstream of discharge point in Great Miami River 1979-1985.

#### Surface Water-Paddy's Run Creek

Godsey, G.L. Summary of Paddy's Run Analysis Data 1975-79. Memorandum to M.W. Boback. 15 August 1980.

NLO (National Lead Company of Ohio). Analytical data sheets of radium, nitrates, some uranium, fluorides water samples collected from Paddy's Run in December 1953 and January-March 1954. Cincinnati, OH: National Lead Company of Ohio. 1953-1954.

NLO (National Lead Company of Ohio). Analytical data sheets of uranium, fluorides, nitrates, oil and pH in 24-hr composite water samples collected from Paddy's Run in 1955. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1955.

NLO (National Lead Company of Ohio). Analytical data sheets of uranium, fluorides, nitrates, oil and pH in 24-hr composite water samples collected from Paddy's Run above and below outfall ditch in 1956. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1956.

1.15

NLO (National Lead Company of Ohio). Analytical data sheets of uranium, radium, alpha, beta, fluorides, nitrates in 3-day composite water samples collected from Paddy's Run above and below outfall ditch in 1957. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1957.

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates and pH in 3-day composite water samples collected from Paddy's Run above and below outfall ditch in 1958. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1958.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, radium, alpha, beta, fluorides, nitrates in 3-day composite water samples collected from Paddy's Run above and below outfall ditch in 1959. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1959.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides and nitrates in water samples collected from Paddy's Run and storm sewer outfall at weir pump in 1959 and 1960. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1959-1960.

NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, chlorides, radium and nitrates in 3-day composite water samples collected from

> Paddy's Run north of Route 126 and at New Haven Bridge in 1960. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1960.

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, chlorides, radium and nitrates in 3-day composite water samples collected from Paddy's Run north of Route 126 and at New Haven Bridge in 1961. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1961.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, chlorides, radium and nitrates in 3-day composite water samples collected from Paddy's Run north of Route 126 and at New Haven Bridge in 1962. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1962.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, chlorides, radium and nitrates in 3-day composite water samples collected from Paddy's Run north of Route 126 and at New Haven Bridge in 1963. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1963.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, chlorides, radium and nitrates in 3-day composite water samples collected from Paddy's Run north of Route 126 and at New Haven Bridge in 1964. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1964.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, chlorides, radium and nitrates in 3-day composite water samples collected from Paddy's Run north of Route 126 and at New Haven Bridge. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1965-1966.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, chlorides, radium and nitrates in 3-day composite water samples collected from Paddy's Run north of Route 126 and at New Haven Bridge in 1967. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1967.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, chlorides, radium and nitrates in 3-day composite water samples collected from Paddy's Run north of Route 126 and at New Haven Bridge in 1971. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1971.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, chlorides, radium and nitrates in 3-day composite water samples collected from Paddy's Run north of Route 126 and at New Haven Bridge. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1972-1973.
- NLO (National Lead Company of Ohio). Handwritten summaries of Paddy's Run analysis data 1980-82. 1982.

#### Waste Pits/Sewage and Water Treatment Plant

NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides and total suspended solids in water collected in waste pit #3 in 1961. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1961.

Page A-41

Page A-42

.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides and total suspended solids in water collected in waste pit #3 in 1962. From FERMCO Box 535-288. Cincinnati, OH: National Lead Company of Ohio. 1962.

A maio

. •

- NLO (National Lead Company of Ohio). Analytical data sheets of uranium, alpha, beta, fluorides, nitrates, chlorides, oil and total suspended solids in 24-hr composite water samples collected in sewage plant in 1961. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1961.
- NLO (National Lead Company of Ohio). Monthly summaries from water treatment plant of chemical composition, volume, total uranium to sewage plant, number of dumpsters to incinerator and total volume and uranium in storm, sanitary and process effluent flow to river. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1965-1968.
- NLO (National Lead Company of Ohio). Analytical data sheets of uranium in 24-hr composite water samples collected daily in 1969 from pit 5. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1969.
- NLO (National Lead Company of Ohio). Analytical data sheets of radium in water samples collected biweekly in from pit 5. From Central Files. Cincinnati, OH: National Lead Company of Ohio. 1972.

### **CP - CONSTRUCTION PROPOSALS**

CP-F-54-71. Lift Station in Storm Sewerage System. (Filed in Storm Sewer section). Cincinnati, OH: National Lead Company of Ohio. 15 June 1954.

1.1

- CP-F-56-24, Rev. 1. New scrap pit. (Filed in Waste pit section). Approved by A. Stewart, P.G. DeFazio and G.W. Wunder. Cincinnati, OH: National Lead Company of Ohio. 13 November 1956.
- CP-F-57-72. Back-Up Filters for Hoffman Vacuum Cleaners Plant 8. Approved by C.R. Chapman, P.G. DeFazio, J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 10 March 1959.
- CP-59-21. Floor Sump Liquor Process Tanks and Piping Plant 8. Project Proposal, Contract No. AT (30-1)-1156. NLO/ICN 2224990. Approved by C.R. Chapman, P. DeFazio, J.H. Noyes. National Lead Company of Ohio. 17 March 1959.
- CP-59-22. Improvement of Turner-Haws Dust Collectors Plant 4 (after the- fact). NLO/ICN 2214017. Approved by C.R. Chapman, P. DeFazio, J.H. Noyes. National Lead Company of Ohio. 19 January 1960.
- CP-59-28. Dust Collection Facility Plant 9 Remelt Area. NLO/ICN 2214025. Approved by C.R. Chapman, P. DeFazio, J.H. Noyes. National Lead Company of Ohio. 31 March 1959.
- CP-59-65. Space Ventilation Dinitration Area- Plant 3 (After-the-fact). NLO/ICN 2214114. Authorized by J. H. Noyes. (4 pages, concerning installation of 6 wall, and 2 roof exhaust fans to improve space ventilation). Cincinnati, OH: National Lead Company of Ohio. 29 December 1959.

Page A-43

- CP-59-86. Additional dry residue chemical pit in scrap pit area. Cincinnati, OH: National Lead Company of Ohio. 26 August 1960.
- CP-59-106. Storm Drainage Revisions at the Digestion Area Storage Pad Plant 2. NLO/ICN 2214215. Approved by C.R. Chapman, P. DeFazio, J.H. Noyes. (Justification based on insoluble uranium lost to storm sewers and river of 350 lbs/mo; 20% of this from Digestion Area). Cincinnati, OH: National Lead Company of Ohio. 5 January 1960.
- CP-60-40. Incinerator Plant 8. (Proposed incinerator-type oxidation facility to handle current plant trash of 16 dumpster and 3 trash trucks per day; large inventory of over 150,000 gallons of contaminated oil and organics already present, with 15,000 lbs. U known to be contained in oil.). Cincinnati, OH: National Lead Company of Ohio. 25 May 1960.
- CP-61-27. Uranium Recovery From Refinery Waste Solvent Plant 3 (After-the -fact), NLO/ICN 2214475. Approved by C.R. Chapman, P.G. DeFazio, J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 19 December 1961.
- CP-62-84. Revision of Drainage System Pilot Plant Warehouse. NLO/ICN 2224878. Approved by S. Marshall, P.G. DeFazio, J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 15 January 1963.
- CP-64-4, CP-64-4 Revision 1. 20 March 1964. Additional Pads and Ground Contamination Control - Plants 3,5,7 and 9. NLO/ICN 2215096. Approved by P.G. DeFazio and J.H. Noyes. (Description of ground contamination problem areas). Cincinnati, OH: National Lead Company of Ohio. 28 January 1964.
- CP-64-38. Revisions to UAP Furnace Ventilation Systems -Plant 8. (With 2 attached Idea Letters dated 16 June 1964 and 18 June 1964). Cincinnati, OH: National Lead Company of Ohio. 23 June 1964.
- CP-66-23. Storm Sewer Sampler. (To enable measurement of water flow through storm sewer to Paddy's Run Creek from 0 to max stream flow capacity of 67,7000 gpm). Approved by P.G. DeFazio, C.R. Chapman, J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 9 June 1966.
- CP-67-9. Drainage at West Driveway Plant 9. (To reduce ground and storm sewer contamination). Approved by S.F. Audia, P.G. DeFazio, C.R.Chapman, M.S. Nelson. Cincinnati, OH: National Lead Company of Ohio. 14 February 1967.
- CP-69-4. Ventilation Alterations for Oxidation Furnace Pilot Plant. Approved by S. Marshall, P.G. DeFazio, C.R. Chapman and J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 14 February 1969.

### **COST STATEMENTS - PRODUCTION INVENTORIES**

Cost Statements: Production Inventories and SS Material in Research, Feed Materials Production Center, National Lead Company of Ohio. (101 pages, monthly conversion costs charted for all plants for normal U, depleted U, enriched U, thorium, and stockpile; some quarterly data). Cincinnati, OH: National Lead Company of Ohio. June 1967.

3

- Cost Statements: Production Inventories and SS Material in Research, Feed Materials Production Center, National Lead Company of Ohio. (88 pages, monthly conversion costs charted for all plants for normal U, depleted U, enriched U, thorium, and stockpile; some quarterly data). Cincinnati, OH: National Lead Company of Ohio. June 1968.
- Cost Statements: Production Inventories, Feed Materials Production Center, National Lead Company of Ohio. (Monthly conversion costs charted for all plants for normal U, depleted U, enriched U, thorium, and stockpile; some quarterly data). Cincinnati, OH: National Lead Company of Ohio. June 1969 through June 1973.
- Cost Statements: Production Inventories, Feed Materials Production Center, National Lead Company of Ohio. (25 pages, monthly conversion costs charted for orange oxide, green salt, depleted U, enriched U). Cincinnati, OH: National Lead Company of Ohio. June 1974 through June 1976.
- Cost Statements: Production Inventories, Feed Materials Production Center, National Lead Company of Ohio, Fiscal Year Report. (Conversion costs charted for orange oxide, green salt, depleted U, enriched U). Cincinnati, OH: National Lead Company of Ohio. September 1976 through September 1983.
- Cost Statements: 1611 Production Inventories and Fund 4A Cost, Feed Materials Production Center, National Lead Company of Ohio, (Conversion costs charted for plants in operation; monthly summary of expenses). Cincinnati, OH: National Lead Company of Ohio. Sept 1984 through Sept 1986.
- Cost Statements: 1611 Production Inventories and Fund 4A Production Operations, Feed Materials Production Center, National Lead Company of Ohio, (Conversion costs schedules for plants in operation; monthly summary of expenses). Cincinnati, OH: National Lead Company of Ohio. Sept 1987 & Sept 1988.

#### DOSE /PREVIOUS ESTIMATES TO POPULATION

يې وې کې د د د د د د د ۱۹۹۰ - د د د د د د د د د د د د د د د د د

- Franke, B. Preliminary Assessment of Radiation Exposures Associated with Releases of Radioactive Materials From FMPC --1951 to 1984. Institute for Energy and Environmental Research, Takoma Park, Maryland. 14 May 1988.
- Lehman, L. Final Report: Review of Existing Literature on FMPC. Prepared for Waite, Schneider, Bayless and Chesley. L. Lehman & Associates, Inc. Burnsville, Minnesota. 13 July 1988.
- Makhijani, A. Release Estimates of Radioactive and Nonradioactive Materials to t6he Environment by the Feed materials Production Center 1951-195=85. Institute for Energy and Environmental Research, Takoma Park, Maryland. 7 July 1988.
- Makhijani, A. and B. Franke. 9 February 1989. Memorandum regarding method used by FMPC to calculate scrubber losses. Institute For Energy and Environmental Research, Takoma Park, Maryland.
- Makhijani, A. and B. Franke. Addendum to the Report "Release Estimates of Radioactive and Non-radioactive Materials to the Environment by the Feed Materials Production Center 1951-1985. Institute for Energy and Environmental Research, Takoma Park, Maryland. May 1989.

lu vieni

Page A-45

Resnikoff, M. Uranium Releases at Fernald. Radiation Doses to Nearby Residents. Radioactive Waste Campaign. New York, New York. 24 February 1989.

## DUST COLLECTORS AND BAG FILTERS

- Adams, W.J. Incident Report Covering the Dust Loss in the Plant 9-NI-1039 Dust Collector. Memorandum to S.F. Audia. Cincinnati, OH: National Lead Company of Ohio. 14 July 1978.
- Audia, S.F. to M.S. Nelson, Dust Collector Performance, (Re: letter Audia to Stewart dated 12/6/55, subject "Estimated Stack Losses for October"). Cincinnati, OH: National Lead Company of Ohio. 8 December 1955.
- Audia, S.F. Investigation of Dust Collectors, G4-3 and 7. Assigned to L.W. Kessler, Production Engineering Department-short form completion report. Cincinnati, OH: National Lead Company of Ohio. 8 April 1960
- Bipes, R.L L. Test of orlon felt bags, Mikro dust collector G20-20, Pilot Plant. Memorandum to members of the Fume and dust Control Committee. Cincinnati, OH: National Lead Company of Ohio. 1 February 1962.
- Bipes R.L. Summary of Monthly Stack Losses from Dust Collectors G5-259 and G5-261 Plant
  5. Memorandum to G.R. Harr. (January 1956 through January 1963, 5 pages). Cincinnati,
  OH: National Lead Company of Ohio. 21 January 1963.
- Bipes, R.L. Filter Bag Specifications for Sly Dust Collectors Plant 8. Memorandum to W.H. Doerr. Cincinnati, OH: National Lead Company of Ohio. 20 March 1964.
- Bipes, R.L. Dust Collectors G6-86 and G6-88 Ventilation Survey Plant 6. Memorandum to Boies. (Two new 25 HP motors installed). Cincinnati, OH: National Lead Company of Ohio. 15 July 1964.
- Bipes, R.L. Test of orlon felt bags, Mikro dust collector G20-20, Pilot Plant. Memorandum to Members of the Fume and Dust Control Committee, Cincinnati, OH: National Lead Company of Ohio. 1 February 1962.
- Blythe D.J. Justification of CP Backup Filter for G1-208 Dust Collector in the Denitration Area. Memorandum to P.G. DeFazio. Cincinnati, OH: National Lead Company of Ohio. 11 June 1954.
- Boies, R.B. Evaluation of polypropylene felt dust collector bags G-2020. Memorandum to J. O. Davis. Cincinnati, OH: National Lead Company of Ohio. 19 October 1962.
- Boies, R.B. Heating and exhaust survey; Plant 5. Memorandum to P.G. DeFazio. National Lead Company Reference Project G-324.(169 page survey of dust collection, heating and ventilation facilities for Plant 5 started January 15, 1964; report is second of series under way for each operating plant). Cincinnati, OH: National Lead Company of Ohio. 21 April 1965.

- Boies, R.B. and E. D. Leininger. Report of Ventilation Survey of Plant 8. Report to P.G. DeFazio; Engineering Project 8-266. Cincinnati, OH: National Lead Company of Ohio. 21 December 1967.
- Boies, R.B. to P.G. DeFazio. Memorandum; Engineering Project No. G-386; Cincinnati, OH: National Lead Company of Ohio. 18 May 1965.
- Brandner, K. E. HF test on wool felt filter material. Memorandum to J. O. Davis. Cincinnati, OH: National Lead Company of Ohio. 8 August 1961.
- Brandner, K. E. Alternate Measuring systems for Plant 8 digester Vents. Memorandum to H.M. Beers. Cincinnati, OH: National Lead Company of Ohio. 14 February 1963.
- Carpenter, T. Radioactive dust collection at FMPC, a failure of quality assurance at a uranium reprocessing facility. Memorandum to N. Smith & L. Sabbath. Washington, D.C.: Government Accountability Project. July 1986.
- Chapman C.R. Memorandum to R. H. Starkey; Handling of stack loss sample from Collector G4-5. Cincinnati, OH: National Lead Company of Ohio. 17 February 1956.

Chapman, C.R. Handling of Stack Loss Sample from Collector G4-3. Memorandum to R.H. Starkey. (Excessive losses reported each month from dust collector G4-3 are of major concern). Cincinnati, OH: National Lead Company of Ohio. 17 February 1956.

- Chapman, C. R., Stack Sampler Filters and Air Sampler Solutions. Memorandum to W. K. Benson. (Lists dust collector numbers for each plant and the processes ventilated by collector, 6 pages). NLO/ICN 2149686. 15 August 1972.
- Connerton, J. F. Plant 9 Dust Collector System. Memorandum to M.V. Carle. (Spare parts list of equipment, vendor, manufacturers' diagrams and specifications; 30 pages). NLO/ICN 2149642. Cincinnati, OH: National Lead Company of Ohio. 12 February 1987.
- Davis, J. O. Specifications for 6-to-4 dust collector bags. Memorandum to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio. 6 February 1962.
- FMPC Radionuclide Air Emission Source Compilation from unknown document, November 1990. 21 pages, lists FMPC Emission points by EP #, kg U per emission pt., source description and control equipment number. Cincinnati, OH: National Lead Company of Ohio. 29 May 1990.
- Garties, J.P. Dust Losses from Oxidation, Box, Muffle and Graphite Furnaces. Memorandum to A. Soldano. National Lead Company of Ohio. 23 November 1956.
- Gessiness, B. Evaluation of the SS Content of Dust Collector Bags and Filters. Memorandum to Plant Superintendents. 15 July 1965.
- Heatherton, R.C. to J. W. Mahaffey, Removal of Air Filters from Plant 5 Heating Units. (Re: filter clogged; suggest permanent removal of air filters; indicate no serious health problems). 22 April 1957.

and the second second

12

Ż

Page A-47

- Held, B. J. Pilot Plant dust collector loading and efficiency tests. Memorandum to J. O. Davis. (Summary of results of efficiency tests of Mikro and Sly). Cincinnati, OH: National Lead Company of Ohio. 7 August 1957.
- Held, B.J. Loading and Efficiency Tests on G1-754 Dust Collector Plant 2. Memorandum to R.B. Wolf. (Measured volume, total material, total loss, collector efficiency, loading, air-bag ratio). Cincinnati, OH: National Lead Company of Ohio. 15 May 1958.
- Kessler, L.W. Interim Report Review of Dust Collector Operations During Fiscal Year, 1958 (P-20000-16). Memorandum to G.R. Harr. (4 pages, with plant by plant loss per month). Cincinnati, OH: National Lead Company of Ohio. 31 July 1958.
- Leininger, E.D. Traverse and temperature measurements collected on 8/9/67 in Plant 4, G4-3 and G4-7. Memorandum to J.F. Wing. Cincinnati, OH: National Lead Company of Ohio. 31 August 1967.
- Mahaffey J.W. Memorandum to S.F. Audia. Crossover and Losses of Enriched SS Material. (Re: bag changes for each enriched run because loss may be as great as 50 lb. per bag; 154 bags). National Lead Company of Ohio. 17 March 1961.
- Mahaffey J.W. Memorandum to C.E. Bussert. Crossover and Losses of Enriched SS Material. (Re: Comments on J. Vath report of 2/20/61; Bag changes for each enriched run because loss may be as great as 50 lb. per bag; 154 bags). National Lead Company of Ohio. 17 March 1961.
- McKelvey, J.W. Monthly Progress Report for the engineering and Special Problems Section for July 1958. Memorandum to R.H. Starkey. (Discussion of Plant 9 Turner Haws Dust Collector, Plant 8 vibrating conveyors, digestion tanks and ). National Lead Company of Ohio. 1 August 1958.
- Merideth A.R. Uranium Losses Through Spills and Dust Collector Stacks. Memorandum to R.M. Spencely, F.C. Capuder, E.M. Nutter. Cincinnati, OH: National Lead Company of Ohio. 18 April 1956.
- Morgan, G.J. Fluid Bed Off-gas Filtration for Bank 2-Plant 4. "Crash" idea Letter -Memorandum to P.G. DeFazio. (Refers to Engineering Project 4-131; problems with dust loading through dust collector G4-4). Cincinnati, OH: National Lead Company of Ohio. 26 November 1963.
- Nelson, M. S. to C.L. Karl, Dust Collector Stack Monitoring (new monitoring system in Plant 8). NLO/ICN 2149709. Cincinnati, OH: National Lead Company of Ohio. 17 December 1964.
- NLCO (National Lead Company of Ohio). Dust Collector G8-4 (Pangborn): diagrams, repairs. Cincinnati, OH: National Lead Company of Ohio. 15 April 1966.
- NLCO (National Lead Company of Ohio). Dust Collector 3002 (American Air Filter); diagrams, repairs. 22 April 1966.
- NLCO (National Lead Company of Ohio). Dust Collector GS-1: diagnosis, repairs.Cincinnati, OH: National Lead Company of Ohio. 6 September 1967.
- NLCO (National Lead Company of Ohio). Dust Collector 6018: diagrams, repairs. Cincinnati, OH: National Lead Company of Ohio. No date.
- NLCO (National Lead Company of Ohio). Information to be Obtained in Order to Investigate Operation of Dust Collector System. General procedures and number of bags used for each dust collector from 1956 through 1960. Cincinnati, OH: National Lead Company of Ohio. 1960.

NLO (National Lead of Ohio). Inadequacy of FMPC Monitoring program (Title Page with author, date missing, 20 pages, incl. Dust Collector Replacement Schedule for all plants with collector number and manufacturer, air flow. May be verification source for stack release pts.) NLO/ICN 2200675. Cincinnati, OH: National Lead Company of Ohio. 1983.

- Nutter, E.M. Operating Characteristics for Selected Dust Collectors. Memorandum to N.R. Leist. (Re dust collectors G4-2, G4-5, G4-14). Cincinnati, OH: National Lead Company of Ohio. 5 March 1984.
- Palmer, W. E. Evaluation of polypropylene felt dust collector bags- g2020. Memorandum to J. O. Davis. Cincinnati, OH: National Lead Company of Ohio. 18 October 1962.
- Palmer. W.E. Elimination of Dust Overlaoding G2020 Dust Collector; Venting of the 3620 Pulverizer and packaging station into 02020 dust collector has been a constant problem. Overloading with UF dust and HP fumes has resulted in frequent expensive bag changes and some loss of valuable material to the atmosphere. In December 1962 extensive modifications were made to the seal leg. 3 March 1963.
- Podlipec, F. J. to G. R. Harr, Progress Report to Date on Dust Collector Improvement (P-20000-6) (Remedial measures and finding dust bag more resistant to HF gas, 4 pages). NLO/ICN 227791. 21 November 1955.
- Ross, K. N. and M.W. Boback. The Control and Sampling of Airborne Contaminants from Uranium Production. NLCO-1087. Prepared for presentation at 101st Annual Meeting of American Institute of M,M,P Engineers, 1972. (Summary of major uranium production operations and ventilation systems used to control dust; methods to determine airborne U in work area, and to monitor uranium in stack discharges, and at plant boundary; calculated efficiencies of remelt area dust collectors). Cincinnati, OH: National Lead Company of Ohio. 15 November 1971.
- Spenceley, R. M. to M. R. Thiesen, Request for Support for EPA Review of NESHAP for Radionuclides Data. (Incl. engineering drawing list of Plant 4 and Plant 5 dust collectors), 6 March 1984.
- Starkey, R.H. Stack Losses from Collector G4-3- Handling stack losses, February 1956, Memorandum to C.R. Chapman. (17 lb. loss from G4-3 compared to 2800 lb. in January). Cincinnati, OH: National Lead Company of Ohio. 21 February 1956.

Starkey, R.H. Dust Collector Bag Specifications. Report to W.A. Smith, Jr. (Recommendations for material specifications for wool felt, tubular-type dust collector bags; with attached memorandum, dated 8 July 1958, from B.J. Held to R.H. Starkey regarding tubular-type dust collector bag specifications). Cincinnati, OH: National Lead Company of Ohio. 9 July 1958.

1. . . . . . .

Ø.

# Appendix A

### Sources of Information

Page A-49

- Starkey, R.H. Stack Loss from Dust Collector #8035 Plant 8. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 14 March 1962.
- Starkey, R. H. Filter bags for Dust Collector G20-20 Pilot Plant. Memorandum to J. O. Davis. Cincinnati, OH: National Lead Company of Ohio. 9 February 1962.
- Starkey, R. H. Testing of Dust Collector Filter Bags. Memorandum to C. Watson. Cincinnati, OH: National Lead Company of Ohio. 18 November 1964.
- Starkey, R. H. Volume Rate of Flow Measurements of American Air Filter, Turner Haws and Wheelabrator Dust Collectors-Plant 9. Memorandum to J.W. Mahaffey. Cincinnati, OH: National Lead Company of Ohio. 8 November 1962.

### ENGINEERING DRAWINGS

(Note: Many of these engineering drawings were produced for construction projects at the FMPC site. Because of this, a project number, such as a CP number, is often noted on the drawing. The project numbers have not been listed here, but can be easily located. The dates listed in the formal reference are the dates of the latest revision of the drawing. If the date of the latest revision differs significantly from the date of the original drawing, the "Revision O" date is noted in the parenthetical remarks. Some of the titles may look odd, but they are given as recorded on the drawing, to the extent feasible.)

## Plant 1 Drawings

 WMCO (Westinghouse Materials Company of Ohio). Plant 1. Preliminary. Four sheet set of drawings showing the layouts of the first, second, third, and fourth floors. Cincinnati, Ohio:
 WMCO. circa 1990. (Drawings for recent planned construction activities? Useful for locating some interior equipment, and for locations of numbered and lettered support columns.)

### Plant 2/3 Drawings

- Norman, R. A. Plant no. 3, denitration, fume scrubbing system, piping diagram. Revision 3. New York: Singmaster & Breyer; drawing number 5250-3M-5036; FMPC drawing index code 02C-7000-F-00826. 9 December 1955.
- Turpin. Plant 2, denitration area, process piping diagram, UO<sub>3</sub> gulping system. Revision 1. Fernald, Ohio: National Lead Company of Ohio. FMPC drawing index code 02C-5500-F-02393. 19 April 1969.
- Schultheis, R. Plant 2, digestion area, reduction of air-borne dust, relocated dust collector no. G-252, general arrangement. Fernald, Ohio: National Lead Company of Ohio. FMPC drawing index code 02A-5500-H-02633. 30 March 1973. (Shows planned new location of stack and dust collector G-252 in Plant 2 after relocation from Plant 5.)
- WMCO (Westinghouse Materials Company of Ohio). Ore refinery Plants 2, 3, & 18, composite equipment arrangement, plans. Revision 1. Cincinnati, Ohio: WMCO; drawing number 5250-2M-5014. FMPC drawing index codes 02X-7000-M-00560, 03X-7000-M-00159, and 18X-7000-M-00042.
  19 July 1987. (Originally produced by Singmaster & Breyer and National Lead Company of Ohio, 25 January 1955.)

<u>></u>/-

2

WMCO (Westinghouse Materials Company of Ohio). Plant 2, interior. Preliminary. One sheet drawing showing the interior layout. Cincinnati, Ohio: WMCO; circa 1990. (Useful for locating some interior equipment, and for locations of numbered and lettered support columns.)

**Plant 4 Drawings** 

;

, t. .

20. 27 . 7 . .

Broerman, R. Plant 4, packaging area, vacuum pump for stack sampler for dust collectors, piping (typical), plans, elevations & schematic. Revision 1. Fernald, Ohio: National Lead Company of Ohio. FMPC drawing index code 04X-5500-P-01874. 11 January 1982. (Revision 0 dated 19 March 1973. Shows typical setup of motor, vacuum pump, and lines to stack samplers for Plant 4. Shows locations of stacks for dust collectors G4-1, G4-2, G4-3, G4-4, G4-5, G4-7, G4-8, G4-13, G4-14, and G4-15.)

Catalytic Construction Company. Feed Materials Production Center, Fernald area, architectural, floor plan at elev. 580'-0", Green Salt Plant 04-C-1. Revision 3. Philadelphia, Pennsylvania: Catalytic Construction Company; drawing number 3004-C-1011-A; FMPC drawing index codes 04X-1450-A-00024 and 04X-1450-S-00025. 2 June 1952.

Cepluch, D.; Broerman, R. Plant 4, reactor area, fluid bed conversion, layout of new fan & stack for collector G-4-7, plans, elevations, sections & view. Revision 1. Fernald, Ohio: National Lead Company of Ohio. drawing number 4-4321; FMPC drawing index code 04A-5500-H-01476. 27 October 1958.

- 1

CHE ST. Fry, R. Plant 4, depleted green salt packaging facility, ventilation alterations, section "A-A." Revision 3. Fernald, Ohio: National Lead Company of Ohio. FMPC drawing index code 04X-5500-H-01800. 14 November 1985. (Revision 0 dated 23 November 1966. Revision 3 indicates replacement of some rain caps with new type.)

George A. Fuller Company. Green Salt Plant, exhaust ducts thru roof. Cincinnati, Ohio: George A. Fuller Company. drawing number 3004-H-GAF#14S-A; FMPC drawing index code 04A-3595-H-00682. 23 June 1952. (Somewhat useful for locating stacks for Plant 4.)

•.

George A. Fuller Company. Local exhaust ducts to units G4-2 & G4-5, upper plan columns 7-8 B-C, elev 629'-6", Green Salt Plant 3004. Revision 1. Cincinnati, Ohio: George A. Fuller Company. drawing number 3004-H-G-A-F-Co-23-s4; FMPC drawing index code 04A-3595-H-00689. circa 16 March 1953. • 1

George A. Fuller Company. Green Salt Plant bldg #3004, exhaust ducts – units G4-706 – col's 4 to 5 & E to G - el. 619'-6" to 588'-6". Revision 1. Cincinnati, Ohio: George A. Fuller Company. drawing number 3004-H-GAF-Co-28-sA; FMPC drawing index code 04A-3595-H-00690. circa 26 March 1953.

George A. Fuller Company. Final connections to dust collectors G4-3 & G4-7, Green Salt Plant bldg #3004. Revision 1. Cincinnati, Ohio: George A. Fuller Company; drawing number 3004-H-GAF-Co-29-sA; FMPC drawing index code 04A-3595-H-00691. 21 March 1953.

Hammon, A. Plant 4, packaging area, dust collection alterations, demoloition of existing duct work, plans & elevation. Fernald, Ohio: National Lead Company of Ohio. drawing number 4-4381; FMPC drawing index code 04A-5500-H-01524. circa August 1959.

NATE: N

Page A-51

- Hammon, A. Plant 4, packaging area, dust collection alterations, west side duct work, plans. Revision 1. Fernald, Ohio: National Lead Company of Ohio; drawing number 4-4394; FMPC drawing index code 04A-5500-H-01541. 18 December 1959.
- Hammon, A. Plant 4, packaging area, dust collection alterations, west side duct work, plan & sections. Fernald, Ohio: National Lead Company of Ohio. drawing number 4-4395; FMPC drawing index code 04A-5500-H-01542. 27 June 1959.
- Hammon, A. Plant 4, packaging area, dust collection alterations, west side duct work, elevations. Fernald, Ohio: National Lead Company of Ohio. drawing number 4-4396; FMPC drawing index code 04A-5500-H-01543. 27 June 1959.
- Hard, R. M. Feed Materials Production Center, Fernald area, process flow sheet, Green Salt Plant, dust collection system. Two sheets. Philadelphia, Pennsylvania: Catalytic Construction Company. drawing number 3004-H-06-R; FMPC drawing index code 04X-1450-F-00562. 19 February 1951.
- Horn, W. F. Plant 4, Green Salt Plant, G4-2 & G4-14 dust collectors, piping & instrumentation diagram. Fernald, Ohio: Westinghouse Materials Company of Ohio. FMPC drawing index code 04X-5500-N-02231; 17 November 1987. (Indicates flow ratings of blowers.)
- Horn, W. F. Plant 4, Green Salt Plant, high vacuum system, G4-4 & G4-9 dust collector, piping & instrumentation diagram. Fernald, Ohio: Westinghouse Materials Company of Ohio. FMPC drawing index code 04X-5500-N-02232; 17 November 1987. (Indicates flow ratings of blowers.)
- NLCO, Engineering Drawings Plant 4; Series of 30 drawings of Plant 4 Dust Collectors and associated processes. 1965-1967.
- NLCO (National Lead Company of Ohio). Changes in pipe sizes required to add G4-805 to exhaust system G4-4 (b'ld'g 3004). Fernald, Ohio: NLCO. sk. number E-4-1; FMPC drawing index code 04A-5500-H-00820. 5 December 1952.
- NLCO (National Lead Company of Ohio). Plant 4, south end, dust collection alterations, flow diagram. Revision 1. Fernald, Ohio: NLCO. drawing number 4-4353; FMPC drawing index codes 04A-5500-F-01496 and 04A-5500-H-01497. circa 24 July 1959.
- NLCO (National Lead Company of Ohio). Exhaust stack, dust collectors G4-3 & G4-7. Fernald, Ohio: NLCO. sk. number M4-244; FMPC drawing index code 04A-5502-H-01072. 21 April 1961. (Shows dimensions of stacks, including original-style rain cap, for dust collectors G4-3 and G4-7.)
- Roberts, B. N. Feed Materials Production Center, Fernald area, process flow diagram, Green Salt Plant, sump recovery system. Philadelphia, Pennsylvania: Catalytic Construction Company. drawing number P-3004-86-F; FMPC drawing index code 04X-1450-F-00434. 24 July 1952.
- Smith, R. W. Feed Materials Production Center, Fernald area, engineering flow diagram, heating & ventilation, general vacuum cleaning system, Green Salt Plant. Revision 1. Philadelphia, Pennsylvania: Catalytic Construction Company. drawing number 3004-P-03-A; FMPC drawing index codes 04A-1450-H-00416 and 04A-1450-F-00417. 16 April 1952.

..

.

Smith, R. Feed Materials Production Center, Fernald area, engineering flow diagram, heating & ventilating, vacuum conveying system, Green Salt Plant. Revision 2. Philadelphia, Pennsylvania: Catalytic Construction Company. drawing number 3004-P-05-A; FMPC drawing index codes 04A-1450-H-00419 and 04A-1450-F-00420. 16 June 1952. 5 ....

Smith, R. W. Feed Materials Production Center, Fernald area, engineering flow diagram, heating & ventilating, dust control, process heating & ventilating, Green Salt Plant. Revision 1. Three sheets. Philadelphia, Pennsylvania: Catalytic Construction Company. drawing number 3004-P-04-R; FMPC drawing index code 04X-1450-H-00418. 6 August Pres Concernation 1952. 

Stull, H. Plant 4, south end, dust collection alterations, plans & elevation. Fernald, Ohio: National Lead Company of Ohio. drawing number 4-4354; FMPC drawing index code 04A-5500-H-01498. 30 October 1958. A Constant and Constant an .

All and a second

1

4 . . .

- Stull, H. Plant 4, dust collection alterations, east side duct work, elevations. Fernald, Ohio: National Lead Company of Ohio. drawing number 4-4393; FMPC drawing index code 04A-5500-H-01540. 13 April 1959. · ·
- Turkowitz, L. Plant 4, reactor area, ventilation of blender & packaging station, ductwork for dust collector G4-12, elevations A-A & B-B. Revision 1. Fernald, Ohio: National Lead Company of Ohio. drawing number 4-4496; FMPC drawing index code 04A-5500-H-01632. 14 November 1985. (Revision 0 dated 23 April 1963. Revision 1 indicates replacement of rain cap, with new style, on stack for dust collector G4-12.)

WMCO (Westinghouse Materials Company of Ohio). Plant 4, composite 1988 thru 1992, project construction periods interior. Preliminary. Seven sheet set of drawings showing the layouts of the various elevations (floors) in the plant. Cincinnati, Ohio: WMCO. circa 1990. (Drawings for recent planned construction activities? Useful for locating some interior equipment, and for locations of numbered and lettered support columns.)

**Plant 5 Drawings** 

•

å

Catalytic Construction Company. Feed Materials Production Center, Fernald area, architectural, elevations, Metals Plant. Revision 3. Philadelphia, Pennsylvania: Catalytic Construction Company; drawing number 3005-C-1002-A; FMPC drawing index code 05X-1450-A-00009. 13 June 1988. (Revision 0 dated 13 December 1951. Shows planned replacements of weather caps (rain caps) for stacks for dust collectors G5-249, G5-250, G5-251, G5-253, G5-260, and G5-261.)

Dickson. Feed Materials Production Center, Fernald area, sections "A-A" & "B-B," heating & ventilating, Metals Plant. Revision 2. Philadelphia, Pennsylvania: Catalytic Construction Company; drawing number 3005-P-56-A; FMPC drawing index code 05X-1450-H-01087; 14 November 1985. (Revision 0 dated 31 March 1952. Shows planned replacements of weather caps (rain caps) for stacks for dust collectors G5-249 and G5-251. Also shows locations of stack sampling connections into these stacks.)

filler with the c Dickson. Feed Materials Production Center, Fernald area, sections "E-E" & "F-F," heating & ventilating, Metals Plant. Revision 2. Philadelphia, Pennsylvania: Catalytic Construction Company: drawing number 3005-P-58-A; FMPC drawing index code 05X-1450-H-01089; 14 November 1985. (Revision 0 dated 30 April 1952. Shows planned replacements of weather

caps (rain caps) for stacks for dust collectors G5-254 (?) and G5-261. Also shows locations of stack sampling connections into these stacks.)

Dickson. Feed Materials Production Center, Fernald area, sections "G-G" & "S-S," heating & ventilating, Metals Plant. Revision 2. Philadelphia, Pennsylvania: Catalytic Construction Company; drawing number 3005-P-60-A; FMPC drawing index code 05X-1450-H-01091; 14 November 1985. (Revision 0 dated 1952. Shows planned replacements of weather caps (rain caps) for stacks for dust collectors G5-258 and G5-260. Also shows locations of stack sampling connections into these stacks.)

- Singmaster & Breyer. Metals Plant no. 5 new wings, elevations, architectural drawing. Revision 3. New York: Singmaster & Breyer; drawing number 5250-5A-5036; FMPC drawing index code 05X-7000-A-00075; 16 May 1986. (Revision 0 dated 22 March 1955.)
- WMCO (Westinghouse Materials Company of Ohio). Plant 5, October 1989 thru 1990. Preliminary. Two sheet set of drawings showing the layouts of the first and second floors in the plant. Cincinnati, Ohio: WMCO; 18 December 1989. (Drawings for recent planned construction activities? Useful for locating some interior equipment, and for locations-of numbered and lettered support columns.)
- WMCO (Westinghouse Materials Company of Ohio). Plant 5. Preliminary. Two sheet set of drawings showing the layouts of the first, second, and third floors. Cincinnati, Ohio: WMCO; circa 1990. (Useful for locating some interior equipment, and for locations of numbered and lettered support columns.)

### Plant 6 Drawings

NLCO, Boies, R.B., Engineering Drawing Plant 6; NLCO Plant Layout; 27 May 1965.

WMCO (Westinghouse Materials Company of Ohio). Plant 6. Preliminary. One sheet drawing showing the interior layout. Cincinnati, Ohio: WMCO; circa 1990. (Useful for locating some interior equipment, and for locations of numbered and lettered support columns.)

#### Plant 7 Drawings

Catalytic Construction Company. Production plant, Fernald area, equipment layout-process bldg. Set of seven drawings; five of plans at various interior elevations and two of cross sections. Philadelphia, Pennsylvania: Catalytic Construction Company; drawing numbers 3241-A103 through 3241-A109; FMPC drawing index codes 07X-1450-M-00004 through 07X-1450-M-00010. (Presumed to be original construction drawings. Originally drawn 15 June 1953, most with revisions through late 1953 or early 1954, and two with revisions in 1987. Show equipment layout.)

## Plant 8 Drawings

 Bunk, L. W. Plant 8, area "C," replacement of box furnace dust collector. Fernald, Ohio: National Lead Company of Ohio; FMPC drawing index code 08X-5500-H-02307; 22
 November 1968. (Shows plans for replacing the Sly 6A Dynaclone dust collector with a Day 44AC10 dust collector, to serve the box furnace. Shows location of exhaust stack for this dust collector and locations of two nearby scrubbers.)

Jurkonitz, L. Plant 8 Calciner Bldg., first floor, drumming station for Hoffman unit, location and duct work connections, drawing number 8-4990. FMPC drawing index code 39A-5500-

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

27

H-0059 and 08D-5500-H--1889. Cincinnati, OH: National Lead Company of Ohio. 5 June 1963. New Street, of the

NLCO (National Lead Company of Ohio). Plant 8, area C, scrubber for box furnace, plan. Fernald, Ohio: NLCO; FMPC drawing index code 08X-5500-H-02312; circa 1968. (Ductwork and piping.) 

NLCO (National Lead Company of Ohio). Plant 8, area C, scrubber for box furnace, sections "A-A" &"B-B." Fernald, Ohio: NLCO; FMPC drawing index code 08X-5500-H-02313; circa 1968. (Shows locations of stacks for scrubber (without rain cap) and dust collector.)

NLCO (National Lead Company of Ohio). Plant 8, crusher area, outside crusher dust collector replacement, demolition, plans & section. Revision 3. Fernald, Ohio: NLCO; drawing number 8-4213; FMPC drawing index code 08X-5500-H-02315; 16 January 1969. (Revision 0 dated circa 1958. Shows the stack for dust collector G43-44C without a rain cap. Indicates the dust collector was to be removed circa 1969.)

WMCO (Westinghouse Materials Company of Ohio). Plant 8, January 1990 to January 1991. Preliminary. Two sheet set of drawings showing the layouts of the first and second floors in the plant. Cincinnati, Ohio: WMCO; 12 February 1990 and 24 January 1990. (Drawings for recent planned construction activities? Useful for locating some interior equipment, and for locations of numbered and lettered support columns.)

10 (0 C 1 1

### Plant 9 Drawings

George A. Fuller Company. Location and detail of exhaust stacks thru roof - new Material Feed Production building #3542. Cincinnati, Ohio: George A. Fuller Company; drawing number 3542-H-GAFCo-7-sA; FMPC drawing index code 09X-3595-H-00275; 4 November 1952. (Shows locations of stacks on roof and heights. But, stacks appear to be numbered by stack number (?), or some other number not directly related to dust collector number.)

WMCO (Westinghouse Materials Company of Ohio). Plant 9. Preliminary. One sheet drawing showing the interior layout. Cincinnati, Ohio: WMCO; circa 1990. (Useful for locating some interior equipment, and for locations of numbered and lettered support columns.)] 900 - **1**6 · · · ·

and the training of

#### **Pilot Plant Drawings**

5 S.C.

. ...

17

WMCO (Westinghouse Materials Company of Ohio). Pilot Plant, interior. Preliminary. One sheet drawing showing the interior layout. Cincinnati, Ohio: WMCO; circa 1990. (Useful for locating some interior equipment, and for locations of numbered and lettered support columns.) 

والمراجع والمراجع والمراجع

#### K-65 and Metal Oxide Silos Drawings

1.1

· · · · · · · ·

· · · ·

. :

Anonymous. FMPC drawing index code 34X-1450-F-00020. (Drawing showing water piping for K-65 drum dumping and washing and slurry to silos. Sheet 1 of 2.) กษณ์ วัตรีการ จับว่า สัตรภาคราสสัตว์มหาวิทางการกา

Catalytic Construction Company. Process flow diagram, hot raffinate storage system. Philadelphia, Pennsylvania: Catalytic Construction Company; drawing number 3034-H-01-F; FMPC drawing index code 34X-1450-F-00037; 14 June 1951.

1 36 . . . t 1 (

ineen innn arttastaré

## Appendix A

### Sources of Information

- Clift, W. K-65 storage farm, K-65 handling & storage, enlarged K-65 storage farm flow diagram. Fernald, Ohio: National Lead Company of Ohio; FMPC drawing index code 34X-5500-F-00061. 4 December 1956.
- Creter, L. W. Process flow diagram K-65 handling & storage. Two sheets. Philadelphia, Pennsylvania: Catalytic Construction Company; drawing number P-3034-37-F; FMPC drawing index code 34X-1450-F-00038. 5 May 1952.
- Geesner, T. J. K-65 storage, K-65 tank embankment stabilization, general layout. Revision 1. Fernald, Ohio: NLO, Inc.; FMPC drawing index code 34X-5500-G-00084; 14 July 1983. (Shows expansion of the silo berms.)
- Glenn, F. J. Engineering flow diagram metals oxide. Philadelphia, Pennsylvania: Catalytic Construction Company; drawing number 3035-H-02-A; FMPC drawing index code 35X-1450-F-00017; 20 June 1952.
- Locke, M. K-65 silos, K-65 radon treatment system, 'as built,' plan, details and sections. Fernald, Ohio: Westinghouse Materials Company of Ohio; FMPC drawing index code 34X-5500-M-00116; 5 October 1990.
- NLCO (National Lead Company of Ohio). K-65 slurrying system. Fernald, Ohio: NLCO; sk. number P-34-6; FMPC drawing index code 34X-5506-F-00043; 8 May 1952.
- NLCO (National Lead Company of Ohio). Tank unloading & drumming system for 'K-65' material. Fernald, Ohio: NLCO; sk. number E-34-3; FMPC drawing index code 34X-5500-F-00051; 23 April 1958. (for proposed removal of K-65 material from silos.)
- NLCO (National Lead Company of Ohio). K-65 storage, earth embankment at K-65 tanks, plan. Fernald, Ohio: NLCO; drawing number 34-4013; FMPC drawing index code 34X-5500-M-00066; 2 December 1963.
- Preload (Preload Enterprises, Inc.). Two 125,000 c.f. slurry storage tanks type K65, Atomic Energy Commission, Fernald, Ohio, Catalytic Construction Co. Revision 4. New York: Preload; drawing number 51T20-3; FMPC drawing index code 34X-1450-A-00086; 15 September 1951. (Drawing from original constructor of K-65 silos. Useful for construction details, characteristics.)
- Preload (Preload Enterprises, Inc.). Two 125,000 c.f. slurry storage tanks type K65, Atomic Energy Commission, Fernald, Ohio, details. Revision 3. New York: Preload; drawing number 51T20-7; FMPC drawing index code 34X-1450-P-00090; 25 September 1951. (Drawing from original constructor of K-65 silos. Useful for locations and details of hatches and other penetrations.)
- Preload (Preload Enterprises, Inc.). Two 125,000 c.f. tanks, Atomic Energy Commission, Fernald, Ohio, engrs: Catalytic Const. Co. Revision 6. New York: Preload; drawing number 51T29-2; FMPC drawing index code 34X-1450-A-00092; Drawing from original constructor of K-65 silos. Cincinnati, OH: National Lead Company of Ohio. 20 November 1951.
- Seiwert, J. F.M.P.C. Fernald, Ohio, protective cover system for K-65 tanks, dome plans & details. Cincinnati, Ohio: Camargo Associates, Limited; FMPC drawing index code 34X-5500-S-00109; 16 December 1985.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page A-55

Ċ.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

5.3

....

<u>.</u>

- CARE HAR DO Smith, E. Process flow diagram K-65 (handling & storage. Preliminary. Two sheets. Philadelphia, Pennsylvania: Catalytic Construction Company; drawing number 3034-H-02-F; FMPC drawing index code 34X-1450-F-00019; 12 July 1951.
- Stull, H. P. K-65 storage farm, K-65 handling & storage flow diagram. Fernald, Ohio: National Lead Company of Ohio; drawing number 34-4005; FMPC drawing index code 34X-5500-F-00060; 7 February 1956.

10 11 11 10

"Old" Solid Waste Incinerator and Sewage Treatment Area Drawings Bosum, D. Sewage Treatment Area Classified Paper Destroyer Installation, drawing No. 39-4002. Cincinnati, OH: National Lead Company of Ohio. 27 August 1957.

- Briscoe, D. Incinerator Building, drawing number MX-44. FMPC drawing index code 39X-5502-S-00011 and 00A-5502-A-00126. Cincinnati, OH: National Lead Company of Ohio. 28 November 1961. sta for a t
- Bunk, L. W. Sewage treatment area, incinerator, modifications to plant incinerator. Fernald, Ohio: National Lead Company of Ohio; FMPC drawing index code 39X-5500-G-00009; 24 April 1969. (Shows size of existing stack.)

NLCO (National Lead Company of Ohio). Waste paper and chemical carton incinerator, drawing number 39-5000; FMPC drawing index code 39X-5500-X-00007. Cincinnati, OH, 31 March 1952 · . . . 1-1-2-52

- NLCO (National Lead Company of Ohio). Incinerator. Preliminary. Fernald, Ohio: NLCO; drawing number 39-4000; FMPC drawing index code 39X-5500-X-00002; 2 October 1953. (Appears to be original plans for installing the incinerator. However, the as-built location of the incinerator differs from that shown on this drawing.) 1.
- NLCO (National Lead Company of Ohio). Foundation plan, details, incinerator. Revision 2. Fernald, Ohio: NLCO; drawing number 39-4001; FMPC drawing index codes 39X-5500-A-00003 and 39X-5500-S-00004; circa 1954. (Revision 1 dated 3 August 1954. Appears to be original plans for installing the incinerator. The as-built location of the incinerator shown on this drawing appears to match the actual location.)
- NLCO (National Lead Company of Ohio). Incinerator details. Revision 1. Fernald, Ohio: NLCO; drawing number 39-4002; FMPC drawing index codes 39X-5500-A-00005 and 39X-5500-S-00006; 1 April 1954.

ALTE : Richards, A. Sewage treatment plant expansion, plot plan. Revision 2. New York: Singmaster & Breyer; drawing number 5250-25M-4019; FMPC drawing index code 25A-7000-F-00033; 14 July 1960. (Revision 0 dated 26 May 1955. Useful for showing location of the incinerator, Manhole 175, and the sewer sampler station on the effluent line to the Great Miami River.)

Schultheis, R. Incinerator, plans & sections. Revision 1. Fernald, Ohio: National Lead Company of Ohio; FMPC drawing index code 39X-5500-M-00012; 28 September 1976. (Revision 0 dated 21 September 1972. Shows size of stack (new).)

- Schultheis, R. Incinerator building, Solid Waste Incinerator Piping and electrical plan and details, FMPC drawing code 02F-5500-P-02808 and 02F-5500-E-02809. National Lead Company of Ohio. 3 March 1979.
- Schultheis, R. Incinerator building, Solid Waste Incinerator general arrangement plan and elevation, FMPC drawing code 02F-5500-M-02805. National Lead Company of Ohio. 26 January 1979.

### **Other Buildings Drawings**

- Geesner, T. J. Bldg 39, liquid waste incinerator, conduit & cable layout. Fernald, Ohio: National Lead Company of Ohio; FMPC drawing index code 39X-5500-E-00041; 10 June 1982.
- Singmaster & Breyer. (Raffinate calciner bldg.) incinerator bldg., plans elevations. Revision 5. New York: Singmaster & Breyer; drawing number 5250-3A-5318; FMPC drawing index codes 02F-7000-A-00957 and 39A-5500-A-00054; 4 August 1988. (Revision 0 dated 11 April 1956. Shows locations of exhaust stacks.)
- WMCO (Westinghouse Materials Company of Ohio). Incinerator Building, Floor Plan, drawing number 39A-5500-A-00063. Approved by G. Paul. Cincinnati, OH, 10 August 1990 (?).

#### **FMPC General Area Drawings**

السيندر

- Locke, M. Production area site plan. Fernald, Ohio: Westinghouse Materials Company of Ohio; 26 March 1990. (Filename ZFAI:[100,4]PRODMAP.DGN. General map of production area, with buildings and some features labeled.)
- WMCO (Westinghouse Materials Company of Ohio). Feed Materials Production Center. Fernald, Ohio: WMCO; 27 June 1989. (R.E.S.-1238. Filename ZFAI:[100,4]RCRA.DGN. General map showing complete FMPC site and surrounding roads and houses. Shows coordinates of the FMPC Site Origin, in USGS, OSP, and site coordinates. Also shows direction of north for each of these coordinate systems.)
- Woolpert Consultants. Fernald facility, Department of Energy, Fernald, Ohio. Seventeen sheets. Dayton, Ohio: Woolpert Consultants; FMPC drawing index codes 75X-5500-G-00112 through 75X-5500-G-00128; circa 1988. (Topographic maps, prepared for Weston, of much of the FMPC facility, at scale of 1 in = 50 ft. Very useful for locating points on the site. Uses Ohio State Plane coordinate system.)

### Miscellaneous Drawings

- Cooper, D. P. 1985 site runoff characterization survey. Fernald, Ohio: NLO, Inc.; FMPC drawing index code 18X-5500-X-00658; 16 September 1985. (This "drawing" consists of copies of Attachments 1, 2, and 3 to an unidentified report, presumably regarding site water runoff and calculations of required capacity of storm catch basin. Includes a reference to availability of backup data on site characterization.)
- Ellis, J. J. General stack sampler assembly & detail. Revision 4. Fernald, Ohio: NLO, Inc.; FMPC drawing index code 00X-5500-N-01368; 18 January 1989. (Revision 0 dated 11 January 1983. Shows filter holder, tubing and connections, and sampling probe designs.)

1.1.

.

.

r i

- NLCO (National Lead Company of Ohio). Sketch and text describing bag filter specifications, for purchasing department. Revision 1. Fernald, Ohio: NLCO; sk. number GS-4-5982, B-4-1; FMPC drawing index code 04X-5505-M-01778; 26 July 1957. (Revision 0 undated. For Ensinger Filter, G4-39.)
- NLCO (National Lead Company of Ohio). Sketch and text describing bag filter specifications, for purchasing department. Fernald, Ohio: NLCO; sk. number GS-4-2611, B-4-2; FMPC drawing index code 04X-5505-M-01779; undated. (For dust collectors G4-2 through G4-7 and (unknown) item G1-208.)
- NLCO (National Lead Company of Ohio). Sketch and text describing bag filter specifications, for purchasing department. Revision 1. Fernald, Ohio: NLCO; sk. number GS-X-450, B-4-3; FMPC drawing index code 04X-5505-M-01780; 22 July 1957. (Revision 0 undated. For G4-11. Was superseded 23 October 1958.)

is all of 6t. -

NLCO (National Lead Company of Ohio). Sketch and text describing bag filter specifications, for purchasing department. Fernald, Ohio: NLCO; sk. number GS-X-450; FMPC drawing index code 04X-5505-M-01781; undated. (For GS-5-247 Hoffman unit. Was superseded 23 October 1958.)

## ENVIRONMENTAL MONITORING REPORTS

and the transformer of the state of the stat

- Aas, C.A., D.L. Jones and R.W. Keys, FMPC Environmental Monitoring Report for 1985. FMPC-2047, Special. Westinghouse Materials Company of Ohio, 30 May 1986.
  - Aas, C.A., S.J. Clement, G.L. Gels & C.A. Lojek, FMPC Environmental Monitoring Annual Report for 1986. FMPC-2076, Westinghouse Materials Company of Ohio. 30 April 1987.
  - Addendum to FMPC Environmental Monitoring Annual Report for 1972. "An Evaluation of the Radiation Dose to the Public Resulting from FMPC Operations." NLCO-1098, Addendum. Health and Safety Division, National Lead of Ohio, Inc. 11 April 1973.

.

1.1

- Berger, J.D., G.S. Gist, C.M. Morrow, D.J. Niederkorn, D.T. Robinson (ORAU). Environmental Program Review of the Feed Materials Production Center Fernald, Ohio. (100 pg review of air monitoring, water treatment and monitoring, groundwater, soil, sediment, vegetation, monitoring, waste management, analytical procedures, QA, dose assessment, emergency preparedness). Prepared by Radiological Site Assessment Program. Oak Ridge Associated Universities, Oak Ridge, TN. October 1985.
- Dolan, L.C. Action Plan in Response to ORAU Environmental Program Review. Letter to J.A. Reafsnyder. (Lists of short-term, 67 action items, and long-term, 10 action items, priority items). Westinghouse Materials Company of Ohio. 15 January 1986.

St. Int. 1

- Dugan, T. A., G. L. Gels, J. S. Oberjohn, and L. K. Rogers, FMPC Annual Environmental Report for Calendar Year 1989. FMPC-2200, Special. Environmental Management Department, Westinghouse Materials Company of Ohio. October 1990.
- Facemire, C. F., D. L. Jones and R. W. Keys, FMPC Environmental Monitoring Annual Report for 1984, NLCO-2028, Special. National Lead of Ohio, 1985. 15 July 1985.

Appendix A to the second

## Sources of Information

- FEMP (Fernald Environmental Management project). Annual Site Environmental Monitoring Report for Calendar Year 1991. FMPC-2275, Special UC-707, Environmental Management Department. Cincinnati, OH: Westinghouse Environmental Management Company of Ohio. December 1992.
- FMPC Environmental Monitoring Annual Report for 1959. Health and Safety Division, National Lead of Ohio, Inc. 1 May 1960.
- FMPC Environmental Monitoring Annual Report for 1971," NLCO-1092, Special. Health and Safety Division, National Lead of Ohio, Inc. 21 June 1972.
- FMPC Environmental Monitoring Annual Report for 1972, NLCO-1098, Special. Health and Safety Division, National Lead of Ohio, Inc. 16 February 1973.
- FMPC Environmental Monitoring Annual Report for 1973," NLCO-1109. 1 April 1974. Health and Safety Division, National Lead of Ohio, Inc.,
- FMPC Environmental Monitoring Annual Report for 1974," NLCO-1117. 4 April 1975. Health and Safety Division, National Lead of Ohio.
- FMPC Environmental Monitoring Annual Report for 1975, NLCO-1133. 1 April 1976. Health and Safety Division, National Lead of Ohio.
- FMPC Environmental Monitoring Annual Report for 1976, NLCO-1142. 1 April 1977. Health and Safety Division, National Lead of Ohio.
- FMPC Environmental Monitoring Annual Report for 1977, NLCO-1151. 1 April 1978. Health and Safety Division, National Lead of Ohio.
- FMPC Environmental Monitoring Annual Report for 1978, NLCO-1159. 1 April 1979. Health and Safety Division, National Lead of Ohio.
- FMPC Environmental Monitoring Annual Report for 1979, NLCO-1164. 1 April 1980. Health and Safety Division, National Lead of Ohio.
- FMPC Environmental Monitoring Annual Report for 1980, NLCO-1168. Health and Safety Division, National Lead of Ohio, 1 April 1981.
- FMPC Environmental Monitoring Annual Report for 1981, NLCO-1180. Health and Safety Division, National Lead of Ohio, 1 May 1982.
- FMPC Environmental Monitoring Annual Report for 1982, NLCO-1187. Health and Safety Division, National Lead of Ohio, 1 May 1983.
- FMPC Environmental Monitoring Annual Report for 1983, NLCO-2018. Health and Safety Division, National Lead of Ohio, August 1984.
- FMPC Environmental Monitoring Annual Report for 1988. FMPC-2173, UC-707, By FMPC Restoration, Westinghouse Materials Company of Ohio. June 1989.

÷....

- FMPC Annual Environmental Monitoring Report for Calenar Year, 1989. FMPC-2200, Special UC-707, Environmental Management Department. Cincinnati, OH: Westinghouse Materials Company of Ohio. October 1990.
- FMPC Annual Environmental Monitoring Report for Calendar Year 1990. FMPC-2245, Special UC-707, Environmental Management Department. Cincinnati, OH: Westinghouse Materials Company of Ohio. Decmeber 1991.

FMPC Environmental Monitoring Quarterly Report Apr - May - Jun 1961. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 10 July 1961.

FMPC Environmental Monitoring Quarterly Report Jan - Feb - Mar 1960. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 1 May 1960.

FMPC Environmental Monitoring Quarterly Report Jan - Feb - Mar 1961. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 10 April 1961.

FMPC Environmental Monitoring Quarterly Report Jul - Aug - Sep 1961. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 10 October 1961.

FMPC Environmental Monitoring Quarterly Report Oct - Nov - Dec 1960 and Summary Report for 1960. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 10 January 1961.

FMPC Environmental Monitoring Quarterly Report Oct - Nov - Dec 1961 and Summary Report for 1961. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 10 January 1962.

- FMPC Environmental Monitoring Semi-Annual Report for Second Half of 1962, Summary Report for 1962. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 20 January 1963.
- FMPC Environmental Monitoring Semi-Annual Report for Second Half of 1963, Summary Report for 1963. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 20 January 1964.

FMPC Environmental Monitoring Semi-Annual Report for Second Half of 1964, Summary Report for 1964, NLCO-939. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 20 January 1965.

FMPC Environmental Monitoring Semi-Annual Report for Second Half of 1965, Summary Report for 1965, NLCO-972, Special. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. 20 January 1966.

11.

FMPC Environmental Monitoring Semi-Annual Report for Second Half of 1966, Summary Report for 1966, NLCO-992, Special. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. February 1967.

FMPC Environmental Monitoring Semi-Annual Report for Second Half of 1967, Summary Report for 1967, NLCO-1013, Special. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. February 1968. Appendix A

630.4

## Sources of Information

Page A-61

- FMPC Environmental Monitoring Semi-Annual Report for Second Half of 1968, Summary Report for 1968, NLCO-1036, Special. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. February 1969.
- FMPC Environmental Monitoring Semi-Annual Report for Second Half of 1969, Summary Report for 1969, NLCO-1055, Special. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. February 1970.
- FMPC Environmental Monitoring Semi-Annual Report for Second Half of 1970, Summary Report for 1970, NLCO-1079, Special. Health and Safety Division. Cincinnati, OH: National Lead Company of Ohio. February 1971.
- US DOE. Environmental Impact Assessment. Prepared under guidance of DOE with assistance of Battelle Columbus Laboratories and National Lead Company of Ohio. Cincinnati, OH: National Lead Company of Ohio. 1977.
- US DOE. Environmental Survey Preliminary Report Feed Materials Production Center, Fernald, Ohio, EH-24. U. S. Department of Energy, Environment, Safety and Health, Office of Environmental Audit. (Presents findings of environmental survey conducted at FMPC June 16-27, 1986; air, soil(uses Myrick bkgrnd data), surface water, hydrogeology, waste management, waste disposal, contamination sites, 1-2 in. thick). Cincinnati, OH: National Lead Company of Ohio. March 1987.
- WMCO (Westinghouse Environmental Management Company of Ohio. Fernald Site Environmental Monitoring Plan. PL-1002. Revision No. 0. Cincinnati, OH: WMCO. November 6, 1992.
- Work Sheets 1975 Environmental Monitoring Report. Radioactive Effluent Report & Onsite Discharge Report. (50 pages of tables, calculations, analytical data sheets, concentrates processed in 1973, general sump discharges; Ra in various concentrates; Ra to Pit 5).

### FMPC REPORTS ON EMISSIONS and SITE ASSESSMENTS

- Barker, J.R. 14 April 1986. History of FMPC Radionuclide Discharge. Memorandum to B.J. Davis. (Cover letter for review of historic discharge report). U.S. Department of Energy.[See Davis 1986]
- Boback, M.W, T.A. Dugan, D.A. Fleming, R.B. Grant, R.W. Keys, May 1987. History of FMPC Radionuclide Discharges, FMPC-2082 (Revision to FMPC-2058), UC-11. Feed Materials Production Center, Westinghouse Materials Company of Ohio. Prepared for the U.S. Department of Energy.
- Boback, M.W., D.A. Fleming, T. A. Dugan, R. W. Keys and R. B. Grant, November 1985. History of FMPC Radionuclide Discharges, FMPC-2039. Feed Materials Production Center, Westinghouse Materials Company of Ohio. Prepared for the U.S. Department Of Energy.
- Boback, M.W., D.A. Fleming, T. A. Dugan, R.W. Keys and R. B. Grant, November 1986. History of FMPC Radionuclide Discharges, FMPC-2058, Revision to NLCO-2039. Feed Materials Production Center, Westinghouse Materials Company of Ohio. Prepared for the U. S. Department of Energy.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

. . .

Ó.

Υ.

- S. Weither ſ Carpenter, T. and D.W. Reicher. Comments of the Government Accountability Project and Natural Resources Defense Council on the Environmental Impact Statement for the Department of Energy's Feed Material Production Center, Fernald, Ohio. Washington, D.C. 25 September 1986.
- Clark, T.R., L. Elikan, C.A. Hill, and B.L. Speicher. Addendum to FMPC-2082: UC 702, History of FMPC-Radionuclide Discharges - Revised Estimates of Uranium and Thorium Air Emissions from 1951-1987. Cincinnati, OH: Westinghouse Materials Company of Ohio. March 1989. We shall be the second state of the second of the ٠. .

. :

Davis, B.J. Public Radiation Exposures from the FMPC Historic Airborne Releases - Data Development. Letter to J. R. Barker. U.S. Department of Energy (Enclosed NLCO-2039, History of FMPC discharges, and FMPC Dose Calculation Assumptions). [See Barker 1986]. 13 February 1986. 12

Dolan, L.C. County Information Guide for Toxic Material Releases at the Feed Materials Production Center. (This document designed to provide information to the community of potential for offsite consequences in event of "unusual" event; lists types and volumes of chemicals stored; population estimates for 5 mile area; hazard analysis of chemicals and soluble U). NLCO-1199, Special Category No. UC41. Prepared for U.S. Department of Energy. NLO, Inc. January 1985. . . . . .

- Dolan, L. C. and C. A. Hill. Addendum to FMPC 2082: UC 11, History of FMPC Radionuclide Discharges, Feed Materials Production Center, Westinghouse Materials Company of Ohio. December 1988.
- Dodd, A.O.; Ross, K.N. Evaluation of environmental uranium contamination at the Feed Materials Production Center. In Health and Safety Laboratory Symposium on Occupational Health Experience and Practices in the Uranium Industry, HASL-58, pp. 175 -178. Cincinnati, OH: National Lead Company of Ohio. 15-17 October 1958.
- the states of the Dodd A.O. 1958 Annual Report - Radiation and Effluent Control Section. Memorandum to R.H. Starkey. (Summary of external radiation, liquid effluents, airborne effluent). National Lead Company of Ohio. 27 February 1959.
- Facemire, C. F., S. I. Guttman, D. R. Osborne, R. H. Sperger. Biological and Ecological Site Characterization of the Feed Materials Production Center, Department of Zoology, Miami University, Oxford, Ohio. Prepared under contract to U.S. Department of Energy, Oak Ridge Operations. January 1990.

1.01.1

- ale de FMPC. FMPC Position in 1954. FMPC Position in 1959. (4 pages each, lists production highlights, technical highlights, technical activities). National Lead Company of Ohio. 26 December 1967.
- 26 . . 1 . . . . . . . FMPC Position in 1954, Report; Operations at FMPC consisted of sampling uranium concentrate, refining and denitration, conversion of orange oxide to brown oxide to green salt, reduction to uranium metal and recasting into ingots, rollling into billets and rods, machining into finished pieces. Recovering all scrap and converting to an acceptable refinery feed reduction of UF<sub>6</sub> to UF<sub>4</sub>, converting refined thorium salts into massive thorium metal and fabricating fuel elements; 26 December 1967.

- FMPC Historical Data and Costs, no author; U.S. Atomic Energy Commission, Fernald Area Office; National Lead Company of Ohio, Divisional Organization Chart; Line item projects; No date.
- Howard, E. M. Site Development and Facilities Utilization Plan for the U.S. Department of Energy Feed Materials Production Center Fernald, Ohio. NLCO-2012, Special. National Lead Company of Ohio, Inc. April 1984.
- Mead, J. C. History of FMPC Residue Recovery Operations, NLCO-1096, Feed Materials Production Center, National Lead Company of Ohio. NLCO. 21 June 1971. Radioactivity in Airborne and Liquid Effluents for Calendar Year 1970. NLO/ICN 2159174. National Lead Company of Ohio. 25 August 1972.
- NLCO (National Lead Company of Ohio). Diary Entries and Log Notes. Daily handwritten descriptive comments of inspections of various plants; equipment delivery, safety checks; entries by J. Kloth, J. Seery, A. Roberts, R. Gentry). National Lead Company of Ohio. 1955 -1956.
- NLCO (National Lead Company of Ohio). Plant Organization Charts NLO/Fernald. (29 pages). 1 June 1957.
- NLCO (National Lead Company of Ohio). Position in 1959, Report does not reflect whose position; 3 page report; Technical activities; 1959.
- Pennak, A.F. FMPC Pollution Controls. NLCO-1097 Special. (General description of air pollutant controls and methods at that time). For Presentation at the EPA Air Pollution Control Technology Training Session, Cincinnati, OH: National Lead Company of Ohio. 11 December 1972.
- Pomeroy, S.E., T.L. Anderson, M.A. Eischen, J.M. Stilwell and D.A. Tolle. Final Report on Ecological Assessment at the Feed Materials Production Center Cincinnati, Ohio. Report to National Lead Company of Ohio. Columbus, OH: Battelle Columbus Laboratories. 30 September 1977.
- Semones, T.R. and E. F. Sverdrup. Uranium Emissions from Gulping of Uranium Trioxide, FMPC/Sub-019. Cincinnati, OH: Westinghouse Materials Company of Ohio. December 1988.

#### FRESH (Fernald Residents Group)

- Alvarez, R. and Arjun Makhijani, Technology Review; Hidden Legacy of the Arms Race Radioactive Waste; Troubles at the Tank Farms, dumping into soil and groundwater, earthquakes and explosions, cleanup plan, dangers of radioactive cement; August/September 1988.
- Bertell, R., American Industrial Hygiene Association Journal report; The nuclear worker and ionizing radiation; 1979.
- Citizen's Clearinghouse for Hazardous Wastes, Inc. CCHW; 25 page report; Center for Disease Control: Cover-Up; Deceit and Confusion. Lois Marie Gibbs, Executive Director. (Health studies attempt to determine whether there's a cause-and-effect relationship between toxic exposure and illness). No date.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page A-63

•The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

1

Connor, T. The Bulletin of the Atomic Scientists article; Nuclear Workers at Risk; Federal officials are accused of abusing the science of radiation and health, as well as the safety of workers and communities near weapons plants. September 1990.

المأثر الهاية وجوارته المراد الا

Olshansky, S.J. and R. G. Williams, The Bulletin of the Atomic Scientist article: Culture Shock at the Weapons Complex; Developing a comprehensive database on health, and making it public, is just one way Energy Secretary James Watkins is shaking up the department; 3. . . . September 1990. •

RWC Waste Paper, Crisis at the Nuclear Bomb Plants; Several articles with topics such as Waste Pit 5 at the Feed Materials Production Center in Fernald, Ohio, Waste Isolation Pilot Plant in Carlsbad, New Mexico, Oak Ridge as the first atomic city, Rocky Flats Nuclear Weapons Plant; Winter 1988-89. ۰.

Sea, G. Fernald Atomic Trades & Labor Council report; Uranium Health Effects Background الجاري والمراجع والم Paper. No date. at soft dine di di

#### GROUNDWATER

the second second

ASI/IT. Engineering Evaluation/Cost Analysis South Plume, Feed Materials Production Center, Fernald, Ohio. In response to FFCA, DOE evaluating removal action for "south uranium plume" prior to RI/FS completion). Prepared for U.S. Department of Energy, Oak Ridge Operations by Advance Sciences, Inc. & International Technology Corp., FMPC.0003.6. August 1990. the state of the s ,

L (A) Test . . .

ι,

Contraction of the second s

Dames & Moore, White Plains, NY. "Feed Materials Production Center Groundwater Study -Task C Report. Prepared for US Department of Energy. July 1985. (Report on source of uranium in plant's sewer system.)

enter la composition de la composition de la proposition de la composition de Dames & Moore. Results of RCRA Sampling Feed Materials Production Center, Fernald, Ohio, Sand and Gravel Aquifer; Pearl River, NY: Dames and Moore; August 1985.

Dames & Moore. Results of RCRA Sampling Feed Materials Production Center, Fernald, Ohio, Pit # 4; Pearl River, NY: Dames & Moore; August 1985. (First of series of quarterl7y reports decribing groundwater monitoring being conducted at FMPC. Since Pit 4 subject to RCRA regulation, 4 monitoring wells sampled; includes soil classification for borings). . .

. . . . . Structure - server - Structure - St Dove, G.G. and S. E. Norris, September 1951. Conditions Governing the Occurrence of Ground Water in the Fernald Area, Ohio, With Reference to the Possibilities of contamination by Disposal of Chemical Wastes, U.S. Geological Survey, Ground Water Branch, Columbus Ohio. REF: IT interim report, 1986. rebut a rebut a state of the second state of the s

Dove, G.D., 1961. A Hydrologic Study of the Valley-Fill Deposits in the Venice area, Ohio, Ohio Division of Water, Technical Report 4. REF: IT interim report, 1986.

inscript

Eddy, P.A., L.S. Prater. Draft Summary of Ground-Water Monitoring Practices at Department of Energy Facilities. PNL-4251 (D), Richland, WA: Pacific Northwest Laboratory. April 1982. and the second second

Engineering, University of Cincinnati sent report to J. A. Quigley; 24 pages, incl. diagrams of plant wells & waste disposal area, pumping tests of main production wells, U analysis of

Page A-65

water samples, Paddy's Run Creek water & algae samples analyses for radium, U, alpha and beta, and soluble and total U content of soil samples from FMPC site).

- Eye, J.D. 16 August 1961. Review of Hartsock report of Feb 1960. Letter to R. Starkey. University of Cincinnati.
- Eye J.D. 23 January 1961. Report on the ground water pollution potential in the Feed Materials Production Center operated by the National Lead Company of Ohio. NLO/ICN 2115249. (Preliminary report dated 22 August 1960 included). Cincinnati, OH: College of Engineering, University of Cincinnati.
- Eye, J.D. 1961. Special Report on the Occurrence and Movement of Ground-Water in the FMPC Area. (Review of 3 previous groundwater reports he wrote; firmly believes that "all potential pollution hazards to the groundwater must be eliminated.."). University of Cincinnati.
- Facemire, C. F., 26 February 1985. Report to the Manager: Aquifer Contamination Control. (U and chemical results from production, test and offsite wells, storm sewer outfall, Paddy's Run, Great Miami River). Feed Materials Production Center, Fernald.
- Geotrans, INC. 1985. Preliminary Characterization of the Ground Water Flow System near the Feed Materials Production Center, Great Miami River Valley- Fill Aquifer, Fernald, Ohio," prepared for the Ohio Environmental Protection Agency, Southwest District office, Dayton, Ohio. REF: IT interim report, 1986.
- Hartsock, J.K. 15 February 1960. Geological Considerations of Waste Control at FMPC. TID-12297. (Movement of ground water; geologic survey; environmental problems with suggested approaches; radium storage tanks as hazard with "gaping crack through which seepage...poured out"). US Atomic Energy Commission.
- IT Corporation. 1 August 1988. Hydrogeologic Study of FMPC Discharge to the Great Miami River Final Report. (Purpose of study to determine if the discharge from the FMPC effluent pipeline is located within the zone of influence of the production well field operated by the Southwestern Ohio Water Company (SOWC) or any other major production field; modeling studies; 35 water samples); RAC also has draft version dated 1 October 1987. Prepared for FMPC, WMCO under contract to U.S. Department of Energy.
- Miami Conservancy District, 1985. Hydrologic Data for the Hamilton-New Baltimore Area --1984, The Water Conservation Subdistrict of the Miami Conservancy District, Dayton, Ohio. REF: IT interim report, 1986.
- Sedam, A.C. 1984. Occurrence of Uranium in Ground Water in the Vicinity of the U.S. Department of Energy Feed Materials Production Center, Fernald, Ohio. Administrative Report prepared for the U.S. Department of Energy. (Results of offsite domestic wells sampled during December 1981 by plant operator and during August 1982 by U.S. Geological survey revealed 54 to 320 micrograms/liter dissolved uranium; confined to area of 100 acres south of FMPC.
- Solow, A.J.; Phoenix, D.R. Characterization investigation study, Volume 3: Radiological characterization of surface soils in waste storage area. Document FMPC/SUB-008; Westchester, PA: Roy F. Weston, Inc. 1987.

Spenceley. R.M. Results of well sampling. Letters to residents in the area of the FMPC. Samples collected Feb 1982 - Dec 1984.

Spieker, A.M. 1968. Ground-water hydrology and geology of the Lower Great Miami River Valley, Ohio,: U.S. Geological Survey, Professional paper 605-A. REF: IT interim report, 1986.

Spieker, A.M.; Norris,S.E. Ground-water movement and contamination at the AEC Feed Materials Production Center Located near Fernald, Ohio, U.S. Geological Survey, 1962. Professional paper 605-c. REF: IT interim report, 1986.

· . :

Starkey, R.H., C. Watson, R.C. Coates, E.B. Riestenberg, J. W. Robinson. 30 September 1962. Report of FMPC Ground Contamination Study Committee. (Detailed history of ground contamination concerns with recommendations; flows in Miami River from Miami Conservancy District; suggest efficiency tests should be done on Plant 8 wet scrubbers; 9 miles of sewer lines designed to flow by gravity to Paddy's Run; detention sump but no means to empty; all rainwater discharged to ditch, then to Paddy's Run; lift station installed at MH 34 in August 1955; good narrative of ground water contamination; bimonthly Cl and nitrate levels in Test Well 1 and production wells from Aug 1959 to Sep 1962.) National Lead Company of Ohio.

U.S. Department of the Interior Geological Survey. Columbus, Ohio.Soil & Material Engineers Inc. 31 July 1985. Hydrogeologic Investigation of the Proposed Storm Water Collection Basin. (Determined the thickness and extent of perched water table aquifer, estimated quantity of groundwater flow, assess 6 observation wells). Prepared by Soil & Material Engineers, Inc., Cincinnati, Ohio. for NLO, Inc.

Weidner, R. B., 8 February 1983. Report to the Manager: Aquifer Contamination Control. National Lead Company of Ohio. (Analytical chemical and U results of test and production wells, offsite wells, Great Miami R., storm sewer outfall and Paddy's Run).

**GROUND CONTAMINATION** 

Beers H.M. 2 May 1961. Ground Contamination Incident - Plant 8. Memorandum to C.R. Chapman. (Spill of acid filtrate (pH 1.5) from precipitator vent line on 28 Apr 1961; 50 g/l U). National Lead Company of Ohio.

Chapman, C.R. to J.A. Quigley, Memorandum; Field Test on Utilization of Contaminated Oil as a Dust Palliative; 11 August 1960.

Comments on Ground Contamination in Process Areas. Biweekly reports on ground contamination surveys of process areas; includes 2-3 pages text and external contamination survey diagram for each plant; some have graph of estimated U losses). Most from R.H. Starkey to J.A. Quigley. We have April-November 1961. National Lead Company of Ohio.

Cuthbert J.H. and J.A. Quigley. 18 July 1961. Ground contamination - Pilot Plant. Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio.

Davis, J.O. 18 September 1957.Ground Contamination. Memorandum to F.L. Cuthbert. Cincinnati, OH: National Lead Company of Ohio.

7

.

Appendix A

Sources of Information

Page A-67

- DeFazio, P. G. 10 January 1961. Contaminated Oil. Memorandum to J. H. Noyes. Cincinnati, OH: National Lead Company of Ohio.
- Dodd A.O. 15 July 1959. Summary of Ground Contamination Survey Program. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio.
- Fischoff R.L. 7 March 1961. Ground Contamination. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio.
- Fischoff, R.L. 9 August 1961. Ground Contamination. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio.
- Flowers D.L. 21 June 1961. Ground Contamination. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio.
- Heatherton, R.C. 29 April 1957. Pilot Plant Ground Contamination Survey. Memorandum to J.O. Davis. Cincinnati, OH: National Lead Company of Ohio.
- Inspection Report Technical Division Ground Contamination Committee. (Reports of quarterly inspections of ground contamination; descriptive narrative for specific areas; somewhat useful). March, June 1961.
- Jeffers, O.H. 1 May 1961. Letter to J.A. Quigley. Discussion Following Inspection of Paddy's Run Re Possibility for Continuous Measurement of Surface Flow. (Extremely poor copy). U.S. Department of the Interior, Columbus, Ohio.
- Karl, C.L. Field Tests on Utilization of Contaminated Oils as Dust Palliatives. Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 14 June 1960
- Karl C.L. 5 September 1962. Letter to J. H. Noyes. Geologist Consultations on Ground Contamination Control. (Extremely poor copy). National Lead Company of Ohio.
- Lehman, L. and E. Hansen. 1988. Secondary Concentration of Air-Released Uranium Through Watershed Runoff at the Feed Materials Production Center, Fernald, Ohio.
- NLCO (National Lead Company of Ohio). Minutes of the Technical Division Ground Contamination Committee Meeting. (Monthly Reports; recommendations for specific problems, person responsible, action, status; some are useful). Most available for 1961.
- NLCO (National Lead Company of Ohio). Summary of Ground Contamination for Months of September, October 1955; March, April 1956; August 1957.
- Noyes, J.H. Idea letter- ground contamination control. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio. 19 February 1962.
- Quigley J.A. Ground Contamination Summary. Report to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 21 June 1961.
- Quigley J.A. Status of Ground Water and Stream Contamination Studies. (Re source of contamination of Test Well #1; <sup>36</sup>Cl added to clearwell of Pit #3 but none found after 6

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

1

ş 🖗

2

weeks; some in Test Well #5 adjacent to clearwell). Cincinnati, OH: National Lead Company of Ohio. 18 September 1962. IC and the second

Sapirie, S.R. Geologist Consulation on ground contamination control. Letter to C.L. Karl. (Suggests locating a gauging station on Paddy's Run). Oak Ridge, TN: U.S. Government/Oak Ridge Operations; 17 May 1962.

Shaw W.E. Memorandum to F.L. Cuthbert. Ground Contamination in Process Areas. (Concerns of Technical Division of large contaminated areas near Pilot Plant, Machine Shop and Plant 6). National Lead Company of Ohio. 23 June 1961.

Shaw W.E. Minutes of the Technical Division Ground Contamination Committee Meeting, September 25, 1961. Cincinnati, OH: National Lead Company of Ohio. 3 October 1961.

Spenceley, R.M. Ground Contamination Survey - Rolling Mill Area. Memorandum to A.S. Yocco. Cincinnati, OH: National Lead Company of Ohio. 8 June 1959.

Spenceley, R.M. Ground Contamination Survey – Machining Area. Memorandum to G.C. Coon. Cincinnati, OH: National Lead Company of Ohio. 8 June 1959.

Starkey, R.H. Ground Contamination Around Pilot Plant. Memorandum to J.O. Davis. Cincinnati, OH: National Lead Company of Ohio. 26 May 1958.

Starkey, R.H. Ground Contamination. Memorandum to J.A. Quigley, M.D.Cincinnati, OH: National Lead Company of Ohio. 8 April 1959.

Starkey R.H. Comments on Ground Contamination in Process Areas. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 19 April 1961.

Starkey R.H. Comments on Ground Contamination in Process Areas. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 22 May 1961.

Starkey R.H. Comments on Ground Contamination in Process Areas. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 23 June 1961.

Starkey R.H. Comments on Ground Contamination in Process Areas. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 24 July 1961.

Starkey R.H. 25 September 1961. Comments on Ground Contamination in Process Areas. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio.

Starkey R.H. Comments on Ground Contamination in Process Areas. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 25 October 1961.

Starkey R.H. Comments on Ground Contamination in Process Areas. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 22 November 1961.

Starkey, R. H. Comments on Ground Contamination in Process Areas. Memorandum to J. A. Quigley. (16 pages, diagrams) of contamination of external areas of all Plants and Experimental Machine Shop). Cincinnati, OH: National Lead Company of Ohio. 19 March 1964.

.

Page A-69

- Starkey, R. H. Comments on Ground Contamination in Process Areas. Memorandum to J. A. Quigley. (Comments on two ground contamination surveys; marked reduction in U losses via storm sewer, 4 pages). Cincinnati, OH:National Lead Company of Ohio. 27 December 1962.
- Starkey, R. H. Comments on Ground Contamination in Process Areas. Memorandum to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 22 October 1962.
- Tippenhauer, D.A. Underground SS Material Loss. Production Engineering Department Completion Report. Cincinnati, OH: National Lead Company of Ohio. 9 April 1957.
- WMCO (Westinghouse Materials Company of Ohio). What are the fly ash pits? Reponse to inquiry by the FMPC Environmental Safety & Health Advisory Committee. Cincinnati, OH: Westinghouse Materials Company of Ohio. 30 March 1989.

### GUMFILM

Barry, E. V. Fallout Program. Memo to J. A. Quigley. NLO/ICN 2127029. 8 December 1953.

- Barry, E.V. Gumpaper Fall-Out Samples. Report to R.C. Heatherton. 1 page. Cincinnati, OH: National Lead Company of Ohio. ICN 2240511. 25 February 1954.
- Barry, E.V. Fall-Out Samples. Report to R.C. Heatherton. Work Request 22-54-12. Cincinnati, OH: National Lead Company of Ohio. ICN 2240510. 23 March 1954.
- Boback, M. W. Fallout Sampling. Memo Route Slip to H. W. Hibbitts (ORO-AEC) and M. S. Nelson (NLO). Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2159238. 9 July 1974.
- Boback, M. W. Sampling for Weapons Fallout. Mound-NLO Contact Report to B. Robinson. 1 page. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2152703. 22 November 1976.
- Boback, M.W. Detection of Weapons Test Fallout. Letter to J.F. Wing, U.S. ERDA, Oak Ridge, TN., Cincinnati, OH: National Lead Company of Ohio. ICN 2115737. 9 February 1977.
- Comar, C. L. Fallout from Nuclear Tests. Washington, DC: U.S. Atomic Energy Commission. NLO/ICN 2670764.
- Culler, F. L. AEC Fallout Information and Response Network. Letter to J. A. Lenhard, U.S. Atomic Energy Commission, Oak Ridge, TN. Oak Ridge, TN: Oak Ridge National Laboratory. NLO/ICN 2187593. 20 July 1973.
- Deal, L. J. Collecting and Reporting Fallout Data from Chinese Tests. Memo to J. R. Roeder, R. M. Moser, R. E. Tiller, M. E. Miles, W. J. Larkin, W. H. Travis, P. G. Holsted, R. W. Hughey, and G. H. Giboney. Washington, DC: U.S. Atomic Energy Commission. NLO/ICN 2187594. 19 June 1973.
- Fallout Samples. 6/18/74 to 7/9/74. NLO/ICN 2159199. Cincinnati, OH: National Lead Company of Ohio. 1974.

• .: . •

1 1

÷.,

Fletcher, H. D. Freedom of Information Request. Letter to S. F. Audia, NLO, Cincinnati, OH. Oak Ridge, TN: U.S. Atomic Energy Commission. NLO/ICN 2129439. 28 October 1976.

Freiwald, A. Fallout Over Fernald. Article in <u>The American Lawyer</u>, July/August 1990. NLO/ICN 2890236.

Hall, M. Fallout From Fernald. Article in <u>Ohio Law</u>. NLO/ICN 2890413. Cincinnati, OH: Westinghouse Materials Company of Ohio. July.

Heatherton, R.C. Perimeter Air Sampling and Fallout Data. Letter to E. H. Luetje, U.S. AEC. Cincinnati, OH: National Lead Company of Ohio. ICN 2126394. 25 January 1957.

- Heatherton, R.C. Fallout Sampling. Memorandum to S.F. Audia. M.W. Boback's Contact Report., 11/22/76. Cincinnati, OH: National Lead Company of Ohio. ICN 2115742. 22 November 1976.
- Huskey, J. T. Filter Housing Quality, Barnebey-Cheney, Columbus, OH. Memo to A. J. Stack. The Rust Engineering Company. NLO/ICN 2223457. Cincinnati, OH: Westinghouse Materials Company of Ohio. 16 September 1985.

Jones, D. L. Revision to Ohio EPA NPDES Monthly Report (December 1985). Letter to B. J. Davis, Oak Ridge, TN. Cincinnati, OH: Westinghouse Materials Company of Ohio. NLO/ICN 2218609. 14 January 1986.

Karl, C.L. Statement to be Used in Reply to Inquiries Concerning Recorded Fallout Data. Letter to G.W. Wunder. Cincinnati, OH: National Lead Company of Ohio. ICN 2126760. 30 November7 1957.

. . . .

• 1 . S

Karl, C. L. Annual Health Protection Review--1963. Letter to J. H. Noyes, NLO, Cincinnati, OH. Oak Ridge, TN: U.S. Atomic Energy Commission. NLO/ICN 2152000. 8 April 1963.

Karl, C. L. Dissemination to the Public of Data on Environmental Levels of Radioactivity. Letter to J. H. Noyes, NLO, Cincinnati, OH. NLO/ICN 2623655. 8 June 1960.

Contraction of the second s

Karl, C. L. Release of Information Concerning Fallout. Letter to J. H. Noyes, NLO, Cincinnati, OH. Oak Ridge, TN: U.S. Atomic Energy Commission. NLO/ICN 2128842. 1 May 1959.

Keller, C. A. AEC Fallout Information and Response Network. Letter to B. N. Stiller. Oak Ridge, TN: U.S. Atomic Energy Commission. NLO/ICN 2187596. 8 June 1972.

Keller, C. A. AEC Fallout Information and Response Network. Letter to M. S. Nelson, NLO, Cincinnati, OH. Oak Ridge, TN: U.S. Atomic Energy Commission. NLO/ICN 2152065. 8 June 1972.

Keller, C. A. Interim Safety Guidelines for Operations in AEC-Owned Nuclear Facilities Other Than Reactors. Letter to M. S. Nelson, NLO, Cincinnati, OH. Oak Ridge, TN: U.S. Atomic Energy Commission. NLO/ICN 2152066. 2 June 1972.

Keller, C. A. Route Slip to Hibbits. Attached to Letter from M. S. Nelson to C. A. Keller AEC Fallout Information and Response Network: dated 10 July 1972. NLO/ICN 2187598.

# Appendix A

1

## Sources of Information

Komitor, M. A. Material Fallout Investigation--G371. Project Completion Report. NLO/ICN 2218411. 9 February 1965.

•

- Kreuzmann, A. B. Minutes of Safety Meeting. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2646690. 24 February 1981.
- Lenhard, J. A. AEC Fallout Information and Response Network. Letter to A. M. Weinberg, Union Carbide Corporation, Oak Ridge, TN. NLO/ICN 2187600. 6 June 1972.
- Love, G. Detection of Weapons Test Fallout Radioactivity. ERDA Contact Report to M. W. Boback. 1 Page. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2152851. 10 February 1977.
- Love, G. Termination of Special Fallout Sampling. ERDA Contact Report to M. W. Boback. 1 Page. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2152707. 24 November 1976.
- Love., G and J. Wing. Air Sampling Results Fallout. ERDA Contact Report to M.W. Boback. Cincinnati, OH: National Lead Company of Ohio. ICN 2115729. 22 November 1976.
- Ludlow, R. Fernald Fallout Denied. Newspaper Article in The Post. NLO/ICN 2360306. 10 June 1989.
- Nelson, M. S. AEC Fallout Information and Response Network. Letter to C. A. Keller, U.S. Atomic Energy Commission, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2152061. 10 July 1972.
- NLO (National Lead Company of Ohio). Sample Report. Fallout Trays. NLO/ICN 2240500. Cincinnati, OH: National Lead Company of Ohio. 20 August 1954.
- NLO (National Lead Company of Ohio). Gumpaper Analytical Data Sheets. Health and Safety Division. NLO/ICN 2240514-2240516. Cincinnati, OH: National Lead Company of Ohio. April 1954.
- NLO (National Lead Company of Ohio). Sample Report. Inside Prod. Area Fence. NLO/ICN 2240505. Cincinnati, OH: National Lead Company of Ohio. 10 August 1954.
- NLO (National Lead Company of Ohio). Summary of NLO Environmental Air Sampling and Fallout Sampling in 1959. 5 pages. NLO/ICN 2623654. Cincinnati, OH: National Lead Company of Ohio. 1960.
- NLO (National Lead Company of Ohio). Status report of 11/1 indicated that weekly checks of painted panels placed throughout the plant area have not indicated any fall-out harmful to painted surfaces. Weekly checks will continue. Cincinnati, OH: National Lead Company of Ohio. 20 November 1965.
- Noyes, J. H. Discontinuance of the FMPC Fallout Tray Program. Letter to C. L. Karl, USAEC, Cincinnati, OH. NLO/ICN 2154271. 3 November 1965.
- Noyes, J. H. Material Fallout Investigation (G-371). Request for Engineering Services. NLO/ICN 2218412. 18 September 1964.

Ę

الإسمالية

Noyes, J. H. Release of Information Concerning Fallout. Letter to C. L. Karl, USAEC, Cincinnati, OH. NLO/ICN 2128840. 1 May 1959.

Noyes, J. H. Transmittal of Industrial Hygiene & Radiation Department Procedure Manual. Letter to C. L. Karl, USAEC, Cincinnati, OH. NLO/ICN 2154272. 11 October 1965.

Pollock, R. P. Request for Release of All Records Relating to Radioactive Fallout within the Continental United States due to Atmospheric Detonation of a Nuclear Device by the Peoples Republic of China on September 26, 1976. Letter to U.S. Energy Research and Development Administration, Washington, DC. NLO/ICN 2657055. 7 October 1976.

Ross, K. N. Chinese Fallout. Report of Isotopic Analyses. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2159182. 27 October 1976.

Rubin, J. H. Collecting and Reporting of Fallout Data from Chinese Testing. Memo to Managers of Field Offices and Directors of Divisions and Offices, HQ. Washington, DC: U.S. Atomic Energy Commission. NLO/ICN 222316?. 15 May 1972.

Saparie, S.R. Inquiries regarding Fallout From Atomic Tests. To Area Managers of seven mnucelar facilities. Oak Ridge, TN: U.S. Atomic Energy Commission.NLO/ICN 2126787. 14 February 1955.

Spenceley, R. M. Stack Monitoring and Sampling. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: NLO (National Lead Company of Ohio). NLO/ICN 2223517. 22 November 1985.

Starkey, R. H. Discontinuance of Fallout Tray Program. Memo to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2159274. 15 October 1965.

Starkey, R. H. Special Fallout Study. Memo to All IH&R Department Personnel. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2128785. 17 March 1960.

Stiller, B. N. AEC Fallout Information and Response Network. Memo to C. A. Keller, Oak Ridge Operations. U.S. Atomic Energy Commission. NLO/ICN 2187595. 19 July 1972.

Tabor, C. D. AEC Fallout Information and Response Network. Letter to C. A. Keller, USAEC, Oak Ridge, TN. Piketon, OH: Goodyear Atomic Corporation. NLO/ICN 2187597. 13 July 1972.

Weinberg, A. M. AEC Fallout Information and Response Network. Letter to J. A. Lenhard, USAEC, Oak Ridge, TN. Oak Ridge, TN: Oak Ridge National Laboratory. NLO/ICN 2187599. 30 June 1972.

Wing, J. F. FMPC Site Environmental Impact Assessment. Conference Call--J. Boyle (ORNL), J. Wing (ORO), M. Boback, and A. F. Pennak (NLO). ERDA Contact Report to A. F. Pennak. 1 Page. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2152709. 6 December 1976.

Wing, J. F. and G. Love. Air Sampling Results--Weapons Fallout. ERDA Contact Report to M. W. Boback. 1 Page. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2152705. 22 November 1976.

• • •

Appendix A

÷.

-

Sources of Information

- Wing, J.F. Fallout From Chinese Bomb Test. ERDA Contact Report to M.W. Boback. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2115747. 5 October 1976.
- Wunder, G. W. Correlation Between Two-Stage Air Sampling Data and the Excretion of Uranium in Urine. Letter to J. H. Noyes, NLO, Cincinnati, OH. New York: National Lead Company. NLO/ICN 2152001. 17 April 1963.

## INCINERATOR AND BURN PIT

Audia, S.F. Uranium content of burn pit residues. Memorandum to C.R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 6 September 1967.

Bipes, R.L. Air dust Evaluation of Smoke Plume. Trash Incinerator. Memorandum to K. E. Brandner. Cincinnati, OH: National Lead Company of Ohio; 18 July 1962.

Klein, F.J. Uranium Fallout Study in Adjacent Vicinity of the Oil Burner and the Incinerator. Memorandum to R.L. Fischoff. 1 page. Cincinnati, OH: National Lead Company of Ohio; ICN 2118685. 12 July 1963.

Klein, F.J. Uranium Fallout Study in Adjacent Vicinity of the Oil Burner and the Incinerator. Memorandum to R.L. Fischoff. 1 page. Cincinnati, OH: National Lead Company of Ohio; ICN 2118694. 1 May 1964.

Klein F.J. 1 May 1964. Memorandum to R.L. Fischoff. Uranium Fallout Study in Adjacent Vicinity of the Oil Burner and The Incinerator. (Lists concentration range and averages at five locations). NLO/ICN 2118894. National Lead Company of Ohio.(Dup of above).

Boback, M.W. 18 October 1972. Low-Cost Incinerator Units for Disposal of Waste Graphite and Oils. NLCO-1093. Prepared for presentation at the AEC Pollution Control Conference, oak Ridge, October 25-27, 1972. (Overview of incineration of contaminated oil and graphite in incinerators onsite).

Neblett, F.W. to Boback, M.W. 8 October 1985. Estimate for Historical Releases - Graphite Burner and Oil Burner. (Block diagrams depicting estimated releases to atmosphere from burner located north of boiler plant.)

Brandner, K.E.; Bipes, R.L.; Williams, L. Incineration of waste contaminated oil. Prepared for presentation at the eighth annual AEC air cleaning seminar, Oak Ridge National laboratory. NLCO-894. Cincinnati, OH: National Lead Company of Ohio; 18 September 1963.

Catalytic Construction Co. 5 March 1952. Engineering Report on Incinerator Requirements Feed Materials Production Center - Fernald, Ohio. Job #3039. (Outlines FMPC needs for waste disposal; diagram of incinerator plant layout). Catalytic Construction Company, Philadelphia.

Chapman, G.R. Contaminated Oil. Memorandum to J.N. Noyes. 31 January 1961.

Davis, J.O and W. E. Palmer. Evaluation of Uranium Content of Various Plant Incinerator Residues. Memorandum to J.B. Stevenson. (Chemical analyses of incinerator dumpster ash

÷

-

2

nicitie (\*

ź

2

and burn pit dumpster ash; g/L U, %U, isotopic % U-235, total lb.). Cincinnati, OH: National Lead Company of Ohio. 9 April 1968.

Fischoff, R.L. Radioactive Contamination in Scrap Burning Pit. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio. 13 April 1962.

Heatherton, R.C. Survey of air contamination from burning uranium chips to convert to oxide. Memorandum to J.A. Quigley. (Air dust samples in vicinity of burning chips on storage pad; burn test done on November 11). Cincinnati, OH: National Lead Company of Ohio; 17 November 1952.

Karl, C.L. Oil Burning. Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 30 December 1963.

Karl, C.L. Incineration of uranium metal, Memorandum to J.L. Bloom (Materials Representative, San Francisco Office). (Design of gas oxidation furnace described; furnace engineered, fabricated and installed for \$17,334; capacity about 600 lb. U chips, sludges or turning per 24-hr day; exhausted through static bed filters before being exhausted to atmosphere). Cincinnati, OH: National Lead Company of Ohio; 12 May 1958.

 Klein, F.J. Uranium Fallout Study in Adjacent Vicinity of the Oil Burner and the Incinerator. Memorandum to R.L. Fischoff. (Feb-May air monitoring survey indicated both are sources of U contamination; U from oil burner five times higher than from incinerator). Cincinnati, OH: National Lead Company of Ohio; 12 July 1963.

Levy, L.M., Handwritten notes on quantity through oil burner; Cincinnati, OH: National Lead Company of Ohio; 30 March 1964.

Levy, L.M., Handwritten notes on quantity through oil burning at the FMPC; Cincinnati, OH: National Lead Company of Ohio; 9 January 1963.

Monnik, H.J. Incinerator General Dimensions and Location, AEC Contract AT(30-1)-1060, Catalytic Construction Company. Contract #3000; Job #3039. Memorandumto D.C. Moore, U.S. Atomic Energy Commission; Cincinnati, OH: National Lead Company of Ohio. 25 June 1952.

Moore, D.C. Incinerator Design and Location, Job #3039. Memorandum to H.H. Eickhoff. AEC Contract AT(30-1)-1060; C.C. Co. Contract #3000; Catalytic Construction Company. 30 June 1952.

NLO (National Lead Company of Ohio). Additional Stack Loss Estimates For Solid Waste Incinerator. Cincinnati, OH: National Lead Company of Ohio. 25 February 1985.

NLO (National Lead Company of Ohio). Analytical Laboratory data sheets of air dust sample analyzed for alpha from chip burner. Cincinnati, OH: National Lead Company of Ohio. January to May 1953.

NLO. Summary of information from Pennington, Weisman, Grant, and references regarding oil burner(3/31/62), graphite burner (11/1/65) and old incinerator (11/16/54). Dates of startup in parentheses.

# Appendix A

.

## Sources of Information

- Riestenberg, E.B. to H. Martin, Memorandum; Resume of Oil Burner and Incinerator Operations During the Month of April, 1964. 06 May 1964.
- Ross, K. N. 12 April 1966. Stack Loss from Graphite Burner. Memorandum to R.H. Starkey. (Stack samples from graphite burner; average of 488 ug U/m3 effluent loss; not operating until 1965 so not important for Task 2 report).
- Ross, K. N. 17 May 1976. Particulate Emissions From Burning Paraffin in the Oil Burner Enclosure. Memorandum to M.W. Boback. (Emission velocity of 350-400 ft/min, stack temp estimate; still above Ohio EPA std of 0.2 lb/100 lb; emission loss of 1.8 lb/hour).
- Ross, K. N. 20 May 1977. Particulate Emissions From the Incinerator Stack. Memorandum to M.W. Boback. (Results of 5 test on stack, all 5 greater than Ohio EPA limit of 0.1 lb. particulates/100 lb burned; average loss U is 0.94 lb/day).
- Sapirie, S.R. Study of Incinerators used for burning contaminated combustible wastes. Memorandum to Belcher, Karl, Thalgott, Stiller. 15 March 1962.
- Starkey, R.H. Answers to specific questions pertaining to pit burning at the FMPC. Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 15 October 1965.
- Starkey, R.H. 18 November 1965. Burning Uranium Contaminated Graphite. Memorandum to J.A. Quigley. (Air dust samples results of burning contamination. U graphite; about 10 mg m<sup>-3</sup> at top of burner.).
- Tolos, W.P. Evaluation of incinerator ash (Code 032 material) drum decontamination residue (Code 021 material). Memorandum to R.C. Kispert. Cincinnati, OH: national Lead Company of Ohio. 17 September 1969.

Williams, L., Handwritten note; Oil Burner. 25 January 1966.

#### INDUSTRIAL HYGIENE & RADIATION REPORTS

- Alpaugh, E. L. Weekly Progress Report--December 26-January 1, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251341. 1 January 1956.
- Alpaugh, E. L. Weekly Progress Report--Week of January 16-22, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251542. 24 January 1956.

Alpaugh, E. L. Weekly Progress Report-January 23-29, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251551. 31 January 1956.

- Alpaugh, E. L. Weekly Progress Report-January 30 through February 5, inclusive. Report to R.
  C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251533. 6 February 1956.
- Alpaugh, E. L. Weekly Progress Report--February 6-12, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251357. 13 February 1956.

Ś;

8

- Alpaugh, E. L. Weekly Progress Report--February 27 thru March 4, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251342. 6 March 1956.
- Alpaugh, E. L. Weekly Progress Report-Week of March 5 to 11, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251372. 12 March 1956.
- Alpaugh, E. L. Weekly Progress Report--March 12 to 18. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251369. 20 March 1956.

Alpaugh, E. L. Weekly Progress Report--March 26 through April 1. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251360. 2 April 1956.

- Alpaugh, E. L. Weekly Progress Report-April 2 to 8. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251563. 10 April 1956.
- Alpaugh, E. L. Weekly Progress Report--Week of April 9-15, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251560. 17 April 1956.

Alpaugh, E. L. Weekly Progress Report-April 23-29. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118164. 7 May 1956.

Alpaugh, E. L. Weekly Progress Report--Week of May 14-20, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251576. 21 May 1956.

Alpaugh, E. L. Weekly Progress Report--Week of May 21-27, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251571. 29 May 1956.

Alpaugh, E. L. Weekly Progress Report--Week of May 28 through June 3. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251566. 5 June 1956.

Alpaugh, E. L. Weekly Progress Report--Week of June 4 to 10, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251382. 11 June 1956.

Alpaugh, E. L. Weekly Progress Report--Week of June 11 to 17, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. 19 June 1956.

est bergen t

1999 (MAR)

Alpaugh, E. L. Weekly Progress Report-Week of July 9 thru 16. Report to R. C.Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251192. 16 July 1956.

Alpaugh, E. L. Weekly Progress Report--Week of August 13 thru 19. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251437. 20 August 1956.

.....

200 4. - - - -4. - - - -

<u>.</u>

Alpaugh, E. L. Weekly Progress Report--Week of September 4 through September 9. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251423. 11 September 1956.

Alpaugh, E. L. Weekly Progress Report--Week of September 10 thru 16. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251416. 18 September 1956.

Boone, F. W. Weekly Progress Report--5/21/56 to 5/25/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251573. 28 May 1956.

Boone, F. W. Weekly Progress Report--6/4/56 to 6/8/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251381. 12 June 1956.

- Brandner, K. E. Monthly Progress Report--Engineering & Special Problems Section, January 1963. Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio. 1 February 1963.
- Brandner, K. E. Monthly Progress Report--Engineering & Special Problems. Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio. 28 February 1963.
- Fischoff, R. L. Monthly Report for January 1963--Radiation & Effluent Control Section. Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio. 31 January 1963.
- Fischoff, R. L. Monthly Report for February 1963--Radiation & Effluent Control Section. Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio. 1 March 1963.
- Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, December 1-31, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251340. 3 January 1956.
- Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Jan. 2-31, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251534. 1 February 1956.
- Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118160. 2 March 1956.

Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of March 1956. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118157. 2 April 1956.

Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118156. 1 May 1956.

Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, May 1 through May 31. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118155. 4 June 1956.

•	P	a	g	e	A	-	7	8	
---	---	---	---	---	---	---	---	---	--

<u>)</u>. •

1

Formation

Section of

.

5

Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of June 1 through June 30. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118153. 3 July 1956.

Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of July Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of July Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of July Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of July Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of July Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of July Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of July Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of July Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of July Heatherton, Heatherton, Heatherton, Heatherton, Month of July NLO/ICN 2118151. 2 August 1956.

- Heatherton, R. C. Monthly Report-Industrial Hygiene & Radiation Department, Month of August 1 through 31. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251424. 6 September 1956.
- Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of October 1 through 31. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118146. 1 November 1956.
- Heatherton, R. C. Monthly Report--Industrial Hygiene & Radiation Department, Month of November 1 through 30. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118144. 5 December 1956.

Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, January 2-8, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251547. 10 January 1956.

Heatherton, R. C. Weekly Report-Industrial Hygiene & Radiation Department, Week of January 16-22, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251540. 25 January 1956.

- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of January 23 through January 29, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251536. 1 February 1956.
  - Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of January 30-February 3, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118165. 8 February 1956.
  - Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of February 6-12, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251355. 15 February 1956.
  - Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of February 13-19, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251351. 21 February 1956.
  - Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of February 20-26, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251345. 2 March 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of February 27 through March 2. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118161. 7 March 1956.

Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of March 3 through March 9, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead

Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of March 12 through 18, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251367. 21 March 1956.

Company of Ohio. NLO/ICN 2251371. 13 March 1956.

- Heatherton, R. C. Weekly Report-Industrial Hygiene & Radiation Department, Week of March 19 through 25. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251363. 27 March 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, For 2 Weeks--April 2 through April 15, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251559. 19 April 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of April 16-20, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251557. 27 April 1956.
- Heatherton, R. C. Weekly Report-Industrial Hygiene & Radiation Department, Week of April 23-April 29, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251555. 1 May 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of May 1-6, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251583. 11 May 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of May 7-13, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251577. 16 May 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of May 14-20, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251570. 22 May 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of May 21-27, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251569. 31 May 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of May 28 through June 1, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118163. 6 June 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of June 4 through 10. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251380. 13 June 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of June 11-17, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251378. 21 June 1956.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page A-79

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

÷.

Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of June 18-24, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251377. 26 June 1956.

Page A-80

. . .

- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, June 25-30, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118154. 3 July 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of August 13 through 17, inclusive. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251436. 21 August 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of August 27 thru September 2. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251425. 4 September 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of September 4 thru September 9. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251421. 14 September 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of September 10 thru 17. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251415. 21 September 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, Week of September 24 through 30. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118149. 4 October 1956.
- Heatherton, R. C. Weekly Report--Industrial Hygiene & Radiation Department, December 26-31, incl. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118162. 4 January 1956.
- Heatherton, R. C. Yearly Report--Industrial Hygiene & Radiation Department. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118158. 26 March 1956.
- Schumann, C. E. Weekly Progress Report-Week of 8/20/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251426. 29 August 1956.
- Starkey, R. H. IH&R Department Annual Report for 1958. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118202. 16 March 1959.
- Starkey, R. H. IH&R Department Monthly Report for January 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118204. 6 February 1959.

Starkey, R. H. IH&R Department Monthly Report for February 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118203. 6 March 1959.

Starkey, R. H. IH&R Department Monthly Report for March 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118201. 3 April 1959.

; ....

- Starkey, R. H. IH&R Department Monthly Report for April 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118200. 5 May 1959.
- Starkey, R. H. IH&R Department Monthly Report for May 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118199. 3 June 1959.
- Starkey, R. H. IH&R Department Monthly Report for June 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118198. 2 July 1959.
- Starkey, R. H. IH&R Department Monthly Report for July 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118197. 5 August 1959.

Starkey, R. H. IH&R Department Monthly Report for August 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118196. 3 September 1959.

- Starkey, R. H. IH&R Department Monthly Report for September 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118195. 6 October 1959.
- Starkey, R. H. IH&R Department Monthly Report for October 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118194. 4 November 1959.
- Starkey, R. H. IH&R Department Monthly Report for November 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118193. 3 December 1959.
- Starkey, R. H. IH&R Department Monthly Report for December 1959. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 6 January 1960.
- Starkey, R. H. IH&R Department Monthly Report for January 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 2 February 1961.
- Starkey, R. H. IH&R Department Monthly Report for February 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 8 March 1961.
- Starkey, R. H. IH&R Department Monthly Report for March 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 12 April 1961.
- Starkey, R. H. IH&R Department Monthly Report for April 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 5 May 1961.
- Starkey, R. H. IH&R Department Monthly Report for May 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 7 June 1961.
- Starkey, R. H. IH&R Department Monthly Report for June 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 10 July 1961.
- Starkey, R. H. IH&R Department Monthly Report for July 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 4 August 1961.
- Starkey, R. H. IH&R Department Monthly Report for August 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 11 September 1961.

i.

.

.

- Starkey, R. H. IH&R Department Monthly Report for September 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 9 October 1961.
- Starkey, R. H. IH&R Department Monthly Report for October 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 7 November 1961.
- Starkey, R. H. IH&R Department Monthly Report for November 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 5 December 1961.
- Starkey, R. H. IH&R Department Monthly Report for December 1961. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 10 January 1962.

Starkey, R. H. IH&R Department Monthly Report for January 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118232. 1 February 1962.

Starkey, R. H. IH&R Department Monthly Report for February 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118231. 5 March 1962.

- Starkey, R. H. IH&R Department Monthly Report for March 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118230. 3 April 1962.
- Starkey, R. H. IH&R Department Monthly Report for May 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118229. 6 June 1962.

Starkey, R. H. IH&R Department Monthly Report for June 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118228. 28 June 1962.

Starkey, R. H. IH&R Department Monthly Report for July 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118227. 6 August 1962.

- Starkey, R. H. IH&R Department Monthly Report for August 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118226. 14 September 1962.
- Starkey, R. H. IH&R Department Monthly Report for September 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 211822?. 4 October 1962.
- Starkey, R. H. IH&R Department Monthly Report for October 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118224. 2 November 1962.
- Starkey, R. H. IH&R Department Monthly Report for November 1962. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118223. 5 December 1962.
- Starkey, R. H. IH&R Department Monthly Report for January 1963. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 7 February 1963.
- Starkey, R. H. IH&R Department Monthly Report for February 1963. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 6 March 1963.
- Starkey, R. H. Weekly Progress Report-January 2-6, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251548. 9 January 1956.

. .

- Starkey, R. H. Weekly Progress Report--Week of 1/9-1/13, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251546. 16 January 1956.
- Starkey, R. H. Weekly Progress Report-January 16-20. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251539. 25 January 1956.
- Starkey, R. H. Weekly Progress Report-January 23 to 29, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251537. 31 January 1956.
- Starkey, R. H. Weekly Progress Report-January 30 to February 5. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251531. 7 February 1956.
- Starkey, R. H. Weekly Progress Report--February 6 to 12. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251356. 13 February 1956.
- Starkey, R. H. Weekly Progress Report--February 13 to 19. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251352. 20 February 1956.
- Starkey, R. H. Weekly Progress Report-February 20 to 26, 1956. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251359. 28 February 1956.
- Starkey, R. H. Weekly Progress Report--3/5 to 3/11. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251374. 12 March 1956.
- Starkey, R. H. Weekly Progress Report--March 12 to 18. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251368. 20 March 1956.
- Starkey, R. H. Weekly Progress Report--March 26 to 30. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251362. 2 April 1956.
- Starkey, R. H. Weekly Progress Report--April 2 to 8. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251565. 10 April 1956.
- Starkey, R. H. Weekly Progress Report--4/9/56 to 4/15/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251562. 17 April 1956.
- Starkey, R. H. Weekly Progress Report--4/16/56 to 4/20/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251558. 24 April 1956.
- Starkey, R. H. Weekly Progress Report--4/23/56 to 4/27/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251556. 30 April 1956.
- Starkey, R. H. Weekly Progress Report--4/30/56 to 5/4/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251582. 11 May 1956.
- Starkey, R. H. Weekly Progress Report--5/7/56 to 5/11/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251581. 15 May 1956.
- Starkey, R. H. Weekly Progress Report--5/14/56 to 5/18/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251574. 22 May 1956.
Page A-84

Starkey, R. H. Weekly Progress Report--Week of June 11-15. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251379. 18 June 1956.

Starkey, R. H. Weekly Progress Report--Week of June 18-22, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251376. 26 June 1956.

Starkey, R. H. Weekly Progress Report--Week of July 9 thru 13, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251191. 18 July 1956.

Starkey, R. H. Weekly Progress Report--7/23/56-7/27/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118152. 31 July 1956.

Starkey, R. H. Weekly Progress Report--7/30/56-8/3/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251442. 9 August 1956.

Starkey, R. H. Weekly Progress Report--8/6/56-8/10/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251439. 16 August 1956.

Starkey, R. H. Weekly Progress Report--8/13/56-8/17/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251435. 21 August 1956.

Starkey, R. H. Weekly Progress Report--8/20/56-8/24/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251445. 29 August 1956.

Starkey, R. H. Weekly Progress Report--8/29/56-9/7/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251422. 13 September 1956.

Starkey, R. H. Weekly Progress Report-Week of September 10 thru 14. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251420. 17 September 1956.

Starkey, R. H. Weekly Progress Report--Week of Sept. 17 thru 21. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251413. 26 September 1956.

Starkey, R. H. Weekly Progress Report--Week of October 1 thru 5. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251408. 10 October 1956.

Starkey, R. H. Weekly Progress Report--10/8/56-10/12/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251407. 15 October 1956.

Starkey, R. H. Weekly Progress Report-10/15/56-10/19/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251402. 23 October 1956.

Starkey, R. H. Weekly Progress Report-10/22/56-10/26/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118147. 1 November 1956.

Starkey, R. H. Weekly Progress Report--10/29/56-11/9/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251392. 13 November 1956.

# Appendix A

57

.....

## Sources of Information

- Starkey, R. H. Weekly Progress Report--Weeks of November 19 thru 30. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118145. 4 December 1956.
- Starkey, R. H. Weekly Progress Report-12/3/56-12/14/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251390. 17 December 1956.
- Starkey, R. H. Weekly Progress Report--12/17/56-12/21/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251388. 27 December 1956.
- Starkey, R. H. Weekly Progress Report--12/24/56-12/28/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118143. 31 December 1956.
- Starkey, R.H. Evaluation of the NLO Industrial Hygiene and Radiation Department. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 24 July 1962.
- Starkey, R.H. Industrial Hygiene and Radiation Department Accomplishments, Calendar Year 1963. Memorandum to R.C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. 22 January 1964
- Stefanec, A. J. Weekly Progress Report--Week of Jan. 2-8; inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251549. 9 January 1956.
- Stefanec, A. J. Weekly Progress Report--Week of 1/9 thru 1/15, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251544. 17 January 1956.
- Stefanec, A. J. Weekly Progress Report-January 23 to 29, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251538. 31 January 1956.
- Stefanec, A. J. Weekly Progress Report--1/30/56 to 2/5/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251532. 6 February 1956.
- Stefanec, A. J. Weekly Progress Report--2/6/56 to 2/12/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251354. 15 February 1956.
- Stefanec, A. J. Weekly Progress Report. Week of February 13-19, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251353. 20 February 1956.
- Stefanec, A. J. Weekly Progress Report. Week of August 27 thru September 2. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2118150. 4 September 1956.
- Stefanec, A. J. Weekly Progress Report. Week of September 24 thru 30. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251411. 30 September 1956.
- Stefanec, A. J. Weekly Progress Report. Week ending 10/7/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251409. 8 October 1956.

Radiological Assessments Corporation

"Setting the standard in environmental health"

Page A-85

Page A-86

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

ł.

1.2.1.A.4

12 N. S. S. S.

ł.

- Stefanec, A. J. Weekly Progress Report. Week of October 8 thru 14, inclusive. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251405. 16 October 1956.
- Stefanec, A. J. Weekly Progress Report. Week ending 10/21/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251403. 22 October 1956.
- Stefanec, A. J. Weekly Progress Report. Week ending 10/28/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251400. 29 October 1956.
- Stefanec, A. J. Weekly Progress Report. Week ending 11/4/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251398. 6 November 1956.
- Stefanec, A. J. Weekly Progress Report. Week ending 11/11/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251395. 13 November 1956.
- Stefanec, A. J. Weekly Progress Report. Week of November 12 thru November 18. Report to R.
  C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251397. 19
  November 1956.
- Stefanec, A. J. Weekly Progress Report. Week ending 11/25/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251394. 26 November 1956.
- Stefanec, A. J. Weekly Progress Report. Week ending 12/2/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251393. 3 December 1956.

Stefanec, A. J. Weekly Progress Report. Week ending 12/9/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251391. 11 December 1956.

Stefanec, A. J. Weekly Progress Report. Week ending 12/16/56. Report to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2251389. 17 December 1956.

Wing, J. F. Survey Section Monthly Report for January 1963. Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio. 30 January 1963.

#### INVENTORY/MATERIAL ACCOUNTABILITY

Several types of monthly or routine reports are available, including: Analytical Department U-Metal Balance during month. Monthly reports that document difference between book inventory and physical inventory of U in analytical department. Calculates unaccounted for U losses.) We have January - Aug 1961 reports, Memoranda by E.V. Henry to R.H. Sisson.

Monthly SS Material Balances. (Comments on normal, enriched, depleted U accounts, Th account, and measured losses; includes statistical control charts for % Book-Physical Inventory Differences, (B-PID)). We have following reports, most are written as letters from J.H. Noyes to C.L. Karl 1960, Aug, Oct 1961, Mar-Dec 1962, Jan, Feb, Apr-Jul, Sep-Nov.

Audia, S.F. 1977. FMPC Refinery Activity - Normal Uranium - November 1953 (Plant Startup) Through March 1977. Letter to H. D. Fletcher. National Lead Company of Ohio.

# Appendix A

÷.

Ţ.

#### Sources of Information

- Audia, S.F. to H. Doran Fletcher, 31 August 1977. Overall Accountability Analyses Report, Plant Startup through September 30, 1976. National Lead Company of Ohio.
- Bogar, L.C. 12 December 1986. Over-all Accountability Analyses Report, Plant Startup Through September 30, 1986. WMCO:EH: 86-159. Westinghouse Materials Company of Ohio.
- Courtney, L. 16 October 1969. Plant 2 Refinery Log Sheet of B-PID and Routine Operating Losses for Oct 1961 through Oct 1962. National Lead Company of Ohio.
- Courtney, L. 14 December 1970. Material Balance Summary from 1953 through 1970 at FMPC: Table II-Enriched Uranium - SS kgs, Table III- Depleted Uranium - SS kgs. Nuclear Materials Control Department, National Lead Company of Ohio.
- Gessiness, B. 1964. Spreadsheets listing "Normal Recovery" for Dry System & Metal, and for Hydro-Met System for FY 1962-1964. Cincinnati, OH: National Lead Company of Ohio.
- Gessiness, B. Nuclear Materials Control for the Normal Winlo Process. Memorandum to H.M. Beers; Cincinnati, OH: National Lead Company of Ohio. 16 September, 1963.
- Gessiness, B. to W. J. Adams, Memorandum; Plutonium Content of NLO Feed Materials (Revision 1). Cincinnati, OH: National Lead Company of Ohio. 10 April 1985.
- Gessiness, B. Comments on SS Materials Control Survey No. OR-156 Station NLO. Memorandum to P.N. McCreery. Cincinnati, OH: National Lead Company of Ohio. 8 March 1962.
- Gessiness, B. Comments on the Safeguards and Materials Management Survey Report, No. OR-267-FVA. Memorandum to C.A. Schwan. Cincinnati, OH: National Lead Company of Ohio. 21 August 1970.
- Gustavson, S.R. to C.H. Walden, Memorandum; SF Material Balance Report Scrap Recovery Process, Cincinnati, OH: National Lead Company of Ohio; December - 1953; Cincinnati, OH: National Lead Company of Ohio. 21 January 1954.
- Inventory Log Sheets, July 1961 June 1963. Monthly totals for beginning inventory, receipts, shipments, measured loss, B-PIDs itemized. Cincinnati, OH: National Lead Company of Ohio.
- Karl, C.L. Uranium Scrap Recovery Program FY 1957. Memorandum to S.R. Sapirie. 5 November 1956.
- Karl, C.L. SS Materials Control Survey No. OR-180 Station NLO. Memorandum to J.H. Noyes, 2 February 1964.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 31 December 1959.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie.(Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 8 January 1960.

12

. ....

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 15 January 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 15 January 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 5 February 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 12 February 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 19 February 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 26 February 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 4 March 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 11 March 1960.
  - Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 18 March 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 25 March 1960.
- Karl, C.L. Weekly Progress: Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 1 April 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 8 April 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 15 April 1960.

. . . .

31

Appendix A

.....

.

Sources of Information

- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 22 April 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 6 May 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 3 June 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 3 June 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 10 June 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 17 June 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 24 June 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 1 July 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 8 July 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 15 July 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 22 July 1960.
- Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 29 July 1960.

2.

2

Ļ,

......

ちゃういい

1. N. W. W.

Karl, C.L. Weekly Progress Report. Memorandum to S.R. Sapirie. (Expected and actual production quantities with comments on the operations of specific process areas.) Cincinnati, OH: National Lead Company of Ohio. 5 August 1960.

Karl, C.L. Unaccounted For Low Enriched Uranium - Plant 8. Letter to J. H. Noyes. (Re: memo from ORO dated 9 July 1964 from Sapirie to C.L. Karl). 14 July 1964.

Morgan, G.J. Idea Letter - Meter and Sampler for the Recovery Plant Effluent Stream (8-204). Memorandum to P.G. DeFazio. (During FY 1963 and 1964, a 121,200 pound discrepancy occurred in Recovery Plant enriched account.) National Lead Company of Ohio. 17 August 1964.

Nelson, M.S. Plant 5. Internal control of Nuclear Material, Crossover Problem. Inter-office Routing Slip to C.A. Schwan. 12 August 1970.

Nelson, M.S., National Lead Company of Ohio to C.L. Karl, US AEC Oak Ridge Operation Office, Memorandum; Summary of SS Inventory Samples and Analyses; ORO Nuclear Materials Control Branch; Safeguards survey No. 0R-267. 22 April 1970.

 Nelson, M. S. 25 November 1970. Material Discards, Plant Startup Through June 30, 1970. Memorandum to C. L. Karl. (Depleted, normal, enriched U SS kgs discarded FY 1952 FY 1970 for 3 categories: 1. to burial pit; 2-solutions or slurries to ponds or rivers; 3. dry stack or wet scrubber losses). National Lead Company of Ohio.

- Nelson, M. S. Summary from 1953 through 1972 of Materials Accountability. Memorandum to C. L. Karl. (Material balance, materials discards, over-all site accountability, 4 pages). Prepared by L. Courtney, National Lead Company of Ohio. 27 October 1972.
- Nelson, M. S. to C. A. Keller. Monthly Progress Report. (Technical and production activities and production statistics for January 1974, 14 pages). NLO/ICN 2197918. National Lead Company of Ohio. 5 February 1974.
- Nelson, M. S. to C. L. Karl. Monthly Progress Report (Technical and production activities and production statistics for May 1972, 9 pages). NLO/ICN 2150748. Cincinnati, OH: National Lead Company of Ohio. 5 June 1972.

NLCO (National Lead Company of Ohio). Records Inventory and Disposition Schedule for Scrap Recovery Plant of the Production Division. Cincinnati, OH: National Lead Company of Ohio. 24 June 1958.

- NLCO (National Lead Company of Ohio). Selected monthly production statistics for 1969. Table of production information for refinery, Plant 4, metals areas, Plant 8. Cincinnati, OH: National Lead Company of Ohio.
- NLCO (National Lead Company of Ohio). Material Balance Summary at FMPC. (From start-up through 1976 for (1)normal, enriched, depleted U, (2)summary of operating losses and discards (SS kgs), and (3) over-all site accountability. Table I V of unknown report, 5 pages). Cincinnati, OH: National Lead Company of Ohio. 25 August 1977.
- NLCO (National Lead Company of Ohio). History FMPC Inventories. NLO/ICN 2111339. 1973. (40 pages of monthly production for plants from 1954-1960; shipments & costs data). Cincinnati, OH: National Lead Company of Ohio.

-

÷...,

- Noyes, J.H. SS Materials Control Survey No. OR-156, Station NLO. Memorandum to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio. 20 March 1962.
- Noyes, J.H. Summary of SS Inventory Samples and Analyses. Memorandum to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio. 21 May 1969.
- Noyes J.H. Memorandum to C.L. Karl. Request for Approved Inventory Write-offs, Enriched Trailer Cake and Sump Effluent - FY 1962. (No attachments - request estimated maximum monthly discard of 2,000 SS pounds of enriched trailer cake and 250 SS pounds enriched sump effluent to chemical pit). Not dated but references letter of 16 June 1961. National Lead Company of Ohio.
- Noyes, J.H. to C.L. Karl, Memorandum; Materials Management and Safeguards Survey No. OR-259, National Lead Company of Ohio. 16 September 1969.
- Nuclear Materials Control Department. 15 November 1966. Summary of Operations and Other Reference Information. (20 pages of tables (most handwritten) of estimated analytical, weighing, sampling precision and bias, limit of error estimate for measured losses on monthly basis, overall B-Pid; material balance summary, 1964-66; enriched fuel core shipments and receipts, liquid UNH receipts from NFS). Prepared for U.S. AEC, DIA, Technical Advisory Committee on Safeguards, Washington, D.C.
- Palmer, W.E. Loss of enriched 0.94% enriched SS material. Memorandum to J.O. Davis. (Material balance for November 1960; loss of 1850 lb. from Pilot Plant). Cincinnati, OH: National Lead Company of Ohio. 23 December 1960.
- NLCO (National Lead Company of Oio). Over-all Accountability Analyses Report, Plant Startup Through. (Usually about 10 pages, incl. lists of beginning & ending inventories for normal, enriched, depleted U). We have 1976, 1984, 1986 as follows:
- Sapirie, S.R. SS Materials Accountability Survey No. OR-113 Station NLO. Report to C.L. Karl, Area Manager. (Survey of control over source and special nuclear (SS) materials by NLO made by AEC/ORO. This is fifth such survey.) Atomic Energy Commission, Oak Ridge Operations. 17 February 1958.
- Sapirie, S.R. SS Materials Control Survey No. OR-125 Station NLO. Report to C.L. Karl, Area Manager. (Survey of control over source and special nuclear (SS) materials by NLO made by AEC/ORO. Inspection of lab, review of analytical procedures and practices, scale calibration and testing program, sampling programs and evaluation of results; monthly production for plants including recovery operations). Atomic Energy Commission, Oak Ridge Operations. 18 February 1959.
- Sapirie, S.R. Normal Uranium Scrap Processing FY 1956 and FY 1957; Memorandum to E. J. Bloch. Cincinnati, OH: National Lead Company of Ohio. 27 November 1956.
- Sapirie, S.R. to E.J. Bloch, Memorandum; Normal Uranium Scrap Processing FY 1956 and FY 1957. Cincinnati, OH: National Lead Company of Ohio. 27 November 1958.
- Sapirie, S.R. Unaccounted for Low Enriched Uranium Plant 8. (Re: Unaccounted for quantity of 53,524 kg of low enriched U in Recovery Operation of Plant 8; this will be included in

. . . . .

N. N. Startstart

1 . 1 P .

0.

i.,

.....

and the second of

7. - 3.

June 1964 Material Balance Report). US Government Cincinnati Area Office to ORO. Cincinnati, OH: National Lead Company of Ohio. 9 July 1964. Stati Begenzario

Schwan, C.A. Comments on the Safeguards and Materials Management Survey Report No. OR-267-FVA. Memorandum to M.S. Nelson. Cincinnati, OH: National Lead Company of Ohio.

1011 210 11

· . .

Schwan, C.A. AEC Contact with Accounting Division. Memorandum to M.S. Nelson. Cincinnati, OH: National Lead Company of Ohio. 22 April 1970.

Spenceley, R.M. Over-all Accountability Analyses Report, Plant Startup Through September 30, 1984 Letter to M.R. Theisen. Cincinnati, OH: National Lead Company of Ohio. 14 1" , 17 i i i i i November 1984. .i and a state

Spenceley, R.M. Over-all Accountability Analyses Report, Plant Startup Through September 30, 1985. Letter to J.A. Reafsnyder. National Lead Company of Ohio. 20 November 1985. ger sheet of

SS Material Accountability Report Normal Uranium as of December 1961. (Beginning inventory, materials received, beginning inventory + receipts, materials removed, ending inventory, ending inventory + removals, Book-Physical Inventory differences [B-PID], prior period B-PID, 35 pages). P. N. McCreery, accountability representative.

SS Material Accountability Report Enriched Uranium (reactor-grade less than 75% U-235) as of December 1961. (Beginning inventory, material received, begin. inventory. + receipts, materials removed, ending inventory, ending inventory + removals, material unaccounted for, 16 pages). P. N. McCreery, accountability representative. National Lead Company of inter management Ohio.

SS Material Accountability Report Depleted Uranium as of December 1961. (Beginning inventory, material received, beginning inventory + receipts, materials removed, ending inventory, ending inventory + removals, Book-Physical Inventory Difference, 4 pages). P. N. McCreery, accountability representative. National Lead Company of Ohio.

- · · · an Chellettert · · · · · SS Material Accountability Report Thorium as of December 1961. (Beginning inventory, material received, beginning inventory + receipts, materials removed, ending inventory, ending inventory + removals, Book-Physical Inventory Difference [B-PID], prior period B-PID, 4 pages). P. N. McCreery, accountability representative. National Lead Company of Ohio. N-otu? .. ... 

Vath, J.E. to J.E. Hart, 17 October 1960. Request for Approved Inventory Write-offs, Normal and Enriched SS Materials -FY 1961: (AEC approval given for removal of 2,200 lb/mo. to stack & sewer losses, 9,400 lb/mo'to chemical pit, 600 lb/mo from pit to river.) National Lead Company of Ohio.

고려한 그는 한 것 같은 것 같이 것

the second second with the second second

VITRO, Handwritten inventory. Scrap Recovery-Vitro. 29 October 1959.

Je , hards? contined is from the first

Walden, C.H. SF Material in Plant 7. NLO-100736. Memorandum to F.L. Cuthbert. Cincinnati, OH: National Lead Company of Ohio. 18 July 1955.

· P 101 2 · .

Wunder, G. W. Monthly SS Material Balances - December 1956. Letter to C.L. Karl (AEC). 29 Carl Fail, Change de Cr X Be January 1957. 4. . .

Ę

111

そうしょうい

La KASAN

No.

がたいいい

5. . .

į,

ş

Wunder, G. W. Material Balance Reports for January 1956. Letter to C. L. Karl. (Includes procedure for determining measured stack losses). National Lead Company of Ohio. 13 April 1956.

1. 1.

1.17.14

Zupancic, L.J. Summary Audit Report Production Recording and Reporting and Nuclear Materials Control. Cincinnati, OH: National Lead Comapny of Ohio. Internal audit to C.L. Karl, U.S. Atomic Energy Commission. 2 December 1969.

## IT DOCUMENTS

- Bogar, L.C. & C. Hill to K. Ladrach, Answers to IT Corporation Questions Regarding Addendum to FMPC-2082. WMCO:PT:89-005. Cincinnati, OH: Westinghouse Materials Company of Ohio. 23 January 1989.
- IT Corporation. August 1989. Knoxville, TN., Project No. 303063, "Assessment of Radiation Dose and Cancer Risk for Emissions from 1951 Through 1984". Feed Materials Production Center, Fernald, Ohio.
- IT Corporation. December 1987. Knoxville, TN. "Radiation dose and risk assessment for the Feed Materials Production Center, Fernald, Ohio." (Draft Technical Report). Project No. 303063.
- IT Corporation. 1989. Knoxville, TN, Project No. 303063, "Radon dose and Risk Assessment for the Feed Materials Production Center". Appendix F of IT Report, "Assessment of Radiation dose and Cancer Risk for Emissions from 1951 through 1984.
- IT Corporation. 1987. Knoxville, TN. "Dispersion/radiation dose assessment modeling protocol for the Feed Materials Production Center", Fernald, Ohio.
- IT Corporation. October 1987. Knoxville, TN. "Radiation dose and risk assessment Modeling" Protocol for the Feed Materials Production Center", Fernald, Ohio. Project No. 303063.55.
- IT Corporation. 7 July 1986. Knoxville, TN. "Summary of air dispersion modeling for FMPC Facility." Project No. 303063.
- IT Corporation. 1986. Knoxville, TN. "Interim Report Air, soil, water, and health risk assessment in the vicinity of the FMPC, Fernald, Ohio."
- IT Corporation. 1987. Knoxville, TN. "Addendum to Interim Report Air, soil, water, and health risk assessment in the vicinity of the FMPC, Fernald, Ohio."
- Ladrach, K. S. (IT) & T. N. Tucker (Lee Wan & Associates, Inc.), Sampling and Evaluation of Supporting Documentation and Calculational methodology for Selected Items in WMCO Report No. FMPC 2082 and Addendum. Submitted to U.S. DOE. 23 May 1989.

#### K-65 SILOS AND MATERIALS/RADON

Anderson, R.V., Proposed Program for E-65 Sampling Study; Evaluate the reliability of the sample taken from the modified K-65 sampling facilities in the hot raffinate building. 07 December 1987.

## The Fernald Dosimetry Reconstruction Project <u>Tasks 2 and 3, Source Terms and Uncertainties</u>

Statistics.

1740 Ar 184

第二人

Anderson, R.V., Schematic of K-65 Reslurry System. 7 December 1987.

Bechtel (Bechtel National, Inc.). Study and evaluation of K-65 silos for the Feed Materials Production Center at Fernald, Ohio. Oak Ridge, TN: Bechtel National, Inc. January 1990.

Belmore, F.M. to C.L. Karl, Memorandum. Shipment of K-65 to Fernald Area. 01 August 1951.

Blythe D.J. Letter to G.W. Wunder, New York, NY: National Lead Company. 13 September 1951.

Boback, M.W. Plans For FMPC Radon Monitoring And Control. Memorandum to R.C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. 14 May 1979.

Boback, M.W. Gamma levels inside K-65 tank. Cincinnati, OH: National Lead Company of Ohio. Internal memorandum to R.C. Heatherton. 11 September 1978.

Boback M.W. K-65 Storage Tanks. Internal memorandum to J.H. Cavendish. Cincinnati, OH: National Lead Company of Ohio. 20 May 1980.

Bogar, L.C. 24 January 1989. Report on the question of gamma build-up due to the introduction of sand into the K-65 domes. Response to inquiry by N. Cohen, New York University Medical Center. WMCO:SR(WR):89-007. Appendix E. of FMPC Environmental Safety & Health Advisory Committee Report. Cincinnati, OH: Westinghouse Materials Company of Ohio.

Borak, T. B. "Calculation of Radon Emission, Dispersion, and Dosimetry from K-65 Storage Tanks at the Feed Materials Production Center". Appendix A of History of FMPC
Radionuclide Discharges, FMPC-2082. Fort Collins, CO: Colorado State University. October 1985.

Borak, T.B. Reply to Comments By the EPA Concerning Appendix I in History of FMPC Radionuclide Discharges. (Comments to questions regarding how source term was estimated). Fort Collins, CO: Colorado State University. June 1986.

Camargo Associates, Limited. 1985. NLO, Inc. K-65 Silos Study and Evaluation, Fernald, Ohio. (Study to determine "effective alternatives for processing and removal of radium-bearing residues" currently in silos; did test borings of soil; used subsurface ground radar of K-65 berm). 1986.

Camargo Associates, Limited. K-65 Silos Study & Evaluation for NLO, Inc. Volume I Sections I through IX. 26 page report. 7 November 1985.

Church, A. Jr. K-65 Sampling Experiment. Memorandum to J.S. Breitenstein. Cincinnati, OH: National Lead Company of Ohio. 12 October 1953.

Consiglio, J.T. to Files NY00, Memorandum; Report of meeting RE: Radium Measurements i Pitchblende Ore and Sludges; 26 June 1953.

Davis P. K-65 Startup. Internal memorandum to R.C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. 19 July 1952.

一、新学、教育、学校主要的工具的主义

## Appendix A

· .

2

#### Sources of Information

- EG&G. Report on Radon, EG&G Aerial Survey, Areas of Anomalous Gamma Radiation in Paddy's Run Creek. 1986. NLO/ICN 2207965.
- Fleming K.N. Survey of the K-65 Area Friday, April 18, 1986. Internal memorandum to S.L. Hinnefeld. WMCO:EH(HP):86:0086; Cincinnati, OH: Westinghouse Materials Company of Ohio; 18 April 1986.
- GAP (Government Accountability Project). Wasting Away, A special report on governmental neglect of the "K-65" radioactive waste at Fernald. (Includes large number of attachments). Washington, D.C.: Government Accountability Project;February 1987.
- Gels, G. L. 1190. Radon Data at Air Monitoring Station-6. (Two weeks of radon conc. on hourly basis with Pylon real-time Rn monitors & Terradex alpha detectors, 3 pages). WMCO:EMT(EM):90-0552. 12 September 1990.
- Green, L. E. K-65 Radon Emanation, Summary of Preliminary Data: Memorandum to M.W. Boback. Cincinnati, OH: National Lead Company of Ohio. 18 August 1980.
- Grumski, J. T. (WMCO), Conceptual Design Report (CDR) K-65 Storage Silo Radon Mitigation and Dome Reinforcement Study, 50 pages. 14 April 1987.
- Grumski, J. T. 30 July 1987. Feasibility Investigation for Control of Radon Emission From the K-65 Silos. (83 pages, includes appendix with analysis of potential and probable accidents occurring at K-65). Westinghouse Materials Company of Ohio.
- Grumski, J. T. & P. A. Shanks. 4 February 1988. Completion K-65 Interim Stabilization Project Exterior Foam Application/Radon Treatment System Operation, WMCO: TD:88-056, 74 pages.
- Heatherton, R.C. to W.J. Adams, Memorandum; Improvements needed at the K-65 tanks; Radon-222 from the decay of radium-226 in the residues wil stream from any opening. Each of the K-65 storage tanks has several openings from which radon can escape. Cincinnati, OH: National Lead Company of Ohio. 26 April 1979.
- Heatherton, R.C. to J.A. Quigley, Memorandum; Radiation Survey of K-65 Test Shipment; 08 September 1952.
- Heatherton, R.C. 26 April 1979. K-65 Tank Improvements. Memorandum to W.J. Adams. National Lead Company of Ohio.
- Hinnefeld S.L. Radium-226 in K-65 tanks. Internal memorandum to M.W. Boback. Cincinnati, OH: National Lead Company of Ohio; 21 June 1982.

Huke, F.B. to Evans, R., Memorandum; K-65 Sludge Radium Assays; 26 March 1963.

Huke, F.B. to Evans, R., Memorandum; K-65 Sludge Radium Assays; 06 July 1963.

IT Corporation, Knoxville, TN, Project No. 303063, "Radon dose and Risk Assessment for the Feed Materials Production Center". Appendix F of IT Report, "Assessment of Radiation dose and Cancer Risk for Emissions from 1951 through 1984. 1989.

÷

 $\overline{\mathbb{M}}$ 

٤.,

.

10.00

Ŀ

- Jensen, L., Radon-222 air samples taken on and near the FMPC, September 25, 1985. US EPA, 10 pages. NLO/ICN 2302246. 24 October 1985.
- K-65 Sampling Study; Ship USA-C-4; Chem K-65; B-64AT-0004; Handwritten date and time log; February 1954.

Karl, C.L. Radium analyses in K-65 sampling test. Memorandum to G.W. Wunder. (C.J. Rodden of New Brunswick Laboratory is prepared to analyze for radium in samples during K-65 experimental run). Cincinnati, OH: National Lead Company of Ohio. 25 January 1954.

Karl, C.L. 30 October 1956. Pitchblende - Q-11 Processing Problems. Memorandum to S.R. Sapirie, ORO. (Difficulties in processing Belgian Congo pitchblende). Fernald Area, US Government.

Keys, R.W. 28 August 1985. Advice About Radon Measurements at K-65 Silos. Record of phone conversation with Tom Borak, Colorado State University. (For advice on estimating source term for Rn and daughters from silos). DOE Contact Report, National Lead Company of Ohio.

Keys, R.W. 28 August 1985. Radon Measurement at K-65 Silos. Record of phone conversation with C.W. Miller. (For advice on estimating source term for Rn and daughters from silos). DOE Contact Report, National Lead Company of Ohio.

Keys, R.W. 27 August 1985. Mansanto-Mound Report #MLM-MU-85-68-0001, Radon and Radon Flux Measurements at the Feed Materials Production Center. Record of phone conversation with W. Cottrell, ORNL Radiological Survey Activities Group. (Implications of the report in terms of request by Hibbets for source term for K-65). DOE Contact Report, National Lead Company of Ohio.

Leist, M.L., Handwritten note; A Typical MCW Raffinate (Dried Basis); 20 August 1968.

Levy, L.M., K-65 Sampling Study in the Hot Raffinate Area; 13 page draft report plus experiment tables; 1973.

Litz, J.E. 30 May 1974. Treatment of Pitchblende Residues for Recovery of Metal Values. Report of project for Cotter Corporation, Canon City, Colorado. Hazen Research, Inc. (Study recovery of the metals in pitchblende residues from Lewiston, NY and Fernald).

Lukens, R.P. and J. W. Delaplaine, Catalytic Construction Company; 12 page report; Hot Raffinate Treatment - Process Design; 6 July 1951.

- Lynch J.R. Q-11 Campaigns. (Summarized production information for Q-11 campaigns). Cincinnati, OH: National Lead Company of Ohio. circa 1955.
- Madoffori J. K-65 Inventory. Internal memorandum to P.C. Feist. Cincinnati, OH: National Lead Company of Ohio; 29 September 1955.

Madoffori J. K-65 Inventory. Internal memorandum to P.C. Feist. Cincinnati, OH: National Lead Company of Ohio, 28 October 1955.

Madoffori J. K-65 Inventory. Internal memorandum, to P.C. Feist; Cincinnati, OH: National Lead Company of Ohio. 29 November 1955.

Page A-97

- Martin, H. K-65 storage tanks. Internal Memorandum to A. Stewart. Cincinnati. OH: National Lead Company of Oho; 8 November 1957.
- Mihalovich, G.S. Report on the Question of gamma build-up due to the introduction of sand into the K-65 domes. Report to L.C. Bogar regarding questions from N. Cohen, New York University Medical Center. See letter, Bogar, 24 January 1989 in K-65/Radon section.

Morgan, J.P. K-65 Sludge Radium Assays. Memorandum to R.D. Evans. Cincinnati, OH: National Lead Company of Ohio; March 1952.

- Morgan, J.P. K-65 Sludge Radium Assays; Memorandum to R.D. Evans. Cincinnati, OH: National Lead Company of Ohio; 21 December 1950.
- Morgan, J.P. K-65 Sludge Radium Assays; Memorandum; to R.D. Evans. Cincinnati, OH: National Lead Company of Ohio; 7 March 1951.
- Morgan, J.P. K-65 Sludge Radium Assays; Memorandum to R.D. Evans. Cincinnati, OH: National Lead Company of Ohio; March 1951.
- Morgan, J.P. K-65 Sludge Radium Assays; Memorandum to R.D. Evans; Cincinnati, OH: National Lead Company of Ohio; 3 May 1951.
- Nelson M.S. K-65 area Survey results and actions. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 10 March 1972.
- Nelson M.S. U content of silos. Letter to C.A. Keller. National Lead Company of Ohio; 21 September 1972.
- NLCO (National Lead Company of Ohio). Elemental Constituents of FMPC Silos; Table showing constituent for Silos 1,2 and 3; 700001A; No date.

Noyes J.H. 1958. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 25 September 1958.

Noyes J.H. Progress photographs on protective work at K-65 tanks. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 1 May 1964.

- Quigley, J.A. Request for Survey at K-65 Storage Area. Memorandum to G.W. Wunder. Cincinnati, OH: National Lead Company of Ohio. (Short note regarding request through Mr. Damewood of local AEC office to check valves and piping; radiation measurements low but no data listed). 24 October 1952.
- Ross, K.N. Storage of Residues From Processing Radium-Bearing Ores. Memorandum to R.C. Heatherton. Cincinnati, OH: National Lead Company of Ohio; 17 July 1957.
- Shanks, P. A. and R. A. Vogel, The K-65 Waste Storage Silos at the Feed Materials Production Center. FMPC-2142. For presentation at the DOE Model Conference, Oak Ridge, TN, October 3-7, 1988. (Describes history of silos, deterioration and remedial actions taken, 10 pages, no tables or figures). Cincinnati, OH: National Lead Company of Ohio. September 1988

Page A-98

. . <sup>\*</sup>. î

1 . . . .

1

1

Elex int

2

Š

.

i:

Ż

- Shanks P. Spreadsheet table of K-65 silo temperature and pressure monitoring data taken March to May, 1987. Personal communication to D.W. Schmidt for Radiological Assessments Corporation; 25 April 1991.
- Schumann, C.E. Industrial hygiene survey of K-65 dumping operations. Memorandum to R.C. Heatherton. (Analytical data sheets of operation of air dust in dpm/cubic meter). Cincinnati, OH: National Lead Company of Ohio. 27 March 1953.
- Shaw, W.E. to J. E. Cirvitti and A.R. Lynch, Memorandum; Analytical Data of Silo Material; Cincinnati, OH: National Lead Company of Ohio. 24 Mary 1968.
  - Smith, R.J. Jr. K-65 Sludge Radium Assays; Memorandum to R. Evans. Cincinnati, OH: National Lead Company of Ohio; 11 June 1952.
  - Smith, R.J. Jr. K-65 Sludge Radium Assays; Memorandum to R. Evans. Cincinnati, OH: National Lead Company of Ohio; 24 June 1952.
  - Smith, R.J. Jr. K-65 Sludge Radium Assays. Memorandum to R. Evans; Cincinnati, OH: National Lead Company of Ohio; 12 August 1952.
- Smith, R.J. Jr. K-65 Sludge Radium Assays; Memorandum to R. Evans; Cincinnati, OH: National Lead Company of Ohio; 19 September 1952.
- Smith, R.J. Jr. K-65 Sludge Radium Assays. Memorandum to R. Evans; Cincinnati, OH: National Lead Company of Ohio; 20 November 1952.

Sec. 347-6 175

- Stief, S.S. Data on radium contents of DOE residues. Letter to D. Goldin. Safety and Environmental Control Division, US DOE. 27 December 1983. er Stef nava£ truge.
- Strattman W.J. Storage tanks for K-65. Internal memorandum to D. J. Blythe. Cincinnati, OH: National Lead Company of Ohio; 12 November 1953.

. 2

- Strattman W.J. K-65 dumping operation K-65 area. Internal memorandum to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio, 6 April 1955. .0961.5
- Upchurch, T.B. Domestic Pitchblende Radium-Bearing Residues. Memorandum to J.W. Ruch. (African Metals Corporation approved request to add 22 tons of domestic pitchblende to K-65 silos). Division of Raw Metals, US Government. 15 July 1958. and the constraint strategy of • •
- Wing. J.F. Material from Storage Tanks. Cincinnati, (Response to questions regarding health and safety aspects of removing K-65 material from the two storage tanks at west edge of project).OH: National Lead Company of Ohio, 22 April 1958. ann.

1 N. 1

Wolf, R.B. to C.R. Chapman, Memorandum; Sampling K-65 Slurry - Campaign No. 1; 27 September 1956.

5. . . .

Wunder G.W. Preload concrete storage tanks. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 23 August 1954.

### LIQUID EFFLUENTS AND GREAT MIAMI RIVER

Í.

61.1

- Alexander, J.K. to Safety & Environmental Control Division Files, Memorandum; Telephone conversation 2/27/78 with Ed Didomenico, USEPA Region V, Regarding NLO NPDES Response; 27 February 1978.
- Audia, S.F. to H.D. Fletcher, Memorandum; Report of Nonconpliance with NPDES Permit No. OH 0009580; a leak in a dilute hydrofluoric acid line; residual fluoride left in ground in the spill area; National Lead Company of Ohio; 2 December 1977.
- Bogar, L.C. Effluent Radiation Report FMPC August 1987. Letter to to J.A. Reafsnyder (US DOE). WMCO:EH (EC): 87-0530. Cincinnati, OH: Westinghouse Materials Company of Ohio. 14 September 1987.
- Bogar, L.C. Trends in Effluent Water Quality. Letter to J.A. Reafsnyder (US DOE). WMCO:EH (EC): 87-0555. Cincinnati, OH: Westinghouse Materials Company of Ohio. 28 September 1987.
- Bogar, L.C. Trends in Effluent Water Quality Source of Increased Gross Beta Activity. Letter to J.A. Reafsnyder (US DOE). WMCO:EH (EC): 87-0620. Cincinnati, OH: Westinghouse Materials Company of Ohio. 4 November 1987.
- Boback, M.W. Radioactivity in MH-175. Memorandum to R.H. Starkey. (Tc-99, Ru-106, Ra-228 levels in MH-175, Mar-April 1969). National Lead Company of Ohio. 6 June 1969.
- Chapman, C.R. Revised estimate of transuranics in liquid effluent. Letter to H.D. Fletcher. (Revised pages for NLCO-1130, Environmental assessment of the processing of reactor recycle materials containing transuranic elements). Cincinnati, OH: National Lead Company of Ohio; 19 February 1976.
- Cuthbert, F.L. Cooperative Analysis of Sewer Effluents and Standards. Memorandum to J.A. Quigley. NLO/ICN 2130720. Cincinnati, OH: National Lead Company of Ohio. 26 November 1956.
- Eye, J.D. Proposal of Mr. Alexander Denagi for studying "The Kinetics of Radioactivity Redistribution in the Miami River Following Waste Disposal from Nuclear Fuel Processing." Letter to J.A. Quigley. 18 November 1960.
- Flowers, D.L. Comparison of State NLO Analytical River Samples. Memorandum to R. L. Fischoff. (Compared data for June 1961; gives only aver conc.; total activity in measured by NLO 60% of that measured by state). Cincinnati, OH: National Lead Company of Ohio; 23 February 1961.
- FMPC Engineering Division Drawing No. G-5016. Plant of Production Area: Probable sources of contamination. (Drawing showing numbered manholes and CBs). National Lead Company of Ohio. 4 August 1959.
- Glass, D.W. Radium Losses to Miami River. Memorandum to C.H. Walden. NLO/ICN 2130422. Cincinnati, OH: National Lead Company of Ohio. 19 April, 1954.
- Heatherton, R.C. Review of needs for water sample analyses. Memorandum to J.A. Quigley. (Meeting for discussing current need for water samples and analyses on samples from MH

Page	A-100
------	-------

-

ž

20

175, river, Paddy's Run, chemical pit, storm sewer, test and production wells.). Cincinnati, OH: National Lead Company of Ohio; 30 January 1969.

Lynch, D.E. Soil and Water Uranium and Radium Survey Progress Report. (Results of soil and water survey made during 1949 at Lake Ontario Ordnance Works, NY, Middlesex Sampling Plant, NJ, Harshaw chemical Works, Cleveland, Ohio, and AEC storage area at Lambert Airport, St. Louis. Some soil sample data from USGS taken in 1948 at St. Louis and radium in Mississippi River water collected near the Mallinckrodt Works by J.J. Koenig and K.J. Caplan; document in Soil and Sediment section). NLO/ICN 2186759. NYO-1521. New York Operations, Office Health and Safety Division, U.S. Atomic Energy Commission. 20 June 1950.

NLO. 1974. Worksheets for 1974 Radioactive Effluent and Onsite Discharge Data Report. (Handwritten, lists liquid effluent releases for MH 175, storm sewer outfall, airborne effluent releases for U, th, radium; discards to Pit 5).

Pennak, S. 14 August 1973. Liquid Effluent Review. (25 pages, incl maps & diagrams, no analytical data). NLO/ICN 2260867. National Lead Company of Ohio.

Quigley, J.A. Monthly Report of Industrial Wastes to Department of Health, State of Ohio. Letter to B. McDill. ( of river flow, vol waste discharged to river, calc U conc. and measured U conc in river; and sewage treatment flow, etc). We have reports for Mar, June, July 1961.

Reafsnyder, J.A. Radioactivity and Uranium in the Liquid Effluent - Feed Materials Production Center - June 1987. Letter to T.A. Winston (Ohio EPA). DOE 422-87. 5 August 1987.

Reafsnyder, J.A. Radioactivity and Uranium in the Liquid Effluent - Feed Materials Production Center - August 1987. Letter to T.A. Winston (Ohio EPA). DOE 422-87. 18 September 1987.

Reafsnyder, J.A. Radioactivity and Uranium in the Liquid Effluent - Feed Materials Production Center - September 1987. Letter to T.A. Winston (Ohio EPA). DOE 50-88. 16 October 1987.

Reafsnyder, J.A. Trends in Radioactivity in Effluent Water - Feed Materials Production Center (FMPC). Letter to L.C. Bogar. DOE 176-88. Cincinnati, OH: US DOE. 23 November 1987.

Ross, K.N. 13 April 1967. Standard River Flow Dilution Figures. Memorandum to R. H. Starkey. (proposes average flow of 700,000 gal/day with average dilution factor of 4600 to 1). National Lead Company of Ohio.

Ross, K. March 1970. Curies per Year Lost in Liquid Effluent. Handwritten notes to Mike for 1967, 1968, 1969 effluent losses.). National Lead Company of Ohio.

Several types of monthly reports regarding liquid effluents. These include Fischoff, R.L. Comments on Monthly River and Effluent Flow. Memorandum to R.H. Starkey. (Narrative and data for river flow, plant effluents and calculated river concentrations, Miami River, Paddy's Run). We have reports for January, February, April-December 1960; January-August 1961; September- December 1959;

Starkey, R.H. Discharge of Liquid Wastes Into The River. Memorandum to J. Hart. (Daily discharge report of liquid wastes for Sanitary Sewer, Storm Sewer, and MH-175 with U concentrations). We have October-December 1959; February, April, May, July-December 1960; January-Aug 1961.

1

12

.

- Starkey, R.H. 31 July 1961. Discharge of Liquid Wastes into the River. Memorandum to J.H. Hart. (Daily totals of gal/day & ppm U to MH 175, sanitary sewer, storm sewer; from pit 3). National Lead Company of Ohio.
- Starkey, R.H. 9 November 1965. Minutes of Informal Meeting on Liquid Effluent. Memorandum to E.B. Riestenberg.
- Twitty, B.L. and H.W. Humphrey, NLCO-970, Summary Technical Report for period October 1, 1967 to December 31, 1965; The Determination of Beta Activities in Plant Effluents; Two methods were devised for determining the beta activity of plant effluents containing uranium and thorium decay products.; February 1966.
- Uranium in Liquid Effluents in Storm Sewer Lift Station, Storm Sewer Outfall, Clearwell. Analytical Data Sheets. 1979, 1980. Available in Central Files and at NLO.
- Weinmann, C.O. Sewer Effluent Standards and Samples. Memorandum to E.L. Alpaugh. (Series of standards were prepared containing 1-10 ppm U and submitted with regular sewer effluent samples to both H&S and Analytical Labs onsite, and to Oak Ridge and New Brunswick Laboratories for analysis). NLO/ICN 2130723. Cincinnati, OH: National lead Company of Ohio. 16 November 1956.

#### NPDES AND LIQUID EFFLUENT DISCHARGE REPORTS

- Audia, S. F. NPDES Analysis Procedures. Letter to J. F. Wing, U.S. Energy Research & Development Administration, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2115048. 16 May 1977.
- Audia, S. F. NPDES Monitoring Report for Fourth Quarter, 1977. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2122519. 2 February 1978.
- Audia, S. F. NPDES Monitoring Report for First Quarter, CY-1978. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2122515. 18 April 1978.
- Audia, S. F. NPDES Monitoring Report for Second Quarter, CY-1978. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2122514. 12 July 1978.
- Audia, S. F. NPDES Monitoring Report for Third Quarter, CY-1978. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2122512. 18 October 1978.
- Audia, S. F. NPDES Monitoring Report for Fourth Quarter, CY-1978. Letter to H. D. Hickman, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2122507. 23 January 1979.
- Audia, S. F. NPDES Monitoring Report for Second Quarter, CY-1979. Letter to H. D. Hickman, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2122497. 3 August 1979.

Page A-102

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

Audia, S. F. NPDES Monitoring Report for Third Quarter, CY-1979. Letter to H. D. Hickman, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2122496. 26 October 1979.

Audia, S. F. NPDES Monitoring Report for Fourth Quarter, CY-1979. Letter to H. D. Hickman, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2122493. 18 January 1980.

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2115023. 20 October 1977.

, e.,

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2115000. 16 January 1978.

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114996. 14 March 1978.

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114971. 17 March 1978.

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114972. 17 March 1978.

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114973. 17 March 1978.

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114975. 20 April 1978.

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114976. 1978.

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. D. Fletcher, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114978. 29 June 1978.

. 211

. . . .

Audia, S. F. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to H. Hickman, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114953. 7 February 1980.

Boback, M. W. Violation of NPDES Sampling Schedule Requirements. ERDA Contact Report to J. K. Alexander. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2115001. 16 January 1978. 2

÷,

1.

20

10 m

Page A-103

- Booth, R. L. Technical Additions to Methods for Chemical Analysis of Water and Wastes. Cincinnati, OH: Environmental Monitoring and Support Laboratory. NLO/ICN 2114898. December 1982.
- Hart, R. J. Feed Materials Production Center, Fernald, Ohio: NPDES Permit No. OH0009580, Findings and Notice of Violation and Order for Compliance (Docket No. V-W-78-A0-16). Letter to G. Alexander, U.S. Environmental Protection Agency, Chicago, IL. Oak Ridge, TN: Department of Energy. NLO/ICN 2115016. 7 December 1977.
- Heatherton, R. C. Draft Proposed NPDES Permit. Memo to W. J. Adams, E. M. Nutter, S. F. Audia, R. M. Spenceley, M. W. Boback, T. A. Dugan, W. C. Hill, J. Farr, L. Pennington, C. E. Polson, and J. D. Pope. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114943. 28 July 1980.
- Heatherton, R. C. Reports for April, May, and June 1976 for Radioactivity and Uranium in Liquid Effluent from the ERDA Feed Materials Production Center, Fernald, OH. Letter to Ohio Environmental Protection Agency. NLO/ICN 2112351. 12 July 1976.
- Hill, W. C. Indiscriminate Discharge of Hexavalent Chromium Compounds. Memo to Division Directors. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114939. 15 June 1981.
- Riestenberg, E. B. FMPC Wastewater Discharge. Memo to A. F. Pennak. NLO/ICN 2115035. 1 August 1977.
- Riestenberg, E. B. Noncompliance with NPDES pH Limit--Storm Sewer Outfall--March 2, 1977. Memo to A. F. Pennak. NLO/ICN 2115059. 11 March 1977.
- Spenceley, R. M. Clearwell Pumping Volume--NPDES. Memo to Attendees-Meeting of September 21, 1983 (M. W. Boback, J. Farr, W. C. Hill, G. E. Koch, N. R. Leist, L. Pennington, W. J. Neyer, E. M. Nutter, and J. B. Patton). Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114912. 22 September 1983.
- Spenceley, R. M. DOE Contact Report, J. Alexander to D. Fleming, NPDES Compliance Inspection by Ohio EPA, dated June 10, 1985. Letter to J. A. Reafsnyder. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2113938. 6 September 1985.
- Spenceley, R. M. NPDES Laboratory Performance Evaluation. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114859. 11 April 1985.
- Spenceley, R. M. Report on Noncompliance with NPDES Permit No. OH 0009580. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114930. 15 October 1982.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH 0009580. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114909. 12 December 1983.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

1

*....* 

Ż

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-4. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114885. 20 March 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 855. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114884. 20 March 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 856. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114858. 23 April 1985.

 Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85 7. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114857. June 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-9. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114854. 16 August 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-10. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114855. August 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-11. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114853. 5 September 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-12. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114852. 10 September 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-13. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114845. 30 October 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-14. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114844. 8 November 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-15. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114843. November 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-16. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114842. 16 November 1985.

Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-17. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114841. 18 November 1985.

Sec. 265

2

- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-18. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114838. 21 November 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-19. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114835. 13 December 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-20. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114836. 10 December 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-21. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114837. 10 December 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580: Report No. 85-22. Letter to J. A. Reafsnyder, U.S. Department of Energy, Cincinnati, OH. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114834. 17 December 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for November 1983. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114908. 18 December 1983.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for March 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114905. 11 April 1984.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for April 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114903. 14 May 1984.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for May 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114902. 11 June 1984.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for June 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114901. 15 June 1984.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for June 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114866. 11 July 1984.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH 0009580 for July 1984. Letter to M. R. Theisen, Department of of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114874. 24 August 1984.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for October 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114872. 8 November 1984.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

1:

- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for November 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114871. 13 December 1984.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for December 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114869. 4 January 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for December 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114870. 4 January 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for December 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114868. 7 January 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for December 1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114883. 16 January 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for January 1985. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114881. 4 February 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for January 1985. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114878. 13 February 1985.
- Spenceley, R. M. Report of Noncompliance with NPDES Permit No. OH0009580 for February 1985. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114876. 26 February 1985.
- Spenceley, R. M. U.S. EPA NPDES Reports for the Third Quarter of CY-1984. Letter to M. R. Theisen, Department of Energy, Oak Ridge, TN. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114873. 22 October 1984.
- Theisen, M. R. NPDES Compliance Inspection. Letter to R. M. Spenceley, National Lead Company of Ohio, Cincinnati, OH. Oak Ridge, TN: Department of Energy. NLO/ICN 2114900. 23 March 1984.
- Travis, W. H. Recurring NPDES Violations, Portsmouth Gaseous Diffusion Plant and Feed Materials Production Center. Letter to D. Wallgren, U.S. Environmental Protection Agency, Chicago, IL. Oak Ridge, TN: U.S. Energy Research and Development Administration. NLO/ICN 2122441. 8 January 1976.
- Weidner, R. B. NPDES Limits and 1985 Noncompliance. Memo to D. G. Howell. Cincinnati, OH: National Lead Company of Ohio. NLO/ICN 2114839. 18 November 1985.
- Wing, J. F. NPDES Regulation of Source, Special Nuclear or By-Product Material. Letter to J. Newman, U.S. Environmental Protection Agency, Chicago, IL. Oak Ridge, TN: Department of Energy. NLO/ICN 2122491. 24 April 1980.

ۇ ي

÷.

**.** : <sup>:</sup>

#### Page A-107

## OHIO EPA & AGRICULTURAL REPORTS

- 1974 June, daily effluent samples from Manhole 175, Great Miami River at New Baltimore and at Ross.
- Ohio Department of Agriculture. 1990 Ohio Agricultural Statistics and Ohio Department of Agriculture Annual Report. Compiled by Ohio Agricultural Statistics Service. Columbus, OH: Ohio Department of Agriculture. 1990.
- Ohio Department of Agriculture. State of Ohio Department of Agriculture 1991 Annual Report and Agricultural Statistics. Compiled by Ohio Agricultural Statistics Service. Columbus, OH: Ohio Department of Agriculture. 1991.
- Ohio Department of Agriculture. State of Ohio Department of Agriculture 1992 Annual Report and Agricultural Statistics. Compiled by Ohio Agricultural Statistics Service. Columbus, OH: Ohio Department of Agriculture. 1992.
- Steva, D. P. Ohio Department of Health Study of Radioactivity in and other Environmental Media in the Vicinity of the U.S. Department of Energy's Feed Materials Production Center and Portsmouth Gaseous Diffusion Plant. (Extensive study of over 100 pages, 4 appendices of measurements of U in soil & drinking water; radon in homes, water, outdoor; direct radiation). Columbus, OH: Ohio Department of Health. December 1988.

## OPERATING LOSSES

- Ericson, M. Routine Operating Losses of SS Material from the Production Stream, May 25 through June 24, 1965. Report to J.H. Noyes. 8 July 1965.
- Galper M. 27 October 1988. Tabulation of Data on Historical Emissions from FMPC. Memorandum to Bryan Speicher and Len Elikan. (Summary of uranium discharge estimates prepared for FMPC personnel to provide single, consistent basis for discussions with outside agencies). Westinghouse Materials Company of Ohio.
- Harrell, E. M. to A. Soldano, 16 March 1956. High "U" loss in trailer residue and filtrate. National Lead Company of Ohio.
- McCreery, P.N. 3 May 1961. Measured Losses and Removals of SS Materials From the Production Stream, FY-1962. Memorandum to C.R. Chapman and F.L. Cuthbert. National Lead Company of Ohio.
- McCreery M.C. Measured Losses and Removals of SS Materials from Production Stream FY 1961. Memorandum to C.R. Chapman. (Average discard limits in lbs per month given for normal, enriched materials).Cincinnati, OH: National Lead Company of Ohio. 22 June 1960.
- Measured Losses and Removals of SS Material From the Production Stream. (Name of this report changed to Routine Operating Losses in 1965). Cincinnati, OH: National Lead Company of Ohio.
  - 1953-1958, handwritten ledger sheets with monthly totals. 1960 except February, March, August, November; 1961 except October, November, December;

Page A-108

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

÷., -

<u>ن :</u>

1962, handwritten ledger sheets with monthly totals. 1963 except January, Mar-September. 1967 through 1986. in Tutstan.

Monthly Operating Loss Reports - FY 53 through FY66, FY 69 - FY 70 - Handwritten Log sheets (8 pages, for normal, enriched, depleted U losses to general sump, stacks, scrubbers, chemical pit, dry pit, sewer and Total). Cincinnati, OH: National Lead Company of Ohio. 

Nelson, M.S. 5 February 1971. Radioactive Effluent Release, Monitoring, and Control. Letter to C.L. Karl. (Tables contain estimates of plantwide releases for 1969 to air and liquid effluents; narrative description of release pts; inventories of 1969 inplant releases). National Lead Company of Ohio. Cincinnati, OH: National Lead Company of Ohio.

Routine Operating Loss Reports. (Official summary reports of losses to stacks, pits, general sump, sewer, river; prior to 1965 called Measured Losses and Removals of SS Material From the Production Stream). Cincinnati, OH: National Lead Company of Ohio. Have Aug 1977, Jul 1978, Jul 1980.

. . . . . . .

1965, have only June;

1966, have Jun, Jul, Aug, Sep, Oct, Nov, Dec;

1967, have entire year;

1968, all except May;

1969, have only Jan-May;

1970, have only Apr, May, Jun.;

and any frequencies of the product of the

1971 - 1980

5

: 5

÷ŧ

en terre Summary of Operating Losses (SS pounds) and Material Balance: FY 1963 & 64 - Handwritten log sheets, material balance included;FY 1962-1970 - Handwritten log summary sheet for depleted, normal, enriched U to stack, burn pit, sewer, general sump, pit, scrubber & Total.FY 1961-1962 - Handwritten log summary sheet for normal and enriched U to pit, stack & sewer. the planet set of the set of th Left for public of the state

PARTICLE SIZE

Analytical Data Sheet (11-19-70) - Plant 8 Kiln, Analysis of particle size above and below 10 microns for 2 samples. (1. 70% < 10 microns; 2. 95% of particles < 10 microns). 14 January 1971.

and the state of the

· · · · · Boback, M.W. 10 April 1985. Particle Size of Uranium compounds. DOE Contact Report of Conversation with W. Hibbitts. Refers to and includes memo from Koch to Herman of April 

Cavendish, J.H., H.M. Beers and M. A. DeSesa. November 1962 (revised April 1961). Hydrometallurgical Processing of Uranium -Bearing Residue Materials to UF4. Prepared for presentation at the symposium on Unit Processes in Hydrometallurgy, National Meeting of American Institute of Mining, Metallurgical and Petroleum Engineers. National Lead Company of Ohio. a state of the attention of the state of

The state of the second second state of the second s

Fleming, D.A. to R. B. Weidner, Particle Size Characterization of Stack Samples, NLO/ICN 2115999. 6 August 1985.

A suggest of a filter of the prove that a sufficient of a structure of the sufficient of

Freitag, J. 27 September 1962. Particle size Analysis - A Comparison of Four Methods. (Coulter counter method, direct measurement from photomicrographs, micromerograph, Andreson

Page A-109

pipette and liquid scintillation technique used on UO3, MgF, UF4 from Winlo Process; discussion of particle shape and orientation). Technical Division, National Lead Company of Ohio.

- Hilbert, R. H. & A. F. Volesky, Laser Diffraction Particle Size Analysis of Powders. FMPC-2077 Topical UC-4. (16 pages, Malvern Instruments Particle Sizer 3600Ec used to check NBS standards and U3O8 dust collector residue). October 1987.
- Koch, G.E. 9 April 1985. Particle Size Distribution of Typical Current UO3, UF4, and MgF2. Memorandum to D.L. Herman. National Lead Company of Ohio. (See Boback DOE Contact Report, 10 April 1985).
- Koch, G.E. 17 April 1985. Particle Size Distribution of Dust Collector Material. Memorandum to D.L. Herman. National Lead Company of Ohio.
- Mercer T.T. 1976. The Role of Particle Size in the Evaluation of Uranium Hazards. (References 1959 paper by Hyatt et al. in Amer. Ind. Hyg. Assoc. J. on particle size studies on uranium aerosols from machining and metallurgy operations). NLO/ICN 2232357. The University of Rochester, Rochester NY.
- Northern Kentucky Environmental Services, A Study of the Particle Size Distribution of the Stack Emissions. 31 Oct 1985.
- Reed, K.P. A Study of the Emissions of the Process Stacks at NLO: Plant #9, Plant #5-260, Plant #5-261. Covington, KY: Northern Kentucky Environmental Services. 26 March 1985.
- Ruhe, R.L. Air Dust evaluation of particle size analysis, Plant 5 Building 55. Memorandum to K.N. Ross. (Air dust sample results collected during particle size analysis of mag. fluoride after new ventilated enclosure eas installed in Bldg 55 control room.) Cincinnati, OH: National Lead Company of Ohio. 8 March 1962.

Spenceley, R. M. to J.A. Reafsnyder, Partial Data for Major Emission Stacks - Second Report. NLO/ICN 2115998. 7 August 1985.

Vaaler, S.C. Feeding of A508 UO<sub>3</sub> not meeting particle size specifications. Plant Test Authorization No. 413. Cincinnati, OH: National Lead Company of Ohio; 31 March 1983.

Weinstein, M.S. and A.J. Breslin. Pre-1972. Environmental Contamination From Burning Uranium Metal. HASL, NY00, Atomic Energy Commission. (Lab and field tests burning 20 grams to 900 lb. natural and depleted U chips; correlation of air contamination, soil concentrations, particle size distribution of uranium oxide in smoke plume). 1972.

PILOT PLANT

1

11

Armbruster, R. Report of Fume Releases 1 November 1960-Pilot Plant, Remelt Area. NLO/ICN 2256501. Pilot Plant-wet area. NLO/ICN 2261020. Cincinnati, OH: National Lead Company of Ohio. 9 December 1959.

Audia, S.F. Summary Report for Plant Dust Collectors, June 1961. Memorandum to Plant Superintendents. NLO/ICN 2131393.Cincinnati, OH: National Lead Company of Ohio. 27 July 1961.

Page A-110

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

З,

: yi

- Bipes, R. L. HF Survey in Pilot Plant. Memorandum to K.E. Brandner. NLO/ICN 2131395.Cincinnati, OH: National Lead Company of Ohio. 12 July 1961.
- Blase, E.F. Exhaust of burnout. Memorandum to R.C. Heatherton. (Five air dust samples of burnout exhaust in Pilot Plant 3037; enriched material, all sampling isokinetic; analytical data sheet). Cincinnati, OH: National Lead Company of Ohio. 7 November 1952.
- Boback, M.W., J.O. Davis, K.N. Ross, and J.B. Stevenson. Disposal of Low-Level Radioactive Wastes From Pilo Plant Operations. NLCO-1075. Prepared for presentation at Third Joint Meeting of the American Institute of Chemical Engineers and the Instituto Mexicano De Ingenieros Quimicos, Denver, Colorado, August 30-September 2, 1970. Cincinnati, OH: National Lead Company of Ohio. 7 July 1970.
- Brandner, K. E. Winlo Eruption in the Pilot Plant. Memorandum to R.S. Starkey. NLO/ICN 2260959. Cincinnati, OH: National Lead Company of Ohio. 13 June 1961.
- Brandner, K. E. 18 July 1961. Dust Collectors Plant 2. Memorandum to G.R. Harr. NLO/ICN 2131396. Cincinnati, OH: National Lead Company of Ohio.
- Brandner K.E. 30 August 1961. Dust Collectors Pilot Plant. NLO/ICN 2131388. Cincinnati, OH: National Lead Company of Ohio.
- CP-69-4. 14 February 1969. Ventilation Alterations for Oxidation Furnace Pilot Plant. Approved by S. Marshall, P.G. DeFazio, C.R. Chapman and J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio.
- Cawdrey, M.M. 1 June 1967. Oxidation of High Enrichments. Memorandum to J.O. Davis. (Items in enriched inventory too high for furnaces in Plant 8; sent to Pilot Plant; lists lot no., isotopic, net wgt., SS wgt.). Cincinnati, OH: National Lead Company of Ohio.
- Chapman, C.R. 22 September 1952. Monthly SF Inventory, Pilot Plant. Memorandum to C.H. Walden. Cincinnati, OH: National Lead Company of Ohio.

CP-F-56-3. March 1956. Pilot Plant Annex. NLO/ICN 2188155. Cincinnati, OH: National Lead Company of Ohio.

- CP-F-56-39. June 1956. Improved Ventilation Facilities for Pilot Plant. includes Construction authorization dated 18 June 1956. NLO/ICN 2214702. Cincinnati, OH: National Lead Company of Ohio.
- CP-62-33. May 1962. Ventilation of Feed Hold Tanks W-11 and W-12 Pilot Plant. NLO/ICN 2214702.(The CP was disapproved by management on July 5, 1962.)
- Cseplo, S. 10 January 1961. Pilot Plant Neutralized Sump Liquor to the General sump. Memorandum to F.L. Cuthbert. NLO/ICN 2277416. Cincinnati, OH: National Lead Company of Ohio.
- Cuthbert, F.L. Review of Pilot Plant stack losses from G20-20. Memorandum to J. H. Noyes. Cincinnati, OH: National Lead Company of Ohio. December 1960 to October 1961.

Calls Land - Lakas

- Cuthbert, F.L. Pilot Plant Dust Collector G20-20. Memorandum to J.H. Noyes. NLO/ICN 2131400. Cincinnati, OH: National Lead Company of Ohio. 18 July 1961.
- Damskey, L.R. Disgust with article, "Disposal of Low-Level Radioactive Wastes from Pilot Plants". Letter to Editor of Chemical Engineering Progress. AIChE Environmental Section of Sierra Club. 5 May 1971.
- DeFazio, P.G. Cancellation of Construction Proposal (CP-62-33), Memorandum to M. Ericson. NLO/ICN 2214704. Cincinnati, OH: National Lead Company of Ohio. 1 August 1962.
- DeFazio, P. G. Replacement of heaters for 6 to 4 reactors in Pilot Plant. memorandum to G. W. Wunder. CP-F-55-80. Cincinnati, OH: National Lead Comapny of Ohio; 19 December 1961.
- FMPC. FMPC Air Emission Source Data Sheet for Pilot Plant. Table from unknown report which lists and describes 15 emission points with type of emissions for pilot plant. NLO/ICN 2160159. 1987.
- Grannen, W.J. Gaseous UF<sub>6</sub> Release, National Lead Company of Ohio February 14, 1966. Letter to J. Grinstead, Employers' Liability Assurance Corporation, Ltd. (Lists non-NLO employees onsite at time of release). 18 February 1966.
- Grannen, W.J. Pilot Plant Incidents of February 14 and February 18, 1966. Memorandum to J.H. Noyes. NLO/ICN 2230341. 14 March 1966.
- Heinke, H. UF<sub>6</sub> fume release at Pilot Plant. Memorandum to J.O. Davis. 7 January 1955. Cincinnati, OH: National Lead Company of Ohio. 7 January 1955.
- Hicks, C.T, Jerome H. Krekeler, and Joseph R. Nelli, NLCO. Laboratory and Pilot Plant Evaluation of Northspan Uranium Concentrate; NLCO 738; Technology-Feed Materials TID-4500, 13th Ed.; 11 page report. 10 April 1958.
- Klein, F.J. Report of Fume Release Pilot Plant, Area 3620. NLO/ICN 2261016. Cincinnati, OH: National Lead Company of Ohio. 10 January 1958.
- NLCO. Enriched UF4 produced in Pilot Plant 3620 unit. Cincinnati, OH: National Lead Company of Ohio. August 1956 to April 1957.
- NLCO. Statement by William Fulton Investigation of Pilot Plant UF<sub>6</sub> Release Cincinnati, OH: National Lead Company of Ohio. February 14, 1966.
- NLCO. 1956. Pilot Plant Open Pot Reduction, dated 2/23/56 and 3/30/56. NLO/ICN 2235098. Cincinnati, OH: National Lead Company of Ohio. 1956.
- NLCO. Process and Equipment Changes at Pilot Plant Uranium. NLO/ICN 2232123. Cincinnati, OH: National Lead Company of Ohio. 1972.
- NLCO. Diagram of Pilot Plant Sump System for Proposed Concurrent Operations of Thorium Gel and 2 inch Extraction Columns Processes. Engineering Division. NLO/ICN 2259195. Cincinnati, OH: National Lead Company of Ohio. April 1977.

~

19.

- Noyes, J.H. Uranium hexafluoride cylinder failed at Pilot plant. Letter to C.L. Karl. (Description of incident of February 14, 1966 release of material enriched to 2.1% U<sup>235</sup>U from K-25 in OR). Cincinnati, OH: National Lead Company of Ohio. 15 February 1966.
- Palmer, W. E. Stack Loss G2020 dust collector. Memorandum to J. O. Davis. Cincinnati, OH: National Lead Company of Ohio. 11 December 1961.
- Palmer, W. E. Operation of dust collector G2020. Memorandum to J. O. Davis. (Dust collector bags onstalled March 20, 1961 with blow rings operating automatically shoed signs of material loss; new bags installed; continuing problems). Cincinnati, OH: National Lead Company of Ohio. 15 June 1961.
- Pennak, A.F. Winlo Feed Tanks W-11 and W-12 Pilot Plant. Memorandum to J.O. Davis, National Lead Company of Ohio. 12 April 1962.
- Pilot Plant Uranium; Process and Equipment Changes. Cincinnati, OH: National Lead Company of Ohio. 1952-1972.
- Samoriga, S.O. Request for Engineering Services Pilot Plant Annex, Stokes Vacuum Remelt Furnace ventilation. NLO/ICN 2214529. Cincinnati, OH: National Lead Company of Ohio; 19 May 1960.
- Starkey, R.H. 9 February 1962. Filter Bags for Dust Collector G20-20 Pilot Plant. Memorandum to J. O. Davis.
- Starkey, R.H., J.O. Davis, P.N. McCreery, W.C. Hill and O.J. Turmelle. Report of Investigation Uranium Loss in the FMPC Pilot Plant Between November 8 and November 25, 1960. Contract No. AT(30-1)1156. Cincinnati, OH; National Lead Company of Ohio. 22 December 1960
- Sapirie, S.R. Uranium Loss in the FMPC Pilot Plant Between November 8 and 25, 1960. Memorandum to G.F. Quinn. NLO/ICN 2185450. National Lead Company of Ohio. 8 June 1961.
- Stefanec, A.J. Air hygiene at 3620 reactor 1/5/55 thru 1/12/55. Memorandum to J.O. Davis (Air dust sample results at Pilot Plant with recommendations for modifications to ventilation; hex leak on January 5).Cincinnati, OH; National Lead Company of Ohio. 27 January 1955.
- Stefanec, A.J. and R. Armbruster. Pilot Plant Operations Which Require Ventilation. Memorandum to R.C. Heatherton. NLO/ICN 2235088. National Lead Company of Ohio. 5 June 1956.
- Vath, J.E. Fire in Pilot Plant Pangeborn Rotoblast Derby Cleaning Equipment, June 4, 1963. Memorandum to B. Gessiness. 5 June 1963.
- Wing, J.F. Proposed Air dust Improvement to the Pilot Plant Enriched Oxidation Furnace. Memorandum to J.O. Davis. NLO/ICN 2232270. Cincinnati, OH: National Lead Company of Ohio. 5 May 1967.
- WMCO (Westinghouse Materials Company of Ohio). Vessel crack shuts down FMPC. Pilot Plant. Press Release. Cincinnati, OH: National Lead Company of Ohio. 20 January 1986.

# Appendix A

## Sources of Information

## PLANT 2/3: REFINERY

- Audia, S.F. Chronological history of enriched refinery operations and enriched UO<sub>3</sub> production.
   Letter to H. D. Fletcher. Letter discussed refinery activity November 1953 to June 22, 1977;
   Plant 2 accounts). Cincinnati, OH: National Lead Company of Ohio; 1 December 1977.
- Carvittti. J.E. Progress report on refinery expansion for period ending 4/5/57. Memorandum to G.R. Harr. Cincinnati, OH: National Lead Company of Ohio; 11 April 1957.
- NLCO. Foremen's log for ore refinery- Plant 3. January-March, August 1957; July-November 1958. Cincinnati, OH: National Lead Company of Ohio.
- NLCO. Operator's shift log for ore refinery Denitration area. June, August-November 1956; January-March, August-December 1957; Jan-June, September-December 1958; Jan-Dec 1967. Cincinnati, OH: National Lead Company of Ohio.
- Noyes, J.H. Summary of FMPC refinery activity. November 1953 through October 1962. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 14 December 1962.

### PLANT 7

- Shaw. W.E. Operation of vibrators at Plant #7. Memorandum to H., Heinke. Cincinnati, OH; National Lead Company of Ohio; 19 April 1954.
- NLCO. Plant 7 Leaderman's Log. (Small binder handwritten notebook with normal and depleted U quantities on shift by shift basis; from Box 39403 in Plant 4 contaminated box area). March through May 1956.
- Spenceley, R.M. Equipment in Plant 7 Which May Contain Quantities of Solidified  $UF_6$ . (Trouble spots identified in the dismantling of piping and equipment in Plt 7). Memorandum to S.F. Audia. Cincinnati, OH; National Lead Company of Ohio; 29 May 1969.

#### PROCEDURES, STANDARDS AND SOPs

- Aas, C.A. SOP Split sampling procedure environmental sampling, ESH-P-52-015. Cincinnati, OH: National Lead Company of Ohio; 29 June 1987.
- Bipes, R. L., Stack Sampler Installation (procedure for new stack samplers installation). NLO/ICN 2257623. Cincinnati, OH: National Lead Company of Ohio; 24 October 1961.
- Boback, M.W. Fluorometric Method of Analysis for Uranium. Cincinnati, OH: National Lead Company of Ohio. 1 April 1960.
- Boback, M.W. Revisions to Fluorometric Method of Analysis for Uranium. Cincinnati, OH: National Lead Company of Ohio. March 1961.
- Boback, M.W., Absorption of Uranium ALPHA Particles by Whatman No. 41 Filter Paper; National Lead Company of Ohio; Prepared for presentation at the Ninth Annual Bioassay and Analytical Chemistry Conference San Diego, California October 10-11, 1963; 20 September 1963.

- Boone, F.W. & R.H. Starkey, Stack Sampling Procedure 5 September 1956. Installation of stack samplers and changing of Type "S" pleated filters (4 pages, incl. stack sampler diagram). Cincinnati, OH: National Lead Company of Ohio; September 1959.
- Cahalane, R.W. SOP Process ventilation by wet scrubbers, NLO-FMPC Manufacturing standards. Cincinnati, OH: National Lead Company of Ohio; 8C-204, supersedes 8C-204, 9-29-62; 9 April 1962.
- Dugan, T.A. Revisions to Fluorometric Method of Analysis for Uranium. Cincinnati, OH: National Lead Company of Ohio. November 1971.
- Gustavson, S.R. to C.H. Walden, Memorandum; Record System for Processing Scrap at NLO Scrap Recovering Plant; 01 September 1953.
- Hicks, C.T., J.H. Krekeler, J.R. Nelli, Laboratory Evaluation of Lakeside Monarch Uranium Ore; NLCO-739; Technology-Feed Materials; TID-4500, 13th Ed.; 14 April 1958.
- Hoover, R. L. to R. H. Starkey, Thorium stack sample procedure. Cincinnati, OH: National Lead Company of Ohio; 3 Feb 1956.
- Hoover, R. L. to R. H. Starkey, Uranium stack sample procedure. Cincinnati, OH: National Lead Company of Ohio; 2 Feb 1956.
- Karl, C. L. to M. S. Nelson, Soil Sampling for Plutonium Contamination (Guidance from AEC describing offsite soil sampling program for Pu Processing Plants). NLO/ICN 2151889. 16 October 1970.
- Klein, F.J. Standard Operating Procedure for the Fallout Sampling Program. Cincinnati, OH: National Lead Company of Ohio. 25 August 1965.
- Quigley, J. A. to F.L. Cuthbert, Status of stack sampling program (Re: Letter, C. Walden to Dr. Cuthbert, 4-18-55, Evaluation of uranium losses). 2 May 1955.
- Morgan, G.J. and F.J. Podlipec, Report; Unirradiated Fuel Element Processing for Recovery of Uranium of Various Isotopic Values; NLCO-1056; Category: UC-47; Technology- Feed Materials; September 1970.
- MS 8-C-207, SOP Oxidation Furnace No. 1, FMPC, NLO-Manufacturing Standards (MS). REF FMPC 2082 Addendum, 1988. 8 pages, 12 September 1983.
- MS 8-C-212, SOP Conversion of UF4 to Calcium uranate (CaU2O7 and Calcium Fluoride (CaF2 Using Calcium Hydroxide (Ca(OH)2)<sup>1</sup> in the No. 2 Oxidation Furnace. REF: FMPC Addendum, 1988. 8 pages, 15 July 1985.
- MS 8-C-209, SOP Primary Calciner, NLO-FMPC Manufacturing Standards. REF: FMPC 2082 Addendum 1988. 6 pages, 26 December 1985.
- MS 8-C-208, SOP Rotary Kiln, NLO-FMPC Manufacturing Standards. Supercedes 8-C-208, 1-28-71. REF: FMPC 2082 Addendum 1988. 8 pages, 13 March 1983.
- NLO (National Lead Company of Ohio). Fluorimetric Method of Analysis for Uranium. Cincinnati, OH: Natinal Lead of Ohio. 1960. Revisions made in March 1961 by M.W. Boback

111 S

. Liunis

: :

and in November 1971 by T. Dugan. (Obtained with Boback, Fluorometric Method of Anaysis for Uranium, 1960).

- NLO (National Lead Company of Ohio). Counting Procedures, Beta Activity. Cincinnati, OH: Natinal Lead of Ohio. 10 May 1961. (Obtained with Boback, Fluorometric Method of Anaysis for Uranium, 1960).
- Ohlinger, R.D., Report 48 pages; The development of a Uranium Isotopic Analytical Program at the USAEC Feed Materials Production Center; For presentation at the 1969 International Conference on Mass Spectroscopy, Kyoto, Japan on September 8, 1969; 14 August 1969.
- Ross, K. N. Methods used to calculate results of stack samples taken at RMI and General Comments. Letter to F. G. VanLoocke (RMI Company). Cincinnati, OH: National Lead Company of Ohio; 27 July 1977 (3 pages).
- Ross, K. N. Stack Sampler Inspection and filter change Procedure (IH&R Procedure No. 1.4). NLO/ICN 2270788. Cincinnati, OH: National Lead Company of Ohio; 2 July 1981.
- Sampling Procedures: Manhole 175, suspended solids, total solids. Standards for Out-Plant Air, liquid effluents (for total alpha and beta, radium, radon, thoron). NLO/ICN 2287471. Cincinnati, OH: National Lead Company of Ohio.
- SOP NLCO-608 Special, Standard Operating Procedure for Preparations and Instructions for Handling Fires in Plant 9 Production and Storage Areas (Section 2.9.4); Robert W. Cahalane National Lead Company of Ohio; 12 January 1956.
- SOP 2-C-404, Pot Denitration, Gulping, and UO3 Milling, FMPC. (In 2082 referenced as: Gulping, Conveying, and Packaging UO3, SOP 2-C-404, FMPC, May 15, 1987). Supercedes 2-C-404, 6-12-73. REF: FMPC 2082 Addendum, 1988. 39 pages, 9 December 1988.
- SOP 2-C-501, Nitric Acid Recovery System, FMPC. Supercedes 2-C-501, 11-06-81. REF: FMPC 2082 Addendum, 1988. 21 pages, 18 August 1988. SOP 11-C-245, Reduction of UF6 to UF4 DCS Controlled Process, FMPC. REF: FMPC 2082 Addendum, 1988. 57 pages, 6 July 1988.
- SOP 6-C-501, Pickling Reclaimable Metal, FMPC. Supercedes 6-C-501, 12-04-86. REF: FMPC 2082 Addendum, 1988. 15 pages, 9 November 1989.
- SOP 6-C-202, SOP- Briquetting, FMPC. Supercedes 6-C-202, 2-13-74. REF FMPC 2082 Addendum, 1988. 17 pages, 6 April 1988.
- SOP 8-C- 203, Box Furnace, FMPC. Supercedes 8-C-203, 12-7-81. REF: FMPC 2082 Addendum 1988. 8 November 1988.
- SOP 8-C-901, Drum Washer, FMPC. Supercedes 8-C-901, 12-15-66. REF:FMPC 2082, addendum, 1988. 5 pages, 15 September 1987.
- SOP 9-C-401, Chemical Decladding of Metallically Clad Uranium (Zirnlo), FMPC. Supercedes 9-C-401, 5-6-74. REF: FMPC 2082 Addendum 1988. 17 pages, 8 August 1988.
- SOP 1-C-915. 28 December 1987. Cleaning of Contaminated Metal and Equipment, FMPC. (In 2082, referenced as: Cleaning of Equipment/Materials Contaminated With Enriched

Uranium Compounds). REF: FMPC 2082 Addendum 1988. 12 pages. Westinghouse Materials Company of Ohio.

Starkey, R. H. Stack sampling procedure. Handwritten date of 3 Feb 1956.(2 pages). Cincinnati, OH: National Lead Company of Ohio. 1956.

Starkey R.H. Deviation of results in stack sample analysis. Memorandum to R. C. Heatherton.(2 pages, incl. table). Cincinnati, OH: National Lead Company of Ohio. April 1956.

Starkey J.A. Ground Contamination Program. Memorandum to J.A. Quigley. (Guidelines for surveys based on SOP for Conducting Ground Contamination surveys of 22 Dec 1960). National Lead Company of Ohio. 24 March 1961.

Weber, J. M. SOP - Sampling Schedule, NLO-FMPC Manufacturing Standards. Cincinnati, OH: National Lead Company of Ohio. 8C-503, supercedes 8C-502 6/2/58. 31 May 1963.

Wing, J. F. RMI Appraisal - April 13-14, 1976. Memorandum to W. A. Johnson (Re: Uranium releases from abrasive saw and difficulty in collecting reliable stack samples from that particular ventilation system, 2 pages). Cincinnati, OH; National Lead Company of Ohio. 7 April 1976.

Wunder, G. W. to C. L. Karl, Material Balance Reports for January 1956 (includes Procedure for determining measured stack losses, 5 pages). 13 April 1956.

Wynn, R. C. to G. R. Harr, Interim Report - Process loss detection - P-24X-11. (Includes tables of check weighing and shipment weights to Plant 5 for July to Sep 1955, 18 pages). 19 Dec 1955.

**OPERATING PROCEDURES: SERIES 3C - Sops (1957-1961)** 

SOP 3C-203. 28 February 1957. Start-Up and Operation of the Fume Scrubbing System.

SOP 3C-103.3, Issue 2. 9 December 1960, Denitration Pot Operation. Production - Ore Refinery.

Production - Plants 2 & 3.

SOP 3C-203. 1 December 1960. SOP - Denitration Fume Scrabbling System. Production - Plants 2 & 3.

SOP 3C-205.2a. 9 September 1957. SOP for Twin Dryer Operations.Production - Plants 2 & 3.

SOP 3C-205.3. 9 September 1957. SOP For the Calciner Unit in the Combined Raffinate Area. Production - Plants 2 & 3. (Obsolete).

SOP 3C-205.2b. 9 September 1957. SOP For Drum Dried Raffinate Calciner. Production - Plant 2 & 3.

SOP 3C-206. 10 April 1961. SOP - The Refinery Sump Operations. Production - Plants 2 & 3.

SOP 3C-301. 1 December 1960. SOP For Dust Collection Systems of the Digestion Area. Production - Plants 2 & 3.

਼ਾਅ ਅਤੇ ਹੈ ਉਹਿਰ ਹ

- SOP 3C-302. 21 April 1961. SOP Operation of Contaminated Dust Collector in Denitration. Production - Plants 2 & 3.
- SOP 3C-303. 9 September 1957. SOP For the Dust Collection and Vacuum Collection Systems in the Combined Raffinate Area. Production Plants 2 & 3.

SOP 3C-401. 27 February 1961. SOP - The Roots-Connersville Pneumatic Conveying System. Production - Plants 2 & 3.

- SOP 3C-401.1. 20 February 1957. SOP for Shutting Down the Roots-Connersville Orange Oxide Pneumatic Conveying System.
- SOP 3C-401.2. 20 February 1957. SOP for Handling Off-Normal Conditions in the Roots-Connersville Pneumatic Orange Oxide Conveying System.
- SOP 3C-501. 24 March 1961. SOP For the Operation of the General Sump System. Production -Plants 2 & 3.

SOP 3-C-502. 5 July 1961. SOP - Ore Refinery SS Inventory. Production - Plants 2 & 3.

## PROCESS DESCRIPTIONS OF PLANTS 2 & 3 - SERIES 3A (1957)

3A-Series. 20 October 1957. The Ore Refinery Operating

3A-101. 22 March 1957. Digestion Area.

3A-102. 18 March 1957. Extraction Area.

3A-103. 20 February 1957. Denitration Area.

3A-201. 5 March 1957. The Nitric Acid Recovery Area.

3A-202, 18 March 1957, Solvent Clean-Up.

3A-203. 20 February 1957. The Fume Scrubbing System in the Denitration Area.

3A-204. 22 March 1957. Hot Raffinate Treatment Area.

3A-205. 22 March 1957. Combined Raffinate Treatment Area.

3A-206. 29 March 1957. The Refinery Sump Recovery System.

3A-207. 18 March 1957. Mixed Bed Deionizers.

3A-301. 1 June 1957. General Description of Dust Collection and Vacuum Collection Systems -Digestion Area.

3A-302. 1 May 1957. The U.S. Hoffman Vacuum Contaminated Dust Collector.

3A-303. 1 July 1957. General Description of Dust Collection and Vacuum Collection Systems -Combined Raffinate Area.

3A-401. 5 March 1957. The Orange Oxide Pneumatic Conveying System.

3A-402. 1 May 1957. The Harshaw Orange Oxide Pneumatic Conveying System.

3A-501. 5 March 1957. General Sump System.

#### PRODUCT SPECIFICATIONS/SAMPLING - SERIES 3B (1957-1959)

3B-203.1. 1 December 1959. Intermediate SS Product. Refinery - Boildown-Denitration Process.

3B-203.1.1. 5 January 1959. Intermediate SS Product - Cascade Grade Uranium Trioxide. Refinery - Denitration Process.

- 3B-403.1 16 October 1957. Uranium Trioxide. Refinery -Boildown and Denitration Process.
- 3B-503.1 29 March 1962. Production Supplies and Materials. Refinery Sump. Calcined magnesite.
- 3B-603.1. 16 September 1957. Partially Concentrated Aqueous Uranyl Nitrate (Evaporator Product).

Radiological Assessments Corporation

"Setting the standard in environmental health"

Page A-11	8 The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3, Source Terms and Uncertainties
	· · · · · · · · · · · · · · · · · · ·
3B-603.2	16 September 1957. Concentrated Uranyl Nitrate
• .	(Final Boildown Product).
3B-603.3	18 September 1959. Uranium Trioxide Product
	(Orange Oxide)
3B-6034	16 Sentember 1957 Purified Aqueous Uranyl
00-000.4	Nitrate (OK Liquor) - Storage Tank Sample
38-603 5 *	Scrubber Liquor from Depitration Filme Scrubber
01-003.0	Sustants + 3 - 4
28 602 7	Nitrie Arid Concentration Draduct (Nitrie Arid
50-005.7	anneximately 60% by weight)
	- approximately 00% by weight).
30-003.0	Mitric Acid Concentrator Process Chioride and
3D-003.9	Nitric Acia Absorber Process Unioriae Control. Nitric Acia Unioriae Removal).
35-603.12	Extraction process residues and not rainingle residues and not rainingle process
Produc	t of Low Radium Content.
3B-603.13	Extraction Process Ratinates (AR) Containing Significant Quantities of Radium.
3B-603.14	Calciner Feed Material (Product of Evaporator).
3B-603.15	Metal oxide (Product of Spray Calciner).
3B-603.16	K-65 Clear Liquor (From K-65 Storage).
3B-603.20	Flocculated Solids of General Sump Wastes.
3B-703.1	Analyses of Partially Concentrated Aqueous Uranyl Nitrate (Evaporator Product).
·3B-703.2	Analyses of Concentrated Uranyl Nitrate (Final Boildown Product).
3B-703.3.	Analyses of Uranium Trioxide Product (Orange Oxide).
3B-703.4	Analyses of Purified Aqueous Uranyl Nitrate (Storage Tank Sample)
3B-703.5	Analyses of Scrubber Liquor From the Denitration Fume Scrubber System.
3B-703.7	Analyses of Nitric Acid (Concentrator Product).
3B-703.8	Analyses of Nitric Acid Concentrator Process Fluoride and Chloride Control.
3B-703.9	Analyses of Nitric Acid Absorber Process Chloride Control.
3B-703.10	Analyses of Nitric Acid Concentrator Ozonation Process.
3B-703.12	Analyses of Combined Raffinate Process.
3B-703.13	Analyses of Hot Raffinate Process.
3B-703.15	Analyses of Metal Oxide (Product of Spray Calciner).
3B-703.16	Analyses of K-65 Clear Liouor.
3B-703.18	Analyses of Treated Effluent From Aqueous Uranium Sump Wastes.
3B-703 19	Analyses of General Sump Effluent (High Fluoride Liouors)
3B-903 Co	trol Charts - Uranium Trioxide Product of Boildown and Denitration Process.
* Date:	1 16 September 1957 for this and following 3B Series
J	
PROCESS	DESCRIPTIONS OF PLANT 4 PROCESSES - SERIES 4A (1956-1961)
4A 3 Augu	st 1959. Flowsheet of Plant 4.
4A-101 9 C	Ctober 1961. Conversion of Orange Oxide to Green Salt
4A-102 14	October 1961. Drum Dumping Station.
4A-201. 14	October 1961, Anhydrous Hydrofluoric Acid Vaporized System.
4A-202.14	October 1961. Ammonia Dissociation and Nitrogen Generator System.
4A-203.14	October 1961, Anhydrous Hydrofluoric Acid And 30 40% Hydrofluoric Acid Recovery
0	

.

.

...

4A-204. 23 April 1956. The Potassium Hydroxide High Pressure Scrubbing System.

4A-205. 23 April 1956. The Potassium Hydroxide Low Pressure Scrubbing System.

, •.

• • • • • •

4A-300 23 April 1956. General Description of Dust Collection and Vacuum Collection Systems. Including

Page A-119

4A-301, G4-2; 4A-302, G-3, 4A-303, G4 & G5, 4A-304, G4-7; 4A-305, G4-10; 4A-306, G4-9; 4A-307, G4-11.; 4A-501 20 February 1957. The Metal Tank Farm.

#### QUALITY CONTROL AND UNCERTAINTIES

- Brown, E.A. Laboratory quality control report for the period November 11, 1966 through December 9., 1966. Report to J.W. Robinson. (Includes tables of analytical determination, estimate of bias, average values; and discussion of control charts). Cincinnati. OH: National Lead Company of Ohio. 11 January 1967.
- Dugan, T.A. Bioassay laboratory department monthly report for June 1976. Report to R. C. Heatherton (Includes alpha measurements, nitrite for river and MH 175 samples; calibration of instruments. Cincinnati. OH: National Lead Company of Ohio. 8 July 1976.
- Quality Control Bi-monthly Progress Report for August and September 1981. (22 pages with 1 page report highlights). 1981.
- Vath, J.E. Summary of operations and other reference information. Report prepared for U.S. AEC, DIA, Technical Advisory Committee on Safeguards. (Analytical precision and bias for U determinations, weighing, sampling; Limit of error estimates for measured losses; material balance FY1965 vs FY1966). Cincinnati, OH: National Lead Company of Ohio; 15 November 1966.
- Wunder, G. W. to C. L. Karl, Summary of FMPC Material Balance Uncertainties (Accountability Department summary of normal uranium accounts for period from plant startup to March 1, 1955: 59,281,219 kg received June 1951 to February 1955; total removal and inventory February 1955, 59,220,698; Material unaccounted as of February 1955, 54,525 kg, 6 pages). Stamped date 24 May 1955.

## RAIN CAPS

- Berzins, A. O., Monthly Project Record for Project 00-85397, Replacement of Weather Caps. NLO, Inc. (Outlines project progress with final entry of 30 April 1986, and "canceled 5/86" handwritten at top of page.) 28 August 1985.
- Boback, M.W. & E.M. Nutter to N. R. Leist, Idea Letter Replacement of Weather Caps at the FMPC. (Suggests replacing deflector-type caps with vertical discharge caps as shown in NLO Engineering Drawing No. 00X-5500-H-01376.) 24 January 1985.

Brander, K.B. Downing Weather Caps. Memorandum to A.F. Pennak. Cincinnati. OH: National Lead Company of Ohio.1 March 1962.

- Fayne, V. 22 January 1985. Scope of Work and list of questions regarding NLO Environmental Program Review. Memorandum to R. Weidner. (Directs analysis to allow removal of rain caps.) National Lead Company of Ohio.
- FMPC Engineering Drawing Index No. 05X-A-01087, Part of Subcontract S-1181, Sections A-A & B-B, Heating & Ventilating, Metals Plant. Catalytic Construction Co. Drawing No. 3005-P-56-A, 31 March 1952. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985a.
The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

:

, i.

- FMPC Engineering Drawing Index No. 05X-A-01089, Part of Subcontract S-1181, Sections E-E & F-F, Heating & Ventilating, Metals Plant. Catalytic Construction Co. Drawing No. 3005-P-58-A, 30 April 1952. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985b.
- FMPC Engineering Drawing Index No. 05X-A-01091, Part of Subcontract S-1181: Sections G-G & S-S, Heating & Ventilating, Metals Plant. Catalytic Construction Co. Drawing No. 3005-P-60-A, 7 May 1952. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985c.
- FMPC Engineering Division Drawing No. 04A-H-01632, "Part of Subcontract S-1181: Plant 4, Reactor Area, Ventilation of Blender & Packaging Station, Ductwork for Dust Collector G4-12, Elevations A-A & B-B". NLO, Inc. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985d.

FMPC Engineering Division Drawing No. 04X-H-01800, Plant 4, Depleted Green Salt Packaging Facility Evangelization Alterations, Section A-A. NLO, Inc. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985e.

- FMPC Engineering Division Drawing No. 00X-H-01376, Weather Cap Standard #1 for FMPC. NLO, Inc. 4 May 1983.
- FMPC Engineering Division Drawing No. 08X-H-02312, Plant 8, Area C, Scrubber for Box Furnace, Plans. NLCO, Inc. (Planned installation of new scrubber system, shows stacks.) 5 December 1968a.
- FMPC Engineering Division Drawing No. 08X-H-02313, Plant 8, Area C, Scrubber for Box Furnace, Sections A-A & B-B. NLCO, Inc. (Shows stack of new scrubber system without rain cap.) 5 December 1968b.
- FMPC Engineering Division Drawing No. 08X-H-02315, Plant 8, Outside Crusher Dust Collector Replacement, Demolition. NLCO, Inc. (Shows stack without rain cap.) NLCO, Inc. Revised 16 January 1969.
- FMPC Engineering Drawing Index No. 05X-A-00009, Architectural Elevations Metals Plant. Catalytic Construction Company Drawing No. 3005-0-1002-A, 13 December 1951. (Shows rain caps installed but not this is not "as built" drawings.) Revised 13 June 1988.
- FMPC Engineering Division Specifications for Subcontract No. S-1181, Plantwide Sheet metal Modifications. For engineering projects numbers: 01-85201-Part I and 00-85397-Part II.
  (Purpose is to install new cyclone and ductwork in Plant 1 and new weather caps on Plants 4 and 5). 15 November 1985.
- FMPC Engineering Drawing Index No. 05X-A-00009, Architectural Elevations Metals Plant. Catalytic Construction Company Drawing No. 3005-0-1002-A, 13 December 1951. (Shows rain caps installed but not this is not "as built" drawings.) Revised 13 June 1988.
- FMPC Engineering Drawing Index No. 05X-A-01087, Part of Subcontract S-1181, Sections A-A & B-B, Heating & Ventilating, Metals Plant. Catalytic Construction Co. Drawing No. 3005-P-56-A, 31 March 1952. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985a.

÷.,

- FMPC Engineering Drawing Index No. 05X-A-01089, Part of Subcontract S-1181, Sections E-E & F-F, Heating & Ventilating, Metals Plant. Catalytic Construction Co. Drawing No. 3005-P-58-A, 30 April 1952. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985b.
- FMPC Engineering Drawing Index No. 05X-A-01091, Part of Subcontract S-1181: Sections G-G & S-S, Heating & Ventilating, Metals Plant. Catalytic Construction Co. Drawing No. 3005-P-60-A, 7 May 1952. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985c.
- FMPC Engineering Division Drawing No. 04A-H-01632, "Part of Subcontract S-1181: Plant 4, Reactor Area, Ventilation of Blender & Packaging Station, Ductwork for Dust Collector G4-12, Elevations A-A & B-B". NLO, Inc. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985d.
- FMPC Engineering Division Drawing No. 04X-H-01800, Plant 4, Depleted Green Salt Packaging Facility Evangelization Alterations, Section A-A. NLO, Inc. (Shows new rain caps installed but this is not "as built" drawing.) Revised 14 November 1985e.
- FMPC Engineering Division Drawing No. 00X-H-01376, Weather Cap Standard #1 for FMPC. NLO, Inc. 4 May 1983.
- FMPC Engineering Division Drawing No. 08X-H-02312, Plant 8, Area C, Scrubber for Box Furnace, Plans. NLCO, Inc. (Planned installation of new scrubber system, shows stacks.) 5 December 1968.
- FMPC Engineering Division Drawing No. 08X-H-02313, Plant 8, Area C, Scrubber for Box Furnace, Sections A-A & B-B. NLCO, Inc. (Shows stack of new scrubber system without rain cap.) 5 December 1968.
- FMPC Engineering Division Drawing No. 08X-5500-H-02315, Plant 8, Outside Crusher Dust Collector Replacement, Demolition. NLCO, Inc. (Shows stack without rain cap.) NLCO, Inc. Revised 16 January 1969.
- FMPC Engineering Division Specifications for Subcontract No. S-1181, Plantwide Sheet metal Modifications. For engineering projects numbers: 01-85201-Part I and 00-85397-Part II. (Purpose is to install new cyclone and ductwork in Plant 1 and new weather caps on Plants 4 and 5). 15 November 1985.
- FMPC Job Order 7662, Stack Removal Plant 1. NLO, Inc. Requested by K. Schaefer, FMPC. (Remove 2 stacks and repair holes in bldg.), 20 August 1986.
- FMPC Job Order K7196, Dust Collector Stack Plant 4. NLO, Inc. Requested by D. Moore, FMPC. (Install new stack with new style rain hood for G4-4 dust collector), 14 April 1986.
- Leist, N. R. to N. R. Leist, H. C. Heareth, C. H. Handel, J. H. Harrison, E. M. Nutter, C. E. Polson, R. B. Weidner, "Idea Letter Replacement of Weather Caps at the FMPC." 31 January 1985.
- Project Authorization PA 00-85397, Replacement of Weather Caps. NLO Inc. (Outlines specifications of new caps with drawing no. 00X-5500-H-01376, lists caps to be replaced: G4-

<u>م</u>

2, G4-14, G4-5, G5-249, G5-250, G5-253, G5-260, G5-261, gives cost estimate and safety assessment). 4 September 1985.

Weidner, R.B. 24 January 1985. NLO Environmental Program Review. DOE Report of Conversation with V. Fayne. National Lead Company of Ohio.

#### RECYCLED FEEDS

Gessiness, B. Plutonium content of NLO feed materials (Revision 1); Memorandum to W.J. Adams; 10 April 1985.

Reafsnyder, J.A. Putonium content of NLO feed materials. Memorandum to R. Erickson; (Tables of recycled feeds). Cincinnati, OH: National Lead Company of Ohio; 15 April 1985.

Schaeffer, M.R. Joint Task Force on Recycle Material Processing; Memorandum to M.R. Theisen; Cincinnati, OH: National Lead Company of Ohio; 23 April 1985.

#### SCIENTIFIC BACKGROUND / FERNALD-RELATED

Eisenbud, M. and J.A. Quigley. Industrial Hygiene of Uranium Processing. A.M.A. Archives of Industrial Health, pp. 12-22. Received for publication 24 October 1955. Presented at Symposium on the Peaceful Uses of Atomic Energy at International Conference held under the auspices of the United Nations at Geneva, Switzerland, August 8-20, 1955.

Gesel, T.F., 1983. Background atmospheric radon-222 concentration outdoors and indoors: A review. Health Physics 45: 289-302.

Harris, R.A. April 1986. Historical Nuclear Materials Balance Report for the Former AEC-Owned Weldon Spring Chemical Plant, Weldon Spring, Missouri. DOE/OR-872. U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tennessee.

Kocher, D.C. 1979. Dose Rate Conversion Factors For External Exposure to Photon and Electron Radiation From Radionuclides Occurring in Routing Releases From Nuclear Fuel Cycle Facilities, Oak Ridge National Laboratories, ORNL/NUREG/TM-283. (Also in Health Physics 38: 543. 1980.)

Myrick, T.E., B.A. Berven, and F.F. Haywood. "Determination of concentrations of selected radionuclides in surface soil in the U.S." Health Physics 45(3): 631-642. September 1983.

NAS - National Academy of Sciences, Committee on the Biological Effects of Ionizing Radiation, "Health effects of exposure to low levels of ionizing radiation", BEIR V, National Academy Press, Washington, D.C. 1990.

NAS - National Academy of Sciences, Committee on the Biological Effects of Ionizing Radiation, "Health risks of radon and other internally deposited alpha-emitters", BEIR IV, National Academy Press, Washington, D.C. 1988. (Non-radiological risks of uranium).

NBS - National Bureau of Standards, 1953, Maximum Bureau of Standards Handbook 52: "Maximum Permissible amount of radioisotopes in the human body and maximum permissible concentrations in air and water." Issued 20 March 1953. (Possible applicable standards in early years at Fernald).

- NBS -National Bureau of Standards, 1959, Maximum Bureau of Standards Handbook 69,: "Maximum permissible body burdens and maximum permissible concentrations of radionuclides in air and water for occupational exposure." Issued 5 June 1959.
- Peterson, H.T. 1983. "Terrestrial and aquatic food chain pathways." In Radiological Assessment, A Textbook on Environmental Dose Analysis, ed. by J.E.Till and H.R. Meyer, NUREG/CR-3332. 1983.
- Starkey, R.H., J.W. McKelvey, B.J. Held and E.L. Alpaugh, Report; Health Aspects of the Commercial Melting of Uranium-Contaminated Ferrous Metal Scrap; National Lead Company of Ohio; April 1960.
- Thind, K.S. July 1987. "Comparison of ICRP Publication 30 lung model-based predictions with measured bioassay data for airborne natural UO2 exposure." Health Physics 53(1): 59-66.
- U.S. Environmental Protection Agency. Industrial Source Complex (ISC) Dispersion Model User's Guide, EPA-450/4-79-030; 1979.
- U.S. Environmental Protection Agency, Radionuclide Interactions with soil and rock media, Volume 1: Processes influencing radionuclide mobility and retention, element chemistry and geochemistry, conclusions and evaluation. (Section on Uranium only, 14 pages). EPA 520/6-78-007; August 1978.

#### SCRUBBERS

- Bardo, R.W. Summary of Emission Data for Plant 8 Wet Scrubbers, CY-1983 (Revised). Memorandum to D.A. Fleming. Cincinnati, OH: National Lead Company of Ohio. 28 March 1984.
- Bardo, R.W. Summary of Emission Data for Plant 8 wet scrubbers, 1/80 thru present, Memorandum to M.W. Boback. Cincinnati, OH: National Lead Company of Ohio. 16
  September 1985.
- Bardo R.W. Scrubber Losses to Environment FY 1954-1984. (Summary table of total, depleted, normal, enriched U; %U-235). Cincinnati, OH: National Lead Company of Ohio. 21 October 1985.
- Beers, H. M. Meeting of the investigation committee on the violent reaction in the D43-101 water slurry make-up takn at the Recovery Plant. Report to C.R. Chapman. (Description of explosion; procedure for start-up; report on planning safety in metals recovery system operation). Cincinnati, OH: National Lead Company of Ohio. 6 January 1960.
- Beers, H.M., L.W. Kessler, E.A. Mode and R.H. Starkey. Plant 8 Off-Gas Systems (P-28000-33). Memorandum to C.R. Chapman, P.G. DeFazio and J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 26 September 1961.
- Beers, H.M. Scrubber losses, Request for Engineering Services. (Request investigating other methods of measuring wet scrubber losses rather than calculating based on efficiency basis). Cincinnati, OH: National Lead Company of Ohio; 28 June 1968.

S.

V:t

Boies, R.B. Feasability Study - Reduction of scrubber losses. Memorandum to P.G. DeFazio. (Summary of meeting held 30 November 1965, agreed that a steady feed rate to scrubbers in Plant 8 could not be maintained under present operating conditions). Cincinnati, OH: National Lead Company of Ohio; 8 December 1965.

Bonfer, D.C. Plant 8 scrubbers. (Report of meeting held on 26 April 1986 regarding test results obtained frm sampling rotary kiln, box and oxidation furnaces). Cincinnati, OH: National Lead Company of Ohio. 28 April 1988.

Cahalane, R.W. SOP - Process ventilation by wet scrubbers, NLO-FMPC Manufacturing standards. Cincinnati, OH: National Lead Company of Ohio: 8C-204, supercedes 8C-204, 9-29-62; 9 April 1962.

Chapman, C.R. 25 January 1965. Request for feasability study - Re: Reduction of scrubber losses. Memorandum to P.G. DeFazio. (Summarizes several letters concnerned about scrubber losses). Cincinnati, OH: National Lead Company of Ohio.

Chapman, C.R. Proposal to Reduce Loss of Uranium via Nash Pumps in Plant 8; Job order# D 5850; Memorandum; to J.A. Quigley; Cincinnati, OH: National Lead Company of Ohio No date.

Chapman, C.R.Proposal to Reduce Loss of Uranium via Nash Pumps in Plant 8; Job order# D 5850. Memorandum to J.A. Quigley; Cincinnati, OH: National Lead Company of Ohio 2 June 1960.

Chenault, E.M. 29 June 1961. Evaluation of Plant 8 Off-Gas Scrubber. Memorandum to K.S. Brandner. Cincinnati, OH: National Lead Company of Ohio.

DeFazio, P.G. Feasibility Study - Re: Reduction of scrubber losses. Memorandum to C.R. Chapman. (Study of U losses incurred in scrubber operation in plant 8 1961 and 1962 for UAP, caustic, rotary kiln and emergency vent on UAP furnace). Cincinnati, OH: National Lead Company of Ohio; 17 February 1963.

DeFazio, P.G. Scrubber improvement program - Plant 8, memorandum to L.M. levy. (Test program, Engineering Project G-382 delayed). Cincinnati, OH: National Lead Company of Ohio; 6 April 1966.

Diehl, A. R. 21 October 1980. Measured Losses - Plant 8 Furnace Off-gas Scrubbers. Memorandum to M.W. Boback. (83% scrubbereff based on manufacturer's mean eff. rating of 70 to 95%). Cincinnati, OH: National Lead Company of Ohio.

Emissions Test Report Calciner Scrubber Stack, Westinghouse Materials Company of Ohio, Fernald, Ohio. (Purpose of testing was to determine filterable particulate and filterable and condensable radionuclide isotope emissions discharged from Plant 8 calciner stack). Prepared by Roy F. Weston, West Chester, PA.NLO/ICN 2697324. October 1988.

Fields, K.E. to List names, Memorandum; Program for Uranium Recovery Operations; PI:FPB; 22 August 1956.

Gardner R.L., G.E. Baker and T.R. Clark. 16 August 1988. N A R System Emissions Estimate. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-502. Westinghouse Materials Company of Ohio.

> الى ئەرىكە بىلىكى بى بىلىكى چەرىكى بىلىكى بىلىكى

1.11

- Gessiness, B. 4 June 1964. Report on the Investigation of B-PID in Plant 8. Report to C.R. Chapman and S. Marshall. national Lead Company of Ohio.
- Gessiness B. 12 January 1968. Comments, Calculations and Concerns re Plant 8 Scrubber Losses. Inter-Office Routing Slip to M.S. Nelson. National Lead Company of Ohio.
- Gessiness, B. and J.E. Vath. 23 February 1968. Determination of Plant 8 Scrubber Losses to the Atmosphere. Inter-Office Memorandum to M.S. Nelson.
- Gessiness B. 30 August 1972.Report of Generation Plant 8 Spent Scrubber Solution. Memorandum to J.E. Beckelheimer. NLO/ICN 2222491. National Lead Company of Ohio.
- Griffith, D. Request for emission data on the calciner and kiln, Letter to P. G. Voillequé. Cincinnati, OH: Westinghouse Materials Company of Ohio; WMCO: EMT: CAP: 91-014; 24 January 1991.
- Gurney F.J., G.E. Baker and T.R. Clark. 8 Sep 1988. Plant 6 Briquetting System Emissions. Memorandum to W.H. Britton and L. Elikan. (Calculations, system diagrams, test description, and system description for Plant 6 scrubber stack; U emission of 1.23 gU/hr determined; 7,119 lbs U processed during 8 hr shift). Westinghouse Materials Company of Ohio.
- Heatherton R. Nitric Acid Scrubber. Memorandum to G. Wunder. NLO/ICN 2126322. 19 February 1952.
- Hill, W.C. Incident report on Plant 8 kiln scrubber exhaust blower sheave change. memorandum to R.M. Spenceley. Cincinnati, OH: National Lead company of Ohio. 4 April 1984.
- Hill C. Loss Estimation from Plant 8 Scrubbers. Letter to Bill. (Short note regarding article in Enquirer reporting numbers higher than in 2082 report). Westinghouse Materials Company of Ohio. 3 January 1989.
- Karl, C.L. to S. R. Sapirie, Memorandum; Uranium Scrap Recovery Program FY 1957; 05 November 1956.
- Karl, C.L. Health and Safety Factors Plant 8 Scrap Recovery. Memorandum to S.R. Sapirio and R.C. Armstrong. 30 October 1962.
- Karl C.L. 26 March 1971. Wet Scrubber Systems Survey. Letter to M.S. Nelson. (Survey of wet scrubber systems performed for National Air Pollution Control Administration y Ambient Purification Technology, Inc.; lists process capacity, major difficulties). National Lead Company of Ohio.
- Levy, L.M. 16 February 1965. Suggested program for scrubber loss reduction, Memorandum to C.R. Chapman. (Handwritten notes regarding document attached). Cincinnati, OH: National Lead Company of Ohio.
- Levy, L.M. Scrubber improvement program Plant 8, Memorandum to P.G. DeFazio. (3 page summary of meeting held 16 March 1966). Cincinnati, OH: National Lead Company of Ohio; 18 March 1966.

Page A-126

teres and states are a

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

.: ••

Marshall J.E. October 1959. Recovery Plant Scrubber Loss Report for the Month of October, 1959. National Lead Company of Ohio.

Mead, J.C. History of FMPC residue recovery operations. (100 page record of the "importance of residue recovery in total mission" of FMPC). Cincinnati, OH: National Lead Company of Ohio; NLCO-1096, special; 25 August 1972.

NLO. Plant 8 off-gas furnace data. ICN 2224555. [Lists type of furnaces, dust type, off-gas cfm and temp, gas analysis loading and particle size]. No author or date.

1 1

NLO. 18 December 1963. Analytical Data Sheet: Impinger, Plant 8 VAP Scrubber. National Lead Company of Ohio.

- NLO. 8 August 1963. Analytical Data Sheet: Impinger, Plant 8 VAP Scrubber. National Lead Company of Ohio.
- NLO. Log on Operating Conditions of NPR Scrubber. NLO/ICN 2156616. National Lead Company of Ohio. 7 November 1963.
- NLO. Log on Operating Conditions of UAP Scrubber. NLO/ICN 2156617. National Lead Company of Ohio. 18 December 1963
- NLO. Report of Chemical Analyses: Oxidation Scrubber, Lab. Nos. 8-7638. NLO/ICN 2235716. National Lead Companyof Ohio. 30 September 1980.

54 S.

- Noyes, J.H. Idea Letter Electrostatic Precipitators for the Primary Calciner and the UAP Furnace Off-Gas System - Plant 8. 28 June 1962.
- Noyes, J.H. Request for Approved Inventory Write-Offs, Normal, and Enriched SS Scrubber materials - FY 1965. Letter to C.L. Karl. National Lead Company of Ohio. 17 July 1964.
- PEDCo Environmental. Data Sheet Stacks and Other Egress Points, TKPP Scrubber Outlet Emission Data. NLO/ICN 2313707. Data from Source Tests by PEDCo Environmental, Cincinnati, Ohio. 25 May 1972.
- Pennak, A.F. Continuous sampling of scrubber stack exhaust gases, letter to C.E. Billings, Billings & Gussman, Inc., Watham, MA; Cincinnati, OH: National Lead Company of Ohio; 30 June 1971.
- Pennak, A. Request for Engineering services regarding feasability of improving scrubber requirements in Plant 8 by converting S & K fume scrubbers to electrostatic precipitators. Cincinnati, OH: National Lead Company of Ohio; 30 September 1963.
- Rakiewicz, R.W.; B. Jackson; D. Phoenix. Source Emissions Test Report Calciner Scrubber Stack. (Purpose of testing was to determine filterable particulate and filterable and condensable radioisotope isotope emissions discharged from Plant 8 calciner stack). West Chester, PA.:Roy F. Weston, October 1988.

Randle, E.W. 12 March 1971. Investigation of Methods of Measuring and Reporting Uranium Losses to the Atmosphere. Memorandum to A.F. Pennak. (Describes method of calculating scrubber stack losses, based on scrubber liquor analysis and 83% efficiency). National Lead Company of Ohio. NLO/IC N 2217394.

- Rathgens L. Not dated. Scrubber Losses for CY 1965-1973. (Handwritten table of SS lbs of U and some Th; note re additional amount of 81,000 SS lbs written off to atm. included both wet and dry stacks).
- Rennich, G. Safety Inspection of NLO Scrap Recovery Plant, Digest Section; Memorandum to Files. 8 June 1960.

Starkey, R.H. 11 April 1961. Evaluation of Plant 8 Off-Gas Scrubbers. Memorandum to H.M. Beers. National Lead Company of Ohio.

- Vath, J. E. 11 August 1964. Plant 8 Scrubber Losses. Memorandum to B. Gessiness. (Sampling of plant data from Oct 1959 thru March 1960, Jun 1961 thru May 1962 and Feb 1964 used to calculate U recovered by Plant 8 scrubbers; tables of scrubber losses to atmosphere with assumed efficiencies fo 75-90%; measured scrubber efficiences of 71-87%).
- Vath, J.E. Suggest Program for scrubber loss reduction, Interoffice rutin slip to L.M. Levy. (Estimated stack losses listed based on 83% scrubber eff). Cincinnati, OH: National Lead Company of Ohio. 23 March 1965.
- Vath, J.E. Discards to burn pit and from wet scrubbers FY 1965. Memorandum to P.C. Feist. Cincinnati, OH: National Lead Company of Ohio; 1 July 1965.
- Weber, J. M. SOP Sampling Schedule, NLO-FMPC Manufacturing Standards. Cincinnati, OH; National Lead Company of Ohio; 8C-503, supercedes 8C-502 6/2/58; 31 May 1963.
- Wing, J.F., Application for a Permit or Variance to Operate an Air Contaminant Source to Ohio EPA; Block Flow Diagram Plant 8 - Scrap Recovery Plant; 29 September 1978.

#### SOILS AND SEDIMENTS

- ATEC (ATEC Associates, Inc.). Laboratory reports of soil exploration on FMPC site, 1982 and 1988.
- Corps of Enigneers. Report of Foundation Investigation Feed Materials Production Center, Fernald, Ohio. [200 page report with test boring results]. Mariemont, OH: Corps of Engineers, Ohio River Division Laboratories; February 1952.
- Eberline Thermo Analytical, Inc. Bichemical analysi sof soil from site north of the FMPC just outside 5 mile radius circle. Requested by Vicky Dastillung. September 1990.
- Eckart, R. and R. Janke. 29 April 1987. Interim Report Derivation of Site-Specific guidelines for the Fernald Feed Materials Production Center. (Main goal of study was to develop set of site-specific residual radioactivity soil guidelines for WMCO FMPC based on DOE document "A Manual for Implementing Residual Radioactivity Guidelines". Study identifies population group and defines pathways that exist for group). University of Cincinnati.

.....

аŝ

Lockwood, M.E. Report of Geotechnical Investigation, NLO, Inc. [Test borings results and graphic logs of 12 test borings made at FMPC]. Cincinnati, OH: The H.C. Nutting Company; 21 September 1984.

Lynch, D.E. Soil and Water Uranium and Radium Survey Progress Report. (Results of soil and water survey made during 1949 at Lake Ontario Ordnance Works, NY, Middlesex Sampling Plant, NJ, Harshaw chemical Works, Cleveland, Ohio, and AEC storage area at Lambert Airport, St. Louis. Some soil sample data from USGS taken in 1948 at St. Louis and radium in Mississippi River water collected near the Mallinckrodt Works by J.J. Koenig and K.J. Caplan). NLO/ICN 2186759. NYO-1521. New York Operations, Office Health and Safety Division, U.S. Atomic Energy Commission. 20 June 1950.

Nelson, M. S. Soil Sampling Locations. Letter to C. L. Karl. (Description of the 7 offsite locations where annual soil samples collected). Cincinnati, OH: National Lead Company of Ohio. 3 June 1970.

经销售资格 化位置分子 计正式分析 推动的

Nelson, M. S. Uranium in Offsite Soil Samples. Letter to C. L. Karl. (Table listing U in soil samples at 7 locations with attached map). Cincinnati, OH: National Lead Company of Ohio. 17 December 1970.

Nelson, M. S. Uranium in Offsite Soil Samples. Letter to C. L. Karl. (Additional soil samples taken to determine extent of increased U concentrations in samples along State Route 128). Cincinnati, OH: National Lead Company of Ohio. 25 May 1971.

Nelson, M. S. to C. L. Karl, Uranium Soil Samples. Letter to C. L. Karl. (Suggests biannual soil sampling program, instead of annual.) Cincinnati, OH: National Lead Company of Ohio. 19 May 1970.

Nelson, M. S. Uranium in Project Soil Samples. Letter to C. L. Karl. (U concentrations at the six boundary air sampling stations given.) Cincinnati, OH: National Lead Company of Ohio. 9 November 1971.

Nelson, M. S. Soil Sampling Procedure. Letter to C. A. Keller, U.S. Atomic Energy Commission. (Description of procedure followed at FMPC for previous two years.) Cincinnati, OH: National Lead Company of Ohio. 12 April 1973.

NLO. 1984. Analysis of Sediment Samples From the Storm Sewer Outfall Ditch, Paddy's Run, and the Great Miami River. (Trend Analysis, 10 yr. period). Cincinnati, OH: National Lead Company of Ohio.

Roelker, R. F. Master Soil Boring Plan Feed Materials Production Center Fernald, Ohio; S & ME Proposal No. CP-1176. Letter to Gerry E. Paul, Westinghouse Materials Company of Ohio. [Almost 200 Records of soil borings done for various clients including Rust Engineering, NLO, Inc., Lockwood Greene Engineers, Inc., ATEC Associates, Inc.]. Fairfield, OH: S&ME (Formerly Soil, & Materials Engineers, Inc.).

Ross K.N. Uranium in Surface Dirt, FMPC. Memorandum to A.O. Dodd. (2" x 1" soil sample results near 23 gumpaper fallout stations; average U on site=1470 mg/sq. ft in top inch). Cincinnati, OH: National Lead Company of Ohio. 6 April 1959.

;

. . .

e gen stranse en sonar ar finder fra de strationer. Se sonar de sin de sonar ar finder de services de services de services de services de services de services de s

- Rust (The Rust Engineering Company). Biodenitrification Facility Upgrade Feed Materials Production Center. [ Geotechnical exploration and sampling of 4 sites at FMPC including BDN Holding Tank, BDN Building, BDN Effluent Treatment System, Calcium Removal System;] Ross, OH: The Rust Engineering Company; Project No. 4144-88-462, Rust W.O. No. 1227; December 1988.
- Spenceley, R. M. to M. R. Theisen, Afrimet Residues Results of Subsurface Soil Sample Analyses (4 pages, results of soil samples collected beneath the two K-65 storage tanks.) 28 December 1982.
- Weidner, R.B. 5 July 1984. Uranium in Soil. Facsimile to V. Fayne, DOE-ORO. (Table of U concentrations in soil at 31 sampling points offsite FMPC, with 2 maps showing locations). NLO, Inc.

### STACK EMISSIONS

- Cuthbert, F.L. to J. H. Noyes, Memorandum; Review of Pilot Plant stack losses from G20-20; December 1960 to October 1961.
- Bardo R.W. 21 October 1985. Stack Losses to Environment. (Table of MC&A uranium inventory for total stack, depleted, normal and enriched U; %U-235). National Lead Company of Ohio.
- Bogar L.C. 7 August 1987. Study of the Emissions of the Pilot Plant Baghouse and HF Vent. Letter to J.A. Reafsnyder. (Attached to WMCO:PT: 88-386, Stack Emissions by Galper et al.). Westinghouse Materials Company of Ohio.
- Briton W.H. August, September, October 1988. Letters to J.A. Reafsnyder approving operation of various stacks in plants.
- Cuthbert F.L. SF material in Plant 7. Memorandum to C.H. Walden. (Negative uncertainty in material balance for normal U and D-38 U operations). National Lead Company of Ohio; 18 July 1955.
- Fleming. D.A. 19 February 1988. Results of Testing of Plant 5 East and Est Pot Air Cooling Area. Memorandum to T.J. Walsh, WMCO:EH(IH):88-116. (31 pages of stack samples collection method, stack traverse data sheets, diagram, analytical data sheets, engineering calculations work schedule log sheet included). Westinghouse Materials Company of Ohio.
- Fleming. D.A. 2 August 1988. Results of Testing of Plant 5 Graphite Breakup Booth Exhaust Stack. Memorandum to M.J. Galper, WMCO:OSH(IH):88-407. (Stack samples collection method, stack traverse data sheet, diagram, analytical data sheet, work schedule log sheet included). Westinghouse Materials Company of Ohio.
- FMPC. 1985. Tables and worksheets related to Stack and Scrubber Thorium Discharges. Copy of Table 88 from FMPC-282 report; table of scrubber losses to environment; Table of inventory differences, routine operating losses ath pit discards, startup through Sept 1980). National Lead Company of Ohio.
- Galper M. 2 November 1988. Bar Charts of Uranium Emissions to the Air, by Year. Memorandum to H.D. Christiansen, WMCO:OSH (RC): 88-0183. Westinghouse Materials Company of Ohio.

11

1

. .

à.C

٠.

Galper M.J., R.L. Gardner and T.R. Clark. 8 August 1988. Stack Emissions. Memorandum to W.H. Britton and L. Elikan, WMCO:PT: 88-386. (8 page list of all vents, stacks and fans in Pilot Plant; potential emission points include thorium hold tanks T-1, T-2, T-3, 6 exhaust fans west side of "wet" annex, 2 roof fans for "dry" annex, wet area dust collector, contaminated with thorium, Stokes vacuum pump for P-2 furnace; scrubber exhaust stack, Hydrogen Safety System [HSS], HVAC system, reactor area room exhaust fans and autoclave area room exhaust fans "justified" thru calculations). Westinghouse Materials Company of Ohio.

Gardner, R.L., G.E. Baker and T.R. Clark. 16 August 1988. N A R System Emissions Estimate. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-502. (More support information for WMCO:PT:88-324, Estimate of U Balance, Metal Dissolver to the NAR by J.B. Patton). Westinghouse Materials Company of Ohio.

Gardner, R.L., G.E. Baker and T.R. Clark. 16 August 1988. Refinery Sump Processing System. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-400. (Brief description, diagram and analysis of U emission potential of refinery sump tanks and stacks). Westinghouse Materials Company of Ohio.

· •.

Gardner R.L., G.E. Baker and T.R. Clark. 16 August 1988. Pilot Plant Hilco Oil Reclamation/Vacuum Pump system. (Calculations and diagram for U emissions from PP Furnace Hilco Oil Reclamation / Vacuum Pump System; concluded operation should restart). Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-501. Westinghouse Materials Company of Ohio.

Gardner R.L., M.J. Galper and T.R. Clark. 5 August 1988. Plant 8 Eimco Filters. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-387. (4 pages calculations and diagram for U emissions from Plant 8 Eimco Filter Vacuum Pump Vents and Filter Ventilation Hood). Westinghouse Materials Company of Ohio.

Gardner R.L., M.J. Galper and B.L. Speicher. 4 August 1988. Plant 8 Rabble Arm Exhausts for Oxy 1, Oxy 2 and Primary Calciner.Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-384. (Diagram of rabble arm exhaust stack). Westinghouse Materials Company of Ohio.

Grumski J.T., G.E. Baker and T.R. Clark. 14 September 1988. Decontamination and Decommissioning Facility Emissions. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-530. (5 pages of calculations, system diagram and text re EPA Method V sampling at Decon and Decom Facility HCl acid bath stack; U emission of 0.11 gU/batch processed determined). Westinghouse Materials Company of Ohio.

Gurney, F.J., G.E. Baker and T.R. Clark. 24 August 1988. Plant 6 Scrap Pickling Emissions -Revision. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-511. (Revision to WMCO:PT:88-503, Plant 6 Scrap Uranium Pickling Air Emissions, August 17, 1988). Westinghouse Materials Company of Ohio.

Gurney, F.J., G.E. Baker and T.R. Clark. 8 Sep 1988. Plant 6 Briquetting System Emissions. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-526. (Calculations, system diagrams, test description, and system description for Plant 6 scrubber stack on 12 Aug 1988; U emission of 1.23 gU/hr determined; 7,119 lbs U processed during 8 hr shift). Westinghouse Materials Company of Ohio.

- Gurney, F.J., G.E. Baker and T.R. Clark. 13 Sep 1988. Plant 6 Sump Process Emissions. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-391. (4 pages of text and diagram for Plant 6 sump processing area indicates that U emissions negligible). Westinghouse Materials Company of Ohio.
- Gurney F.J., G.E. Baker and T.R. Clark. 11 August 1988. Plant 9 Zirnlo/Derby Pickling. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-392. (6 pages of calculations, diagram re U emissions from Plant 9 pickling operation; U emission is 4.8 gU/week). Westinghouse Materials Company of Ohio.
- Gurney F.J., G.E. Baker and T.R. Clark. 11 August 1988. Plant 5 Remelt Vacuum Pumps and Hilco System. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-390. (3 pages calculations and diagrams for U emissions from Plant 5 Remelt Furnace Hilco Oil Reclamation/Furnace Vacuum Pump System). Westinghouse Materials Company of Ohio.
- Gurney F.J., G.E. Baker and T.R. Clark. Plant 5 Remelt East Cooling Booth Stack. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-397. (Sampling data, calculations, diagram re U emissions from Plant 5 Remelt Stack based on 9 samples; U emission is 11.6 gU/week). Westinghouse Materials Company of Ohio. 12 August 1988.
- Gurney F.J., G.E. Baker and T.R. Clark. Plant 5 Graphite Breakup/Saw Enclosure Booth. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-396. (Sampling data, calculations, diagram re U emissions from Plant 5 Remelt Stack; U emission is 6 gU/week).Westinghouse Materials Company of Ohio. 12 August 1988.
- Gurney F.J., G.E. Baker and T.R. Clark. Plant 5 Reduction Area Operations Uranium Air Emissions. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-506. (7 pages of data, calculations, diagram re U emissions from Plant 5 Reduction area including reduction pot air cooling wells, sump tank vent, and Jolter muffler/vents). Westinghouse Materials Company of Ohio. 21 September 1988.
- Gurney F.J., G.E. Baker and T.R. Clark. Plant 6 Scrap Uranium Pickling Air Emissions. Memorandum to W.H. Britton and L. Elikan, WMCO:PT:88-503. (Calculations, diagram and description of operation re Plant 6 Scrap Pickling Stack Test; U emission of 41 gU/week based on 60 hour per week operation). Westinghouse Materials Company of Ohio. 17 August 1988.
- Held, B.J. Loading and Efficiency Tests on G1-754 Dust Collector Plant 2. National Lead Company of Ohio. 15 May 1958.
- Held B.J. Dates of Estimated Percents of Uranium for Monthly Stack Loss Report, April 1958. Memorandum to J.A. Quigley. National Lead Company of Ohio. 5 May 1958.
- McCreery, P. N. Report of Monthly Stack Losses. Memorandum to R. H. Starkey, Short memo re reporting of losses). Cincinnati, OH: National Lead Company of Ohio. 17 January 1956.

NAR system, Pilot Plant HILCO, Plant 6 Scrap Pickling.

Page A-132

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

.

يكي

- Nelson M.S. 29 June 1956. Memorandum to R. C. Wynn. SF Material Loss Investigation: Plant 7. (Monthly material balance in Plant 7 regularly failed to check, 1 page). National Lead 111.41. Company of Ohio.
- Nutter, E.M. Incident report Plant 4 stack discharge. Memorandum to R.M. Spenceley. (85.4 kg U discharged from dust collector G4-14 during July 1981). Cincinnati, OH: National Lead Company of Oho; 9 November 1981.
- Nutter, E.M. Incident report Plant 4 stack discharge. Memorandum to R.M. Spenceley. Cincinnati, OH: National Lead Company of Oho; 23 September 1981.
- Nutter, E.M. Incident report Plant 4 stack discharge. Memorandum to R.M. Spenceley. Cincinnati, OH: National Lead Company of Ohio; 13 November 1981.
- Patton J.B. Estimate of Uranium Balance, Metal Dissolver to the N A R. Memorandum to K.A. Solomon and M.J. Galper, WMCO:PT:88-324. (4 pages calculations and diagram of Nitric Acid Recovery [NAR] system for U content of NOx exhaust stream from metal dissolver). Westinghouse Materials Company of Ohio. 29 June 1988.
- Starkey, R.H. Stack Loss from Dust Collector #8035 Plant 8. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 14 March 1962. (See dust collectors)

The second strategy in the

Martin and

- Stack Emission Records. Grouped in folders as follows: \* 1953-1956:
- \* 1957-1959;
- \* 1960-1962;
- \* 1963-1964;
- \* 1965 & 1971-1979;

. . . · · ·

*.*t.

- \* 1966-1970;
- \* 1980-1983;
- \* 1984-1986;
- \* 1987-1989.

WMCO:EVP:88-113. 22 August 1988. Plant 5 Remelt East Cooling Booth Stack, Plant 6 Scrap U Service and the service and coming poons but Pickling. -:1, :L

A BRUDD J

WMCO:EVP:88-114. 23 August 1988. Plant 5 Graphite Breakup/Saw Booth.

WMCO:EVP:88-117. 30 August 1988. Refinery sump processing system,

WMCO:EVP:88-130. 20 September 1988. D & D Facility Emissions.

WMCO:EVP:88-136. 26 September 1988. D & D Facility, Plant 6 Briquetting System.

WMCO:EVP:88-142. 5 October 1988. Plant 5 Reduction Area Operations. and the total of the second state of the second

> · the last

WMCO:EVP:88-144. 7 October 1988. Plant 6 Sump Processing Area. No Chartenet of

WMCO:TS :88-240. 20 September 1988. Plant 6 Briquetting System Emissions an an an an Altan an Anna an Altan An An An An Anna an An W. History S. P.

### **STACKS - PHYSICAL FEATURES & UNMONITORED**

# Appendix A

Sources of Information

- Boswell M.B. 5 December 1988. Continuous Stack Sampling of Unmonitored, In-service, Principal Radioactive Stacks. Memorandum to J. A. Reafsnyder, WMCO:P:88-457. (Identifies and lists stacks in Plant 6, 8 and 2/3 recommended for permanent continuous stack monitoring, 2 pages.) Westinghouse Materials Company of Ohio.
- Fleming, D. A. to D. E. Ames, 1 September 1987. New Stack Sampler Flow Rates and Stack Loss Conversion Factors, WMCO: EH(IH): 87:182. (Flow rates and Stack loss CF for 5 dust collectors stacks: G2-64, G2-76, G-235, G2-6014, G2-6042). Westinghouse Materials Company of Ohio.

Fleming, D. A. to D. E. Ames, 28 July 1987. New Stack Sampler Flow Rates and Stack Loss Conversion Factors, WMCO: EH(IH): 87:140. (Flow rates and Stack loss CF for 3 s stacks: G5-267, G5A-100, North ESP). Westinghouse Materials Company of Ohio.

- Gessiness, B. 4 June 1964. Report on the Investigation of B-PID in Plant 8. Memorandum to C.R. Chapman and S. Marshall. ((SS accountants determined that enriched recovery in Plant 8 resulted in tentative loss of 152,000 lbs from July 1962 to Feb 1964). National Lead Company of Ohio.
- Held, B.J. 7 November 1958. Special Stack Samples Taken at the Request of the Accountability Department. Memorandum to R.H. Starkey. Tests run on G4-4 dust collector to evaluate stack sampling method; samples taken 29 Aug 1958 to 17 Oct 1958). National Lead Company of Ohio.
- Hill, C. A. to T. R. Clark, 10 March 1989. List of FMPC stacks by category, WMCO:PT:89-110, 14 pages. Westinghouse Materials Company of Ohio.
- NLCO (National Lead Company of Ohio). Plant 5 Reduction (UF4 to Derbies) Process and Equipment Changes; 1952-1969.
- Starkey, R.H. 24 December 1962. Operation of Plant 5 Burnout Without Ventilation. Memorandum to G.R. Harr. National Lead Company of Ohio.
- Starkey, R.H. 16 July 1964. Information Pertaining to Unmeasrued Uranium Losses. Memorandum to L.M. Levy. (Lists stacks, fans from each plant with estimated loss/month). National Lead Company of Ohio.

### STORM SEWER AND PADDY'S RUN

- Boback, M.W. and F.J. Klein. 2 December 1964. Survey of conditions Along Paddy's Run. Memorandum to J.A. Quigley. (Comments on walking tour along Paddy's run: much household garbage; dead fish; light gray crust sampled, alpha activity due to U). National Lead Company of Ohio.
- Beers, H. M. 6 January 1960. Memorandum to to C.R. Chapman. Reported Storm Sewer Uranium Loss From Plant 8. (Occurred 21 Nov 1959, 1880 ppm U, 500-750 gallons). Cincinnati, OH: National Lead Company of Ohio.
- Beers, H. M. 17 December 1962. Memorandum to C.R. Chapman. Slightly enriched (300 series) uranium loss to the storm sewer. Cincinnati, OH: National Lead Company of Ohio.

11 **1** 4 4 1

Beers H.M. 2 November 1960. Storm Sewer Losses - Plant 8. Memorandum to R. H. Starkey. (Occurred 1 October 1960, high U digestion slurry approximately 50 gm/l, 155 lbs.). National Lead Company of Ohio.

Blase, E.F.; Starkey, R.H. Pollution studies at Paddy's Run. FMPC-293. (Describes investigation to determine extent of pollution; coal pile drainage samples, no U analysis; diagram of catch basins and MH). Cincinnati, OH: National Lead Company of Ohio; 14 September 1953.

Bussert C.E. 8 May 1956. Memorandum to C. H. Walden. Plant 6 Material Losses From Faulty Process Lines. (Brief memo re replacement of underground with overhead lines). Cincinnati, OH: National Lead Company of Ohio.

Davis J.O. and W.E. Palmer. 28 February 1968. Evaluation of Uranium Content of Various Plant Wastes. (Residue from second incinerator test campaign of burnt solvent, shipping crates and sewage sludge processed in Pilot Plant and analyzed for total U and % U-235). Cincinnati, OH: National Lead Company of Ohio.

DeFazio F.G. 1 April 1957. Contamination - Storm Sewer System. Memorandum to A. Stewart. NLO/ICN 2126885. Cincinnati, OH: National Lead Company of Ohio.

DeFazio F.G. Idea Letter - Revision of Drainage System in Pilot Plant Area. Memorandum to J.H. Noyes. (Related to CP-62-84). Cincinnati, OH: National Lead Company of Ohio. 29 November 1962.

DeFazio F.G. Storm Sewer Contamination. Memorandum to A. Stewart. (April 3, 1957 spill "pushed" into storm sewer manhole; 11,900 ppm). Cincinnati, OH: National Lead Company of Ohio. 22 April 1957.

Diehl, A. R. Industrial Sewage System - Flow Diagrams. (Report includes 3 drawings (nos. 00475, 01268 & 01267) of the sewage system that show total streams from production area to General sump as well as discards to wet chemical pit and to Gt. Miami R.; table lists source measurement and sampling methods). Cincinnati, OH: National Lead Company of Ohio. 11 July 1968.

Eye J.D. 28 August 1961. Contamination of Paddy's Run by Process Chemicals Used in the Feed Materials Production Center. NLO/ICN 2113654. (14 pages, has Table of fluoride and U concentrations in water from Manholes around site collected in August 1961). University of Cincinnati, Cincinnati, Ohio.

Fischoff, R.L. Comparison study of background water pollutants in Paddy's Run, Internal memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 29 August 1960.

Fischoff, R.L. High Uranium Concentration in Plant 6 Water Seepage Pit. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio;

Ling Tret ......

Flowers, D.L. Proposed Solution to Contamination Problem in Paddy's Run. Memorandum to R.H. Starkey. NLO/ICN 2119946. Cincinnati, OH: National Lead Company of Ohio. 13 January 1960.

Gessiness B. Enriched Uranium Loss to the Storm Sewer - Plant 8. Memorandum to H. M. Beers. (Re loss on 13 December 1962, based on samples from MH 23 and digester sample

taken in Plant 8, assumed 225 gallons, equivalent to 355.5 SS lbs, isotopic assay of 0.947% U-235, then determined that 152.9 SS lbs enriched U & 202.6 SS lbs normal U in effluent loss to storm sewer). Cincinnati, OH: National Lead Company of Ohio. 21 December 1962.

- Gessiness, B. Excessive Storm Sewer Losses. Memorandum to M. S. Nelson. (Concerned about excess SS losses to storm sewer, esp. 1100 SS lbs lost during first nine days of September; September 10 loss of 1200 lbs in 12 hr; of greater concern, 2600 - 2900 lbs monitored as passing through MH-175 during same 12 hour period.) Cincinnati, OH: National Lead Company of Ohio. 13 September 1962.
- Hart, R.J. NPDES Permit No. OH0009580, Order No. V-W-78-AO-16 Feed Materials Production Center, Fernald, Ohio; Memorandum to D.S. Bryson. Cincinnati, OH: National Lead Company of Ohio. 1 March 1978.
- Henderson, W.H. Acceptance report on renovations to outfall sewer, subcontract no. 8-974; Date of test 10/24/73. Memorandum to C. A. Schwan. 12 April 1973.
- Lenyk, R.G. Storm sewer at FMPC. Memorandum to A.F. Pennak. (Survey done to locate sources of uranium contamination at storm sewer lift station). Cincinnati, OH: National Lead Company of Ohio. 14 April 1977.
- Klein, F.J. Sampling Storm Sewer Outfall Water to Paddy's Run. Handwritten memorandum to K.N. Ross. (Suggests using U concentration at Lift Station as value for overflow to Paddy's Run). Cincinnati, OH: National Lead Company of Ohio. 1965.
- NLCO (National Lead Company of Ohio). Estimated Uranium Losses in lbs. via Storm Sewer System. (Monthly diagram of Rainfall and losses, including loss to Paddy's Run for January 1959 - December 1961). NLO/ICN 2261683. Cincinnati, OH: National Lead Company of Ohio. 1961.
- NLCO (National Lead Company of Ohio). Estimated Uranium Losses in lbs. via Storm Sewer System. (Monthly diagram of rainfall and U losses, incl. loss to Paddy's Run for January 1960 - December 1962). NLO/ICN 2261626. Cincinnati, OH: National Lead Company of Ohio. 1962
- NLCO (National Lead Company of Ohio). Estimated Uranium Losses in lbs. via Storm Sewer System. (Poor copy: Monthly diagram of losses, incl. loss to Paddy's Run for January 1963 -August 1963). NLO/ICN 2278326. Cincinnati, OH: National Lead Company of Ohio. 1963
- Noyes J. H. Plant 8 Uranium Loss. Memorandum to C.R. Chapman, S. Marshall, P.G. DeFazio, J.A. Quigley. (Occurred 10 September 1962 reported to AEC). Cincinnati, OH: National Lead Company of Ohio. 11 September 1962.
- Noyes J.H. Storm Sewer Losses During September. Memorandum to C.L. Karl. (U losses will exceed approved discard limit of 1975 lb for month, esp. to storm sewer because of moving drummed material in corroded containers, and loss of 1000 lb U from Scrap Recovery Plant on 10 September 1962). Cincinnati, OH: National Lead Company of Ohio. 24 September 1962.

ΰ.

Ś

- Noyes J.H. Supplementary Report Storm Sewer Loss in Plant 8. Memorandum to C. L. Karl. (Occurred 10 September 1962, 1000 lbs; 13 December 1962, 355 SS lbs - 300 series material). Cincinnati, OH: National Lead Company of Ohio. 18 December 1962.
- Noyes J.H. Final Report Storm Sewer Loss in Plant 8. Memorandum to C.L. Karl. (Occurred 10 September 1962, 1000 lbs (0.711); 13 December 1962, 355 SS lbs (0.947-300 series material). Cincinnati, OH: National Lead Company of Ohio. 31 December 1962.
- Noyes, J.H. Control of Ground Contamination And Releases Of Process Wastes to The Storm Sewer System. Memorandum to all Division Directors. National Lead Company of Ohio. 25 January 1963.
- Noyes J.H. Idea Letter Storm Sewer Sampler. Letter to C.L. Karl. (Re CP-66-23; to install 1,000 gpm Weir flow meter for Paddy's Run). Cincinnati, OH: National Lead Company of Ohio. 21 March 1966.
- Patton J.B. Study of Precipitation/Stormwater Flow of FMPC 1978 Through 1984. Memorandum to N.R. Leist and D.P. Cooper. (Monthly analysis of measured rainfall compared to measured storm water flows at FMPC in response to Ohio EPA request for more details re Storm Water Retention Basin). Cincinnati, OH: National Lead Company of Ohio. 14 July 1985.
- Pennak A.F. Idea Letter Storm Sewer Sampler. Letter to P.G. DeFazio. (Re CP-66-23; install Weir flow meter for storm sewer to Paddy's Run for flows 0 to 67700 gpm). Cincinnati, OH: National Lead Company of Ohio; 10 March 1966.
- Pennak A.F. Incident report on "Failure of alarm to ring in water treatment plant when high pH occurred at Manhole 66". Memorandum to S.F. Audia. Cincinnati, OH: National Lead Company of Ohio; 25 April 1978.

Pennington, L., Report of Operation of Sewage Treatment Works at NLO to the Department of Health, State of Ohio. (Lists daily sewage flow in gal, sludge digestion, 4 pages). Cincinnati, OH: National Lead Company of Ohio; May 1975.

Quigley, J.A. Recommended NCG Values For The Storm Sewer Outfall and paddy's Run. (Recommended concentration guides (NCG) for U and total activity in Paddy's Run). Cincinnati, OH: National Lead Company of Ohio; 2 September 1965.

. ...

- Riestenberg, E.B. Incidents Affecting Storm Sewer System. Memoranda to H. (Bimonthly descriptive summary of incidents involving high pH, excess materials to Storm Sewer; 10 reports from 1965 1969. Cincinnati, OH: National Lead Company of Ohio. 1965 1969.
- Riestenberg, E.B. Storm sewer contamination. Memorandum to A.F. Pennak. (Description of contamination problem identified on 28 April 1978). Cincinnati, OH: National Lead Company of Ohio. 8 May 1978.
- Ross, K. N. Uranium Losses in the Storm Sewer System. Memorandum to M. W. Boback (U losses to storm sewer avereraged several hundred pounds per month; sampling method outlined to determine where U entering system; 2 pages). Cincinnati, OH: National Lead Company of Ohio. 5 January 1972.

Page A-137

- Ross, K.N. Uranium Lost to Paddy's Run. Handwritten memorandum to R.H. Starkey. (U concentrations from grab samples vs. automatic sampler). Cincinnati, OH: National Lead Company of Ohio.1965.
- Spenceley, R.M. to Reafsnyder, J.A., Memorandum; Water Pollution Control Project No. 18-83501 (CP 82-02) - Storm Water Retention Basin. Cincinnati, OH: National Lead Company of Ohio. October 1985.
- Starkey, R.H. Contamination in Paddy's Run Creek. Memorandum to H.D. Riestenberg. (Sample collection schedule and sampling points). Cincinnati, OH: National Lead Company of Ohio. 18 July 1961.
- Starkey R.H. Uranium Losses to the Storm Sewer and River Concentrations. Memorandum to J.A. Quigley. NLO/ICN 2134165. Cincinnati, OH: National Lead Company of Ohio. 12 September 1962.
- Starkey, R.H. High Uranium Losses Via the Storm Sewer. Memorandum to J.A. Quigley. (Since Feb. 19, U loss increased from 10 to 80 lb. per day). Cincinnati, OH: National Lead Company of Ohio. 28 February 1969.
- Stewart A. Contamination Storm Sewer System. Memorandum to C.R. Chapman, S.F. Audia and M. Martin. NLO/ICN 2126884. Cincinnati, OH: National Lead Company of Ohio. 2 April 1957.
- Strattman, W. J., H. M. Beers, B. Gessiness, R. H. Starkey, W. J. Adams, E. Mode, 1962.
  Report of Investigation Storm Sewer Loss in the Recovery Plant (Plant 8) on September 10, 1962. (pH meter detected excess U, but operator assumed meter broken; 1000 lb. lost; diagram). NLO/ICN 2199694. Cincinnati, OH: National Lead Company of Ohio.
- Tippenhauer, D.A. Underground SS Material Loss. (Plant 6 water seepage moderate to heavy in uranium content noted; recommended all lines to be relocated overhead, 4 pages). NLO/ICN 2277992. Cincinnati, OH: National Lead Company of Ohio. 9 April 1957.
- Walden, R.H. to C. E. Bussert. Plant 6 Material Losses from Faulty Process Lines. (Brief memo re replacement of underground with overhead lines). Cincinnati, OH: National Lead Company of Ohio. 3 May 1956.
- WMCO (Westinghouse Materials Company of Ohio). Watr Plant operations for July 1986. Daily clearwell volumes June 1984 to June 1986. (Daily volume to storm sewer, outfall clearwell, sewage, general sump, MH175). Cincinnati, OH: National Lead Company of Ohio. 1986.

#### SUMP AND SEWAGE SYSTEM

- Chapman, C.R. Uranium losses from the general sump in November. Memorandum to A. Stewart, Jr. Cincinnati, OH: National Lead Company of Ohio; 19 December 1955.
- Chapman, C.R. "E" metal sump alteration and relocation. Memorandum to L.M. Levy; Cincinnati, OH: National Lead Company of Ohio; 26 September 1968.

Davis, J. O. 3620 unit waste liquor. Memorandum to W. J. Strattman. Cincinnati, OH: National Lead Company of Ohio; 22 march 1954.

Page A-138

· · · · · · · · ·

المعد المحالة والرجي الريار المادي

.....

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

A PARA DeFazio, F.G. to S.F. Audia and H.M. Beers, Memorandum; Replacement of Southwest Area Floor and Sump Trenches; Cincinnati, OH: National Lead Company of Ohio; 01 October 1969.

بعث جافان المراجع

Eberle, H. Decant Tank - Sump Area. Memorandum to L. Levy. Cincinnati, OH: National Lead Company of Ohio; 22 March 1960.

• / •

Emison, B. 6 April 1970. Temporary Operating Procedure - Sump Operation - Pilot Plant. Index No. T-11-C-217. Cincinnati, OH: National Lead Company of Ohio.

A. S. A. B. B. B. S. L. Eye, J.D. Dewatering Pit #3. Letter to R.H. Starkey. (Suggests reducing the flow of waste from ; the general sump to Pit 3; suggests using extra tanks as temporary waste treatment devices.). Cincinnati, OH: University of Cincinnati; 4 June 1963.

Fischoff, R.L. High Uranium Concentration in Plant 6 water seepage pit. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead of Ohio. 5 February 1963.

FMPC General Sump Effluent Control Log. Daily entries for discharges to General Sump from process plants; from General Sump to Waste Pits for 1959, 1960, 1961, 1962.

Glass, D. W. Spent KOH from 3620 to general sump. Memorandum to J. O.Davis.Cincinnati, OH: National Lead Company of Ohio; 26 March 1954.

the second se Harries R. W. Report on Uranium Content of the Laboratory Sump for the Month of July. Memorandum to R.H. Walden. (Table of U conc., gallons outage, pounds of U.) Cincinnati, OH: National Lead Company of Ohio. 11 August 1953.

• .

.

1 . .

Letter and the second second and the second second

Levy, L.M. Discard Raffinate U levels, during current UAP campaign. Memorandum for distribution. (Because of high insoluble U levels, greater than 0.5 g/L in extraction feed, necessary to discard raffinate which exceed spec.s of 0.5 g U per liter). Cincinnati, OH: National Lead Company of Ohio. 21 November 1967.

Levy, L. M. Disposition of 2.1% material at the general sump. Memorandum for general distribution. (Re 2.1% U-235 from Pilot Plant fume release of 2/14/66 held at General Sump; U concentration of 0.045 lb. U/gallon, measured 1.873% U-235 ). Cincinnati, OH: National Lead Company of Ohio. 23 March 1966. • • • •

Marshall. S. Sump Liquor collection system - Pilot Plant chemical area. Memorandum to P.G. DeFazio. Cincinnati, OH: National Lead Company of Ohio: 22 November 1967.

and the second second state of the second second

McCreery, P.N. Measured Losses of Neutralized Evaporator Product. Memorandum to G. Harr. (385 lb. U transferred to pit on May 3, 1960 as recorded in Daily Operating Log of General Sump). Cincinnati, OH: National Lead Company of Ohio. 11 May 1960.

e trade la alta da parte McCreery, P.N. Specifications for Plant Effluent Pumped to the General Sump. Memorandum to general distribution. Cincinnati, OH: National Lead Company of Ohio. 23 August 1965.

计符号 化盐酸氢盐盐 Nelson, M.S. Relocation of "E" Metal Sump System in Plant 9. Memorandum to F.G. DeFazio. Cincinnati, OH: National Lead Company of Ohio. 24 November 1958.

.

. . .

Page A-139

- NLCO, Acceptance Report; Revision of Drainage Facilities (CP-58-72); North of Production Area & South of East Parking Lot; Byrnes-Conway Company; Visual; Subcontract S-370; Cincinnati, OH: National Lead Company of Ohio. 21 October 1959.
- NLCO. Improved waste effluent processing at the general sump. CP-67-19, Rev. 1. (Description, justification and estimate sheet for purchase and installation of 4 new tanks and equipment to improve waste effluent surveillance. Cincinnati. OH: National Lead Company of Ohio. 18 April 1968.
- NLCO. Sump Technician's Log for Ore Refinery General Sump. July-December 1958. Cincinnati, OH: National Lead company of Ohio. 1958.
- Nelson, M.S. to P.G. DeFazio, Idea Letter; Processing of Floor Sump Liquor, Plant 8; National Lead Company of Ohio; 02 January 1959
- Nelson, M.S. Idea Letter Sump liquor collection system Pilot Plant chemical area. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio. 12 December 1967
  - NLCO. Improved waste effluent processing at the general sump. CP-67-19, Rev. 1. (Description, justification and estimate sheet for purchase and installation of 4 new tanks and equipment to improve waste effluent surveillance. Cincinnati. OH: National Lead Company of Ohio. 18 April 1968.
  - Noyes, J.H. Remedial Work on Drainage System to Handle Surface Runoff. Memorandum to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio. 15 August 1958.
  - Noyes, J. H. Recovery of Uranium for Fernald Sump Liquors. Memorandum to C.K. McArthur. (Only two sump streams identified as of this date: Pilot Plant [1,500 gallons/day] and Laboratory [26,000 gallons/day]). NLO/ICN 2277998. Cincinnati, OH: National Lead Company of Ohio. 27 March 1958.
  - Palmer, W. E. E-9 material in KOH and sump liquor. Memorandum to C. H. Walden. Cincinnati, OH: National Lead Company of Ohio. 9 February 1955.
  - WMCO (Westinghouse Materials Company of Ohio). Waste Management Projects Charts of disposal practices, estimates of solid and liquid waste volumes, water pollution control system. NLO/ICN 2156840. Cincinnati, OH: Westinghouse Materials Company of Ohio. 1989.
  - WMCO. Landfill (Pit 4) Interim Surface Plan Runoff Control Plan. (40 pages, in accordance with DOE RCRA). Cincinnati, OH: Westinghouse Materials Company of Ohio. 1986.

### THORIUM

Boback, M.W. Tables and worksheets on thorium and radium Isotopes in refinery (Plant 2/3) stack discharges. (Includes copy of Table 89 from FMPC-2082 report; 10 analytical data sheets, dated 11-5-85 ore samples from various locations; several pages of questions, and handwritten answers, by FMPC individuals). Cincinnati, OH: Westinghouse Materials Company of Ohio. 1985.

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

6.0

- Bonfer, D.C. Thorium-A search of available records at the FMPC. Report to A.M. Schwartzman. PO(DCB)88-012. (Compilation of records from Technical Library, Central Files and Production Technology Department files to consolidate information concerning processing of thorium and thorium compounds at the FMPC). Cincinnati, OH: Westinghouse Materials Company of Ohio. 15 November 1988.
- Briggs, G.G. and J.H. Cavendish. Thorium metal production. (For presentation at the 1971 AIME Centennial Meeting, New York, New York, March 2, 1971). Cincinnati, OH: National Lead Company of Ohio; January 1971.
- Cavendish, J.H. Meeting held on March 10, 1970 to discuss cutting up of thorium derbies in Plant 6. Memorandum to files. (Necessary to have ventilation and /or respirators because air samples during test were significantly higher than MAC; SOP will be prepared and training of operators will begin). Cincinnati, OH: National Lead Company of Ohio; 10 March 1970.
- Chapman, C.R. Redrumming of thorium residues. Memorandum to P.G. DeFazio. 31 January 1966.
- Costa, J.J. to H.M. Beers, Memorandum; Ppm thorium has been added to the Request of Analysis of cod 48 (phosphate ash) material; Lots 8G-48-062 through 8G-48-080 have been submitted for thorium analyses. Cincinnati, OH: National Lead Company of Ohio. 3 April 1957.
- Courtney, L. Table II from unknown report of materials discards of thorium from FY 1952 to FY 1970 to pits, to river, to stacks. Cincinnati, OH: National Lead Company of Ohio. 20 November 1970.
- DeFazio, P.G. Ventilation for Redrumming of Thorium Residues. Memorandum to C.R. Chapman. (200 to 400 drums of thorium residues in storage area need to be redrummed). Cincinnati, OH: National Lead Company of Ohio.; 14 December 1965.
- Dunaway. D.L. Early thorium shipments from the FMPC. Memorandum to L.C. Dolan. WMCO:CO(MCA):88-394; Cincinnati, OH: Westinghouse Materials Company of Ohio; 30 November 1988.
- Hill, C. A. Thorium Process Emissions and Upper Limit Estimate. Memorandum to T.R. Clark. WMCO:PT:89-153. (In Notebook Addendum to FMPC-2082 and Primary References March 1989, 9 pages), 21 March 1989.
- Jester, H. L. to C. W. Huntington, Thorium Oxalate by the Oxalate Precipitation Process -Current Status. (Includes flow sheet for oxalate process and a list of 6 unclassified and 4 classified reports on thorium oxide by oxalate process at FMPC. Cincinnati, OH: National Lead Company of Ohio. 16 January 1964.

5 . 110

an the state

Kispert, R.C., W.P. Tolos, J.W. Rector, J.H. Mueller, N.R. Leist, Summary Technical Report for the Period October 1, 1965 to December 31, 1965; NLCO-970; Development of a Thorium Purification System; Thorium distribution coefficients were determined in the laboratory for the tributyl phosphate (TBP)-thorium nitrate and diamyl amyl phosphonate (DAAP)thorium nitrate systems. The data developed in these tests were used in pilot-scale (2-inchdiameter perforated-plate pulse columns) development tests of a liquid-liguid extraction process for the purification of thorium. This process was subsequently implemented in

Page A-141

semiworks extraction equipment. DAAP was the superior extractant. Cincinnati, OH: National Lead Company of Ohio. 1965.

- Klein, F.J. 19 February 1970. Ventilation survey of Thorium Handling Equipment in Pilot Plant and Plant 9. Memorandum to K.N. Ross. Cincinnati, OH: National Lead Company of Ohio.
- Lawrence, M.H. Thorium redrumming operation. Incident observation report to J.F. Wing. (Handwritten report of operation in Bldg. 65 of re-drumming thorium cake; very dusty situation, K. Ross stopped operation after an hour; diagram and air sample results). Cincinnati, OH: National Lead Company of Ohio. 14 October 1965.
- Lower, C.W. Table of thorium inventory differences, routine operating losses and pit discards, startup through September 1988. Cincinnati, OH: National Lead Company of Ohio.21 October 1988.
- Mautz, E.W.; Magoteaux, O. R.; Runion, T.C. Accountability aspects of the thorium plant. FMPC-168; Cincinnati, OH: National Lead Company of Ohio; 16 March 1953.
- Mautz, E.W.; Magoteaux, O. R.; Runion, T.C. Review of FMPC thorium production operation and survey of development needs, FMPC-173, Metallurgy & Ceramics. Cincinnati, OH: National Lead Company of Ohio; 26 March 1953.
- Magoteaux, O. R.; Mautz, E.W.; Runion, T.C. Health and safety aspects of new materials feed plant for thorium production.; FMPC-150; Cincinnati, OH: National Lead Company of Ohio; 5 March 1953.
- NLCO (National Lead Company of Ohio). Progress Reports Production of Thoria Powder for BAPL LWBR, 1971-1975. Westinghouse Purchase Order #73-Y-474785. (Status of work in progress in relation to schedule; notes indicate that no thorium oxalate for BAPL-LWBR produced during: July - December 1973, and January - April 1974.; includes monthly Material Movement reports and annual and biannual Cumulative Summary Material Movement reports). Cincinnati, OH: National Lead Company of Ohio. November, December 1971, Jan-Dec 1972, Jan-Jul 1973, May-Dec 1974, Jan-Mar 1975.
- NLO, Inc. Table 5-8, Thorium inventory composition from FY-1985 Environmental Safety and health Plan; Cincinnati, OH: National Lead Company of Ohio; 10 January 1985.
- NLCO (National Lead Company of Ohio). Handwritten log sheets of operating losses of thorium to general sump, dry and chemical pit and stacks for FY 65 and FY 66.

Thorium Inventory Folder, Records Received From FMPC.

### Pilot Plant Thorium Data, 1966-1968 Folder.

1000

- Davis, J. O. Pilot Plant Monthly Report. Monthly report to S. Marshall. Cincinnati, OH: National Lead Company of Ohio.; June 1964, January - December 1968.
- NLCO. Handwritten logbook pages for pilot plant. Monthly notations for 1966. Cincinnati, OH: National Lead Company of Ohio; 1966.

Page A-142

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

Ross, K.N. Thorium metal production housekeeping. Memorandum to J.E. Beckelheimer. Cincinnati, OH: National Lead Company of Ohio; 8 June 1970.

Ross, K.N. Radium and Ruthenium in Effluent From the Production of Thorium Hydroxide. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 13 March 1967.

Thorium Gel (Th( $OH_4$ )) Preparation 1964-1969 Folder

Cavendish, J.H. Conversion of the thorium contained in the Th(NO<sub>3</sub>)<sub>4</sub> solution at Hanford into a form suitable for long-term storage. Memorandum to W.E. Shaw. (Memo presents views of Production Technology Department on best ways to process thorium for long term storage; two processes discussed: production of thorium nitrate tetrahydrate and production of thoria gel).Cincinnati, OH: National Lead Company of Ohio; 23 February 1972.

Gessiness, B. NMC field monitoring report on the thoria gel process - May (startup) through September 30, 1977. Memorandum to J.F. Schiltz.(Includes table of thoria gel process, FY-1977 production and distribution summary). Cincinnati, OH: National Lead Company of Ohio; 6 December 1977.

Gessiness, B. NMR Report on the thoria gel process - May 1977 through September 30, 1978. Memorandum to J.F. Schiltz. (No table attached). 6 December 1978.

医网络小白 网络小白的小白白 计进行分词 把某人

Gessiness, B. NMC report on the thoria gel process - May 1977 through September 30., 1978. Cincinnati, OH: National Lead Company of Ohio; 14 December 1978.

Gessiness, B. NMR Final report on the thoria gel process - May 1977 through January 1979. Memorandum to E.M. Nutter. (Processing of thorium nitrate solution receipts from Hanford to storable thoria gel which began in May 1977 was completed in Jan. 1979). Cincinnati, OH: National Lead Company of Ohio; 27 March 1979.

NLCO (National Lead Company of Ohio). Thoria gel production activities. (Summary of production activities for 1969). Cincinnati, OH: National Lead Company of Ohio; 1969.

NLCO (National Lead Company of Ohio). Batch thoria gel process flow diagram; Pilot plant storable thorium. Cincinnati, OH: National Lead Company of Ohio;

NLCO (National Lead Company of Ohio). Flow diagram of thoria gel process. Cincinnati, OH: National Lead Company of Ohio

NLCO (National Lead Company of Ohio).<sup>9</sup> Process flow sheet for production of dense thoria powder and wafers at GE-NSP. Cincinnati, OH: National Lead Company of Ohio.

NLCO (National Lead Company of Ohio). Process flow sheet for producing sintered NLO ThO<sub>2</sub>. gel for vibratory compaction. (Chart from unknown origin, hand dated 7/9/67). Cincinnati, OH: National Lead Company of Ohio; 9 July 1967.

Pennak, A.F. Idea letter - Improved thorium precipitation facility. Letter to P.G. DeFazio. 29 January 1969.

Thorium metal 1955-1957 Folder, Records Received From FMPC.

· · · · · ·

ė.,

Page A-143

#### Thorium Metal Production Pilot Plant 1969-1971 Folder

- NLCO (National Lead Company of Ohio). Notice of Production for crushed and dezinced thorium derbies in Pilot Plant. Monthly tally sheets for April - September 1970, January -March, May, June, September, October 1971.
- Cavendish, J.H. Proposal for establishment of a multi-derby lot of thorium metal for specification compliance and shipment to Y-12. Letter to D.W. Smith. 22 September 1970.
- Marshall, S. Status of thorium derby waivers. Memorandum to M.S. Nelson. Cincinnati, OH: National Lead Company of Ohio; (Number of derbies rejected by Y-12). 8 July 1970.
- Marshall, S. Chemical acceptability of thorium derbies. Memorandum to M. S. Nelson. Cincinnati, OH: National Lead Company of Ohio; 24 November 1970.
- NLCO (National Lead Company of Ohio). Flow sheet for production of thorium metal. Cincinnati, OH: National Lead Company of Ohio; No date.
- Ross, K.N. Air dust concentration in the Pilot Plant thorium process. (Table of average air dust concentrations in d/m/cubic meter of all thorium metal production operations sampled during the 1970 campaign). Cincinnati, OH: National Lead Company of Ohio; 19 November 1970.

Thorium Production for Bettis 1971-1976 Folder, Records Received From FMPC.

Boback, M.W. Health protection aspects of thorium production. Memorandum to R.C. Heatherton. (Review of thorium work at FMPC for future thorium production work in the Pilot Plant; concern about health hazards). Cincinnati, OH: National Lead Company of Ohio; 8 March 1976.

- Briggs, G.G. Monthly report for period ending June 13, 1966 to W. Burkhardt. Briggs, G.G.;
  Schrader, W.A. Consists of three short reports: Briggs, G.G.; Schrader, W.A. "Evaluation of precipitation processes for the production of ThO<sub>2</sub>", T24-2-4; Briggs, G.G.; Mendel, M.G. "Depleted uranium oxide for Savannah River (0.22% U<sup>235</sup>)", D-468; Briggs, G.G.; Mendel, H.G. "Thorium nitrate tetrahydrate crystals for Westinghouse", M-476. Cincinnati, OH: National Lead Company of Ohio; 14 June 1966.
- Chapman, C.R. Process outline for production of thorium oxide without calcium additions. Approval request to Bettis Atomic Power Laboratory, contract no. 73-Y-474785; Cincinnati, OH: National Lead Company of Ohio; 8 June 1972.
- Chapman, C.R. Walsh cycle adjustment. process outline. Request for engineering change to Bettis Atomic Power Laboratory, contract no. 73-Y-474785; Cincinnati, OH: National Lead Company of Ohio; 7 July 1972.
- Mode, E.A.; Cavendish, J.H. Production Order No. D-511. Letter to B.H. Neuman, Bettis Atomic Power Laboratory, West Mifflin, PA). 23 September 1970.

Nelson, M.S. Flow sheet of overall thorium processing. 6 April 1970.

Neuman, B.H. Process parameters for 350 lb. batches of ThO<sub>2</sub> powder sent to NLO. Letter to J. V. Myers. West Mifflin, PA: Bettis Atomic Power Laboratory. 20 August 1970.

Page A-1----

11:1

12

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

1

÷.,

Chapman, C.R. Walsh cycle adjustment. process outline. Request for engineering change to Bettis Atomic Power Laboratory, contract no. 73-Y-474785; Cincinnati, OH: National Lead Company of Ohio; 7 July 1972.

Mode, E.A.; Cavendish, J.H. Production Order No. D-511. Letter to B.H. Neuman, Bettis Atomic Power Laboratory, West Mifflin, PA). 23 September 1970.

Nelson, M.S. Flow sheet of overall thorium processing. 6 April 1970.

Neuman, B.H. Process parameters for 350 lb. batches of ThO<sub>2</sub> powder sent to NLO. Letter to J. V. Myers. West Mifflin, PA: Bettis Atomic Power Laboratory. 20 August 1970.

NLCO (National Lead Company of Ohio). TOP-Preparation of thorium oxalate for Westinghouse, Index No. 11-C-227. (Description of process and equipment; industrial safety requirements procedures; prepared by Quality Assurance, 16 pages). 16 November 1970.

NLCO (National Lead Company of Ohio). Thoria powder production for Bettis. (Table of monthly thorium production from Nov. 1971 through Jan. 1976; no thoria production July 1973 to April 1974 and February 1975 to January 1976). 1976.

- NLCO (National Lead Company of Ohio). Flow diagram for Bettis oxalate process for thorium production., CP 70-8. 1972.
- Noyes, J.H. Proposal for processing thorium in the NLO refinery Revision No. 1. letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 24 March 1966.

Patton, J.B.; Hakimian, F.H. Process design description of the Pilot Plant scale unit for continuous production of thorium hydroxide gel (T24-02-07 Interim report). Memorandum to W.W. Mautz. (Lists major equipment items used for production of thorium hydroxide and their location in production stream). Cincinnati, OH: National Lead Company of Ohio; 28 January 1969.

Verosky, L. Bettis Memorandum purchase order 73-Y-474785. Letter to S.F. Audia (Bettis will not need additional thorium oxalate shipments; they request NLO store reminder until December 31, 1977, and equipment held on standby until that date). West Mifflin, PA: Bettis Atomic Power Laboratory; 21 June 1976.

Pilot Plant Thorium Extractions 1964-1980 Folder Cavendish. NLO thorium purification system. Letter to W. Frankhauser. (Description of extraction process used in Pilot Plant to purify thorium nitrate solutions). Cincinnati, OH: National Lead Company of Ohio; 23 February 1966.

NLCO (National Lead Company of Ohio). Thorium process tank location diagrams for pilot plant extractions. (Includes daily digestion flow chart). Cincinnati, OH: National Lead Company of Ohio; No date.

no date. - 297 de se comencia por programa por el comencia de la comencia de la comencia de la comencia de la c

NLCO (National Lead Company of Ohio). Thorium material flow sheet for extraction. Cincinnati, OH: National Lead Company of Ohio; No date.

edente de la construction de la

- Spenceley, R.M. Thorium accountability report, plant startup through September 30, 1980. Letter to M.R. Thiesen, Weapons Division, US DOE/ORO; Cincinnati, OH: NLO, Inc.; 17 June 1981.
- Starkey, R.H. Problems associated with thorium processing Plant 8. Memorandum to C.R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 1 October 1968.

### Thorium Processing General Folder, Records.

- Briggs, G.G. Flow sheets for production of "light" ThO<sub>2</sub>, of "sol-gel" oxide ThO<sub>2</sub> and of "dense" ThO<sub>2</sub> (From cost estimate documents for production of these three Th compounds). Cincinnati, OH: National Lead Company of Ohio; March 1965.
- Cavendish, J.H. Transmittal of thorium processing flow sheets. Memorandum to L.M. Levy. (Flow sheets for various thorium processing operations both at NLO and GE-NSP; estimated recovery efficiencies and disposal or residues are shown). Cincinnati, OH: National Lead Company of Ohio; 12 May 1969.
- Cavendish, J.H. Thorium scrap from Tennessee Nuclear specialties. Memorandum to J.H. Cavendish. (Suggest that thorium pellets, thorium metal powder, reduction residue, and miscellaneous thorium scrap not be accepted because of hazards of processing). Cincinnati, OH: National Lead Company of Ohio; 5 September 1975.
- Davis, J.O.; Raupers, C.A.; Samoriga, S.O. Thorium-chip remelt test PP9-6-2. Memorandum to S. Marshall. (Regarding thorium chip recovery experimental program of 800-lb. per day thorium-chip recovery unit; Pilot Plant Annex duplex furnace used for test) Cincinnati, OH: National Lead Company of Ohio; 1 May 1964.
- Karl, C.L. Thorium production plans for remainder of FY-1968. (Includes thorium schedule and thorium inventories for July December 1969). 1968.
- Leist, N.R. Thorium purification system for the ore refinery. Memorandum to J.H. Cavendish. (Flow diagram of thorium purification is existing extraction area equipment;). Cincinnati, OH: National Lead Company of Ohio; 4 June 1965.
- Leist, N.R. Thorium purification system for the ore refinery. Memorandum to J.H. Cavendish. (Flow diagram for thorium purification in existing digestion, metal dissolver and raffinate area equipment; capable of 5 ton/day thorium production rates) Cincinnati, OH: National Lead Company of Ohio; 4 June 1965.
- Leist, N.R. Thorium flow sheets and sample schedule. Memorandum to J.H. Cavendish. (Flow diagram of dual solvent extraction system for thorium purification and nomenclature list of the process streams normal to the system; sample schedule suggested for initial operation). Cincinnati, OH: National Lead Company of Ohio; 4 June 1965.
- Leist, N.R. Thorium processing of low-grade scrap residues in the refinery. Memorandum to J.H. Cavendish. (Recovery of uranium from the thorium oxalate waste streams of the plant 8 process; chloride content still too high, suggest using tributyl phosphate extraction process; includes flow sheets for processes). Cincinnati, OH: National Lead Company of Ohio; 28 December 1970.

12 T. .

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

- NLCO (National Lead Company of Ohio). Handwritten notes on ThO<sub>2</sub> (5 pages on new equipment, the clean out of existing equipment, and modification to pilot plant equipment). Cincinnati, OH: National Lead Company of Ohio; 1965
- NLCO (National Lead Company of Ohio). Handwritten notes on disposal for thorium processing in the NLO refinery. (7 pages on process description, including 2 figures of digestion and extraction, and denitration; very poor copy. Cincinnati, OH: National Lead Company of Ohio; 1965
- NLCO (National Lead Company of Ohio). Thorium operations committee meeting. 4 (Includes process flow diagram of thorium oxide production; shutdown of bank 7 in plant 4 scheduled for 1 January 1956 for modification to green salt production with plant 9 wet area one week sooner). Cincinnati, OH: National Lead Company of Ohio; November 1955.
- NLCO (National Lead Company of Ohio). Flow diagrams and yields for three options: compactible oxide, thorium metal, MK 31 B Geometry; extruded thoria tube. Cincinnati, OH: National Lead Company of Ohio; Not dated.
- NLCO (National Lead Company of Ohio. Thorium information Sections 6.0, Delivery of major uranium products; 8.0, Thorium production and costs; and 9.0, Product quality of unknown report. (Details of thorium operations at metals fabrication, recovery, special products and pilot plant from 1954 to 1975; deliveries from 1952 through 1976). Cincinnati, OH: National Lead Company of Ohio; Not dated.
- Smith, W.A. Incident Report Nuclear Fuel Services, Inc., thorium nitrate solution. (Leakage of thorium nitrate solution from truck in Erwin, TN.) Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 11 December 1968.

### UNUSUAL EVENTS, MAJOR LOSSES, OSHA COMPLAINTS

. : <

. .

Adams. W. J. Report of the orange oxide dishcarge from the roof stacks of the refinery denitration area on July 25, 1969. (Description of release of 400 lbs. orange oxide from refinery gulping system onto rook of dentration area. 1969.

- Adams, R. M. Investigation of Major Dust Losses Plant 9 Dust Collector G9N1-1039, September 4, 1984 Thru December 14, 1984. Cover letter to M.R. Theisen dated 8 Feb 1985. NLO Investigating Committee, FMPC. Cincinnati, OH: National Lead Company of Ohio. 16 January 1985.
- Adams, W.J. List of major dust loss incidents 1953-1964. Memorandum to M.R. Theisen. Cincinnati, OH: National Lead Company of Ohio. 3 January 1985.
- Armbruster, R. Report of Fume Releases : 1 November 1960. Pilot Plant, Remelt Area. NLO/ICN 2256501; 9 December 1959. Pilot Plant-wet area. NLO/ICN 2261020. Cincinnati, OH: National Lead Company of Ohio. [In Pilot Plant folder]
- Beers, H.M. 11 June 1958. Investigation Report Explosion of D43-104 Digester in Plant #8 At 7:00 P.M., May 10, 1958. Memorandum to M.S. Nelson. (5 page report with photographs, describing explosion; also summarizes similar explosions in 1954, on January 6, 1957, and January 22, 1957). Cincinnati, OH: National Lead Company of Ohio.

:

.

1

1

144

S.C.

Page A-147

- Beers, H.M., H. Eberle, W. J. Adams, A.B. Kreuzmann, R.C. Coates, E.L. Giebel. 18 January 1960. Report of Explosion in Slurry Make-up Tank in the Scrap Recovery Plant at the Feed Material Production Center at Fernald, Ohio on December 29, 1959. Contract No. AT(30-1)-1156. Cincinnati, OH: National Lead Company of Ohio.
- Bipes, R.L. Fire Damper Positioning North E.S.P. Incident Observation Report to R.H. Starkey regarding incident on 11 February 1963. Cincinnati, OH: National Lead Company of Ohio. 21 February 1963.
- Boback, M. W. & R.C. Heatherton. Bioassay Aspects of a UF, Fume Release. Presented at 12th Annual Bioassay and analytical Chemistry Meeting, Gatlinburg, TN, October 13-14, 1966, 15 pages. Cincinnati, OH: National Lead Company of Ohio; 1966.
- Boyd, M.A., W.D. Fletcher, S.L. Hinnefeld, D.W. Hoover, G.E. Koch, R.W. Lippincott, J.D. Pennington. Investigation of January 19, 1986 Failure of Reaction Vessel at the Feed Materials Production Center UF, to UF, Reduction Facility, Fernald, Ohio. DOE-ORO-875. (Over 150 pages with 26 figures and 10 appendices). Prepared by DOE Incident Investigation Board. June 1986.
- Brevard R.F. 30 March 1961. Incident Report of Ground Contamination of Gravel Area South of Plant 9. (Re spill on 27 Mar 61). Memorandum to L.M. Levy. Cincinnati, OH: National Lead Company of Ohio.
- Brevard R.F. Contaminated Spill in Graveled Area, West Side Plant 9, 3/20/61. (Re spill on 20 Mar 61). Memorandum to L.M. Levy. Cincinnati, OH: National Lead Company of Ohio. 23 March 1961.
- Brevard R.F. Machining Area Dust Collector Failure on 8/25/61. (DC shut off due to short in thermostat, caused deluge system to activate; dust house flooded). Memorandum to L.M. Levy. Cincinnati, OH: National Lead Company of Ohio. 11 September 1961.
- Cline, E., Report of Fume Release. Cincinnati, OH: National Lead Company of Ohio. 19 March 1961.
- Costa, J.J. Spillage of South African Concentrates Lot 247. Memorandum to C.H. Walden. (Spill of 871 lb. along roadway of storage pad near Plant 2.) Cincinnati, OH: National Lead Company of Ohio; National Lead Company of Ohio. 9 June 1954.
- Davis, J. G. Hex Leak, Nov. 7, 1953. Report to F.L. Cuthbert. (Details of hex cylinder leak through valve outlet; estimated 100 lb. of hex released; "largest hex release that has ever been releases in the 3620 unit."; lists the 61 people exposed). Cincinnati, OH: National Lead Company of Ohio. 12 November 1953.
- DeFazio, F.G. 22 April 1957. Storm Sewer Contamination. Memorandum to A. Stewart, Jr. Cincinnati, OH: National Lead Company of Ohio.
- Fischoff, R.L. 25 October 1962. Storage of Drums North of Plant 1. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio.
- Fischoff, R.L. Incident Involving Radiation Detection Alarm Instument-Plant 9. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio;2 November 1962.

Page A-148

24

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

> . .

Halcomb, R. N. Explosion in Pilot Plant of 6/29/56. Memorandum to A.J. Stefanec. Cincinnati, OH: National Lead Company of Ohio. 6 July 1956.

Harr, G. R. Uranyl nitrate release. Memorandum to J. H. Noyes. (Summary of loss of about 1000 lb. of hot uranyl nitrate solution fro the 8" vent of the #212 sparge tank to denitration pad, east of Refinery and the gravel area east of Plant 4; actual accounting of magnitude of loss not possible since did not know level in sparge tank prior to release; 1000 lb. based on contamination in gravel. Cincinnati, OH: National Lead Company of Ohio. 23 July 1959.

Harr, G. R. Explanation of General Sump Uranium Loss of 111.4 lbs. "U" on 8/29/60. Memorandum to C.R. Chapman. Cincinnati, OH: National Lead Company of Ohio. 2 September 1960.

Harrell, E. M. Spillage of SF material. Memorandum to C.R. Chapman. (Description of diuranate cake spill on December 6, 1954 in transport to storage pad; no amounts given). Cincinnati, OH: National Lead Company of Ohio. 8 December 1954.

Heatherton R.C. Air Contamination from broken crucible in 3037 in Pilot Plant. Memorandum to J. A. Quigley. (Occurred 2 November 1952). NLO/ICN 2277979. Cincinnati, OH: National Lead Company of Ohio; National Lead Company of Ohio. 7 November 1952.

Heatherton, R.C. Airborne uranium from metal fires. Memorandum to L.M. Levy. (Brief description of fire on April 10, 1970). Cincinnati, OH: National Lead Company of Ohio. 24 April 1975.

Levy, L.M. Incident report - U loss to storm sewer on 6-28-67. Memorandum to S.F. Audia. Cincinnati, OH: National Lead Company of Ohio; 11 July 1967.

Martin, H. Preliminary Report of the Investigation of Material Loss - Plant 4. Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 3 June 1963.

Martin, H., R. Bipes, B. Gessiness, C. Roeder, R. Wolf. Report of Investigation Uranium Loss in G-4-8 Dust Collector. (May 7 - 27, 1963, stack sampler indicated 939 lb. U loss as black oxide in dc G-4-8, 16 pages). National Lead Company of Ohio. 7 June 1963.

- Martin, J.R., P.L. Slattery and G.J. Marciante. Investigation of Enriched Uranium Release at the Feed Materials Production Center - September 4 to December 7, 1984. ORO-855. (Over 150 page document with 3 appendices). Department of Energy, Oak Ridge Operations. 6 February 1985.
- Noyes, J.H. Revised Procedure for Reporting Serious and Non-Serious Incidents, including Loss of or Damage to Government Property. Memorandum to All Supervisors. Cincinnati, OH: National Lead Company of Ohio. 27 March 1961.

NLCO (National Lead Company of Ohio). Report of fire in stored drummed chips near Plant 6; Cincinnati, OH: National Lead Company of Ohio. 18 October 1962.

QA (Q.A. Committee). Incident reports and recommendation follow-up. Agenda for meeting held on August 27, 1985. (From Central Files, Ross box; incidents in 1984 and 1985).NLO/ICN ' 2116888. Cincinnati, OH: National Lead Company of Ohio. 27 August 1985.

- Rennich, G. to Files, Memorandum; Safety Inspection of NLO Scrap Recovery Plant, Digest Section. 8 June 1960.
- Ross, K.N. Drum Fire Plant 6. Memorandum for general distribution. Cincinnati, OH: National Lead Company of Ohio. 13 April 1965.
- Ross, K.N. Cleaning Dust from Heaters Plant 5. Incident Observation Report to R.H. Starkey. (Concern about cleaning method of blowing dust; no respiratory protection). Cincinnati, OH: National Lead Company of Ohio. 10 November 1966.
- Starkey, R. H. Excerpts from 3620 logbook concerning UF<sub>6</sub> leaks since 7/10/53. Memorandum to R.C. Heatherton. (Dates, shift and incident given; no quantitative information). Cincinnati, OH: National Lead Company of Ohio. 8 October 1953.
- Stevenson, J.B., Interim Report; Investigation of Chip Fire at Plant 6 October 18, 1962. Cincinnati, OH: National Lead Company of Ohio. No date.
- Spenceley, R.M. to Gessiness, B., Memorandum; Abnormal Loss Rolling Mill June, 1960; Cincinnati, OH: National Lead Company of Ohio. 30 August 1960.
- Starkey, R.H. Investigation of Remelt Furnace Explosion-Plant 9-2/21/62. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 21 February 1962.
- Stratman, W. J. Metal oxide spillage Silo area. Memorandum to A. Stewart, Jr. Cincinnati, OH: National Lead Company of Ohio. 30 January 1956.
- Turner, P.L. Metal oxide spill in the combined raffinate area. Memorandum to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. 6 April 1954.
- US DOE (US Department of Energy/Oak Ridge Operations). Investigation of September-December 1984 Plant 9 Excessive Uranium Emissions, Feed Materials Production Center. Report by Incident Investigation Board; ORO-855; Oak Ridge, TN: US Department of Energy/Oak Ridge Operations Office. 6 February 1985.
- US DOE Incident Investigation Board, Report; Investigation of September-December 1984 Plant 9 Excessive Uranium Emissions Feed Materials Production Center. 06 February 1985.
- US DOE (US Department of Energy/Oak Ridge Operations). Investigation Report on Plant 2/3 Gulping Emisson at the Feed Materials Production Center June 1988. DOE-ORO-897. Oak Ridge, TN: US Department of Energy/Oak Ridge Operations Office; (Investigation Board Report of June 7-28, 1988 increase in airborne U from Plant 2/3 Refinery; tried to determine what Plant 2/3 emissions were under actual production operations). November 1988.
- US DOE/ ORO (US Department of Energy/Oak Ridge Operations). Investigation of uranium trioxide spill at the Feed Material Production Center, Plant four. Report by Incident Investigation Board; DOE/ORO-878;Oak Ridge, TN: US Department of Energy/Oak Ridge Operations Office. 11 November 1986.
- Vaaler S. C. and K. R. Nuhfer. Airborne Emission From Historical Non-routine Events. Memorandum to B. L. Speicher, WMCO: PT: 89-107, 23 pages, Feed Materials Production Center, Fernald, National Lead Company of Ohio. 9 March 1989.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

Ε.,

÷,

ج. فلفلار

.....

Vaaler S. C. and K. R. Nuhfer. Airborne Emission From Historical Non-routine Events. Memorandum to B. L. Speicher, WMCO: PT: 89-107, 23 pages, Feed Materials Production Center, Fernald, National Lead Company of Ohio. 9 March 1989.

Walden, C. M. Spillage of UO, on storage pad. Memoradnum to M. M. Cawdrey. Cincinnati, OH: National Lead Company of Ohio. 8 July 1954.

Walden, C. H. to L. Zupancic, Memorandum; Possible Incidents Involving SS Material; Cincinnati, OH: National Lead Company of Ohio. 31 October 1957.

· · · ·

Warner, W. T.; Fey, C. J.; L. M. Levy, H. Martin, E.B. Riestenberg, R.H. Starkey, E.L. Giebel. Report of uranium hexafluoride gas release on February 14, 1966 at the Feed Materials Production Center, Fernald, Ohio. Cincinnati Area Office, US Atomic Energy Agency. 16 March 1966.

Wing, J. P. Rockwell Furnace Blowouts and Associated Air Dust Levels. Memorandum to L.M. Levy. Cincinnat, OH; National Lead Company of Ohio. 22 October 1962.

WMCO (Westinghouse Materials Company of Ohio). Occupational Safety and Helath suggestion/complaint. (30 page summary of approximatley 100 complaints by workers for January to June 1988; 3 incidents related to discharges of materials, asbestos). Cincinnati, OH: Westinghouse Materials Company of Ohio. 28 June 1988.

Zimber, C.W. to E.D. Leininger, Incident Observation Report; Emptying of Rotex Dust Collector No. 6018; Cincinnati, OH: National Lead Company of Ohio. 10 September 68. 1.13

4

### URANIUM IN MILK

1.1

Y

Karl, C.L. Activity in Milk from Cows Grazing on AEC Land. Letter to J.H. Noyes. (9 monthly composite milk sample U conc. listed; since low, plan to reduce frequency of sampling to every 6 months). US AEC. 20 October 1966. 1 m

Nelson, M.S. and J. H. Noyes. Activity in Milk from Cows Grazing on AEC Land. Letter to C.L. Karl. National Lead Company of Ohio. 13 December 1965. . Com Lette

Nelson, M.S. and J. H. Noyes. Activity in Milk from Cows Grazing on AEC Land. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio. 14 October 1966.

NLO.. Analytical Data Sheets. Montlhy milk 6 October 1965 sample from Byron Knollman farm Cincinnati, OH: National Lead Company of Ohio. 19 November 1965.

Ross, K.N. Activity in Milk from Cows Grazing in AEC Land. Letter to R.H. Starkey. (3 monthly composite samples from Knollman farm analyzed fro total activity and U). Attached to Nelson letter of 13 Dec 1965. Cincinnati, OH: National Lead Company of Ohio. 30 November 1965. 网络科学家 白垩

WASTE PITS/LAND BURIAL ASI/IT (Advanced Sciences, Inc. International Technology Corporation). Engineering evaluation/cost analysis waste pit area, storm water run-off control, Feed Materials Production Center, Fernald, Ohio, FMPC-0002-4. Prepared for U.S. Department of Energy. May 1990.

Page A-151

- Audia, S.F. Technical Division Recommendations for Reducing Uranium Losses in Plant 8 Trailer Cake. Memorandum to J.D. Cavendish. Cincinnati, OH: National Lead Company of Ohio. 3 March 1971.
- Audia, S.F. On-site Disposal of Solid Waste-Hamilton County. Memorandum to H.D. Fletcher, Ohio Health Department Report. 15 April 1977.
- Audia, S.F. to H.D. Fletcher, Memorandum; Solid Waste Information Management System Reports; Completed forms ERDA-735 for solid radioactive wastes generated and buried at FMPC during the first Quarter - FY 1977. 31 January 1977.
- Audia, S.F. to H.D. Fletcher, Memorandum; Solid Waste Information Management System Reports; Completed forms ERDA-735 for solid radioactive wastes generated and buried at FMPC during the second Quarter - FY 1977. 03 May 1977.
- Audia, S.F. to H.D. Fletcher, Memorandum; On-Site Disposal of Solid Waste Hamilton County, Ohio Health Department; National Lead Company of Ohio. 15 April 1977.
- Blythe, D.J. Select location and provide design for new scrap pit. Request for Engineering Services ICN 2232203. Requested by C.R. Chapman. (Existing scrap pit filling at rapid rate; estimated that it would be filled in nine months). Cincinnati, OH: National Lead Company of Ohio. 13 August 1954.
- Chapman, C.R. Results of first use of scrap pit. Memorandum to J.A. Noyes. Cincinnati, OH: National Lead Company of Ohio. 2 September 1953.
- Dames & Moore. Results of RCRA Sampling Feed Materials Production Center, Fernald, Ohio, Pit # 4; Pearl River, NY: Dames & Moore; August 1985. (In groundwater section) (First of series of quarterly reports describing groundwater monitoring being conducted at FMPC. Since Pit 4 subject to RCRA regulation, 4 monitoring wells sampled; includes soil classification for borings).
- Eye, J.D. Leakage of waste pits to shallow groundwater. Letter to J.A. Quigley. (Stresses urgent need for taking corrective measures; lists 4 steps involving test wells). Cincinnati, OH: University of Cincinnati. 25 May 1962.
- Cavendish, J.H. Insoluble Uranium Losses in the Plant 8 Trailer Cake (PT-82-01). Memorandum to S.F. Audia. Cincinnati, OH: National Lead Company of Ohio. 10 February 1971.
- Courtney, L. Discards to NLO pits. (Tables of discards to pits during FY 1969 to 1972 and FY 1960 to FY 1962; prepared at request of A. Pennak for AEC report). Cincinnati, OH: National Lead Company of Ohio. 12 July 1972.
- DeFazio, P.G. Capacity and condition of scrap pit. Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 24 May 1955.
- Defazio, P.G. to W.A. Smith, Memorandum; Soil Testing; CP-68-13-New Wet Chemical Scrap Pit. 19 June 1968.

Page A-152

- DeFazio, P.G. Capacity of scrap pit. Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio. 28 October 1954.
- DOE (U.S. Department of Energy). Initial screening of alternatives for Operable Unit 1, Task 12 report, Feed Materials Production Center, Fernald, Ohio. Remedial investigation and Feasibility study. Oak Ridge, TN: U.S. Department of Energy. January 1991.

Harris, W.B. to Files, Memorandum, Visit with Mr. Bruce McDill, Ohio State Health Department on July 30, 1953. 03 August 1953.

- Harris, W.B. to C.L. Karl, Memorandum; Disposal of Solid Insoluble Waste Materials. 03 August 1953.
- Heatherton, R.C. Plant 7 disposal to scrap pit. Memorandum to J.A. Quigley. (Dispose of calcium fluoride with high uranium levels of 0.5% U to scrap pit). Cincinnati, OH: National Lead Company of Ohio. 8 July 1954.
- Karl, C.L. to J.H. Noyes, Memorandum; Uranium Scrap Recovery Trailer Cake Assay. 15 July 1958.
- Karl, C.L. to J.H. Noyes, Memorandum; CP-68-13 New Wet Chemical Waste Pit. United States Atomic Energy Commission. 14 May 1968.
- Kispert, R.C. Update of economics of processing pit sludge and cold metal oxide for U recovery. Memorandum to L.M. Levy. (Economic incentives update for recovering uranium from pit sludge and cold metal oxide silo). 6 November 1978.
- Krause, M. J., September 1988. Interim Covering of Waste Pit 4 at the Feed Materials Production Center, FMPC-2140. For presentation at DOE Model Conference, Oak Ridge, TN, October 3-7, 1988. (Describes Pit 4, unique among the six pits because it contains mixed waste and has been classified under RCRA as hazardous waste landfill. Outlines design of domed cap for pit to meet US EPA request for interim closure, 9 pages, no tables or figures). 2 Cincinnati, OH: National Lead Company of Ohio.
- Leist, N.R. High Uranium Losses in the Plant 8 Trailer Cake (PT-82-01). Memorandum to J.H. Cavendish. Cincinnati, OH: National Lead Company of Ohio. 10 February 1971.
- McGill, B.M. Plan of proposed retention scarp pit. Letter to area manager of U.S. AEC. (Ohio Department of Health concurred with proposal). Columbus, OH: Ohio Department of Health. 10 September 1953.
- Merritt, R.W. Waste storage pits NLO. Internal memorandum to J. Keverain. (Summary of meeting with Sam Audia). National Lead Company. 7 July 1977.

Meyer, J.H. Daily loading of scrap pit. Memorandum to P.G. DeFazio. Cincinnati, OH: National Lead Company of Ohio. 23 May 1955.

Nelson, M.S. to C.L. Karl, Memorandum; Solid rad waste stored on site at FMPC. 07 April 1972.

Nelson, M.S. Process residue pit storage of radioactive wastes. Letter to C.L. Karl. (Annual report for 1970 of land burial of solid radioactive wastes). Cincinnati, OH: National Lead Company of Ohio. 8 January 1971.

. . . . .

537 S. 1

•

.....

Page A-153

- NLCO (National Lead Company of Ohio). Volume of waste pits at FMPC and diagram of waste disposal operation. (Handwritten notes of volume from FY1952 to FY 1972). Cincinnati, OH: National Lead Company of Ohio. 1972.
- NLCO (National Lead Company of Ohio). Diagram of waste pit area showing location of new pit 5. Cincinnati, OH: National Lead Company of Ohio. No date.
- NLCO (National Lead Company of Ohio).New scrap pit, CP-F-56-24, Revision 1. Cincinnati, OH: National Lead Company of Ohio. 13 November 1956.
- NLCO (National Lead Company of Ohio).Additional dry residue chemical pit in scrap pit area, CP-59-86. Cincinnati, OH: National Lead Company of Ohio. 26 August 1960.
- NLCO 24 October 1974. Environmental Assessment Wet Chemical Waste Pit No. 6. Project No. G-635, CP-74-5. (Re construction of new wet chemical waste pit [No. 6] adjacent to and east of Pit 5; capacity of pit will be 3,340,000 cu ft). Approved by M.S. Nelson. National Lead Company of Ohio.
- NLCO (National Lead Company of Ohio). Study of radioactive waste storage areas at the Feed Materials Production Center, NLCO-1143 (special). (Review of facilities and operating practices for waste disposal and storage; concludes that "no evidence that radioactive material moving from pits"). Cincinnati, OH: National Lead Company of Ohio. 25 April 1977.
- Noyes, J.H. to C.L. Karl, Memorandum; Solid Waste Disposal; Suggest opening landfill on-site rather than burning waste at pits. 14 March 1968.
- Noyes, J.H. Land Burial of Radioactive Wastes, July-December 1966. Memorandum to C.L. Karl. (6,774 cubic feet). Cincinnati, Ohio: National Lead Company of Ohio. 9 January 1967.
- Noyes, J.H. Land Burial of Radioactive Wastes. Memorandum to C.L. Karl. (72,695 cubic feet). Cincinnati, OH: National Lead Company of Ohio. 9 January 1963.
- Noyes, J.H. Land Burial of radioactive wastes, monthly report for June 1967. Memorandum to C. L. Karl. (55,760 cubic feet). Cincinnati, OH: National Lead Company of Ohio. 13 July 1967.
- Noyes, J.H. Management of radioactive waste disposal; Memorandum to C. L. Karl. (No serious accidents or unusual incidents in past 2 years). Cincinnati, OH: National Lead Company of Ohio. 14 October 1960.
- Noyes, J.H. Idea Letter; New Wet Chemical Waste Pit. Memorandum to C. L. Karl. Cincinnati, OH: National Lead Company of Ohio. 26 December 1967.
- Noyes, J.H. 1 July 1961. Land Burial of Radioactive Wastes for June 1961. Letter to C.L. Karl. National Lead Company of Ohio.
- Noyes, J.H. 7 August 1961. Land Burial of Radioactive Wastes for July 1961. Letter to C.L. Karl. National Lead Company of Ohio.

Page A-154

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

- Pennak, A.F. Handwritten note; 1973 Rad Waste Management Plant; 5 pages of calculations and notes on solid waste. 14 June 1973.
- Pennak, A. F. Quantities of solid waste from CY 64 CY 73. Memorandum to O. J. Turmelle. Cincinnati, OH: National Lead Company of Ohio. 20 June 1972.
- Poff, T.A., C.E. Pepper and B. Gessiness. 21 February 1985. Elemental Constituents in the FMPC Pits and Silos. Memorandum to W. J. Adams. (7 pages, including tables of waste quantity of U, U-235, thorium, radium-226). National Lead of Ohio.
- Robinson, C. M. Current practices for disposal of solid waste generated at facility. Memorandum to J. A. Quigley. (3500 lb. domestic refuse per day; 2500 lb. of pallets per day; 350 lb. of shipping boxes per day; 400 to 500 pounds of dried, digested sewage sludge per day; 10 to 12 drums of oil sludges per week; 3 drums of solvents per week; Hamilton County). Cincinnati, OH: National Lead Company of Ohio Solid Wastes. 28 May 1968.
- Spenceley, R. M. U Losses to the Environment. Memorandum to J. A. Reafsnyder. (Summary of liquid and airborne effluent U releases, table of U discards to pits for FY 52 -FY 84 = total 5,252,012 kg). Cincinnati, OH: National Lead of Ohio. 13 June 1985.
- Starkey, R. H. High activity to the pit during the NFS (Nuclear Fuel Service) UNH campaign of January 22-26, 1968. Memorandum to J. A, Quigley. (Lists quantities of soluble beta activity pumped to Pit 3, volume & activity of water pumped from pit, river flow, and calculated beta activity in river, 3 pages). 9 February 1968.
- Theis, C.V. Visit to Atomic Energy Commission's Fernald, Ohio Area, September 26, 1955. Memorandum to A.E. Gorman (Atomic Energy Commission, Washington, D.C.). (Describes waste facilities near Paddy's Run, drum storage of waste, and ground disposal of thorium process waste). NLO/ICN 2162584. Albuquerque, NM: US Department of the Interior, Geological Survey. 31 October 1955.
- Thiesen, M.R. EPA notification of hazardous waste site for waste pits 1, 2 and 3. (Includes description of waste pits). U.S. Department of Energy. 1988.
- Travis, W.H. to Hamilton County Health Department, Memorandum; Report Form: On-Site Disposal of Solid Wastes, Feed Materials Production Center, Fernald, Ohio; Includes quantities of waste materials to incinerator and to sanitary landfill. U.S. Energy Research and Development Administration. 07 June 1977.
- Vath, J.E. 3 August 1964. Report on the Sampling of Plant 8 Trailer Cake. Memorandum to B. Gessiness. (7 lots of trailer cake pipe-sampled by NMC and the PLP to chemical pit and compared to original plant sample value; suggests that more U discarded from process to pit than originally thought). National Lead Company of Ohio.
- Wing, J.F. FMPC and Weldon Spring Pits DOE contact report to M.W. Boback. (Tables of physical data on FMPC and Weldon Springs waste pits). Cincinnati, OH National Lead Company of Ohio. 20 July 1981.
- Wunder, G.W. Scrap pit. Idea letter to C.L. Karl. (Presents methods of dumping residues into pit; diagram of waste pit with paved approach and apron). Cincinnati, OH National Lead Company of Ohio. 1954.

1.0 2

تسريد فتترق والمتأر ومعارك فاستعد ويعارجني

1

and the second

k

Page A-155

Wunder, G.W. New scrap pit. Idea letter to C.L. Karl. (Waste pit 50% full, suggest new 300,00 cu. ft. pit). Cincinnati, OH: National Lead Company of Ohio. 20 March 1956.
#### APPENDIX B

#### PLANT PROCESSES AND WASTES

In this appendix the functions of each of the major processing facilities at the Feed Materials Production Center (FMPC) are discussed briefly. The major activities in each facility are highlighted and the chemical conversions that occurred are presented (WMCO 1988). Discussions with plant staff have indicated that the basic processing scheme was employed throughout all years of operation. The chemical forms of the radioactive materials are particularly important to the estimation of doses from material released to the atmosphere. More detailed information about uranium processing is available in Harrington and Ruehle (1959).

The FMPC was primarily concerned with processing uranium. Most of the uranium received at the FMPC had been separated from the naturally occurring daughter radionuclides, including <sup>226</sup>Ra. Appendix J describes the disposition of wastes from processing of raw uranium ores early in the history of the FMPC. Relatively small amounts of thorium were also processed at various times. General descriptions of the thorium processes are given in a later section. Cuthbert (1958) provides more detailed information on thorium processing.

To reflect the emphasis on uranium processing at the FMPC, presentation of plant functions in this appendix follows the flow of uranium through the various facilities as it was changed from the incoming material to finished products. The primary processing sequence involved Plant 1, Plant 2/3, Plant 4, Plant 5, Plant 9, and Plant 6. These facilities are discussed in that order. Figure B-1 illustrates flows of materials between facilities. Figure B-2 shows the layout of the plants within the Production Area at the FMPC.

Uranium that was recycled from other facilities entered the FMPC production scheme at a location consistent with its chemical form. For example, uranium delivered to the FMPC as  $UO_3$  could be fed directly to Plant 4 without processing in Plant 2/3. Recycled uranium was separated from fission and activation products prior to shipment to the FMPC; however, some of those radionuclides were present as contaminants. Appendix D contains the results of recent measurements performed to identify levels of fission and activation products in materials at the FMPC. Near the end of this appendix, the functions of other facilities and waste management activities are described.

#### PLANT 1 — THE SAMPLING PLANT

(maril)

Incoming materials for the FMPC were weighed, sampled, and analyzed for uranium (U) content in Plant 1. Initially, the plant handled large quantities of uranium ore and concentrates and had a crushing, grinding, and blending capacity of more than 9 metric tons per hour (about 20,000 pounds per hour).





1

i.

Figure B-2. Locations of major processing facilities within the production area at the Feed Materials Production Center.

In 1970, a digestion system was installed in Plant 1 to permit processing of uranium enriched to as much as 5% <sup>235</sup>U. This system was used intermittently in the later years of plant operation.

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

÷.,

2

Thus two types of processes were used in Plant 1:

• mechanical treatment: feed materials were dried, crushed, milled, ground,

classified, and blended if necessary

• digestion: feed materials were dissolved in acid solutions

Material prepared in Plant 1 was transferred to Plant 2/3 for processing as described in the following section.

#### PLANT 2/3 — THE REFINERY

The function of the refinery was to separate the uranium contained in various feed materials and convert it to a high-purity product, uranium trioxide  $(UO_3, called orange oxide because of its color)$ . This was accomplished using three chemical processes: digestion, extraction, and calcination (or denitration).

• digestion: uranium bearing materials were digested with nitric acid in an agitating tank to produce a slurry containing uranyl nitrate,  $UO_2(NO_3)_2$ , and nitric acid in solution and insoluble impurities.

• extraction: the aqueous slurry was mixed with an organic solvent consisting of tributyl phosphate dissolved in kerosene. The uranyl nitrate was preferentially extracted out of the aqueous phase into the organic solvent while the impurities and most of the nitric acid remained in the aqueous slurry. The purified uranyl nitrate was then preferentially extracted from the organic solvent into deionized water in the absence of nitric acid.

• calcination or denitrification: the uranyl nitrate solution was concentrated in a closed evaporator system and by further heating in large tanks. The concentrated material was then transferred to denitration pots. The pots were fired for several hours to convert the uranyl nitrate to uranium trioxide and drive off the volatile nitrogen oxides  $(NO_x)$ . The heat induced decomposition process is:  $UO_2(NO_3)_2 \rightarrow UO_3 + NO_x$ . The denitration pots were vented through a scrubber system so the nitrogen oxides could be recovered, as nitric acid, which was recycled to the digestion area.

The UO<sub>3</sub> product was transferred from the pots using a vacuum line. This transfer process, called "gulping" the pot of UO<sub>3</sub>, carried the product through cyclone separators to storage hoppers. The UO<sub>3</sub> was then ground and packaged for shipment to Plant 4 or offsite.

Some experimental work with thorium was conducted in the Refinery during the late. 1960s. No production scale thorium operations were undertaken in the facility.

#### PLANT 4 — THE GREEN SALT PLANT

Plant 4 was named for its product, uranium tetrafluoride (UF<sub>4</sub>, called green salt because of its color). The conversion of UO<sub>3</sub> to UF<sub>4</sub> was a two-stage process.

• reduction: powdered UO<sub>3</sub> was heated in stainless steel fluid bed reactors with dissociated ammonia (H<sub>2</sub> and N<sub>2</sub>) at temperatures ranging from about 530 to 590°C. The reduction of uranium trioxide to uranium dioxide (UO<sub>3</sub> to UO<sub>2</sub>) is: UO<sub>3</sub> + H<sub>2</sub>  $\rightarrow$  UO<sub>2</sub>+ H<sub>2</sub>O. The uranium product of this reaction was called brown oxide.

Page B-4

Appendix B Plant Processes and Wastes

> • hydrofluorination: the UO<sub>2</sub> produced by the reduction process was then reacted with anhydrous hydrogen fluoride in a series of three counter current flow screw reactors. The temperature in the metal reactors increases from about 150°C for the first to about 650°C for the last reactor. The hydrofluorination reaction is:  $UO_2 + 4 \text{ HF} \rightarrow UF_4 + 2H_2O$ . The UF<sub>4</sub> product was weighed, blended if necessary, and packaged for shipment to Plant 5.

Production of thorium tetrafluoride in Plant 4 occurred soon after startup of the facility in 1954. The reaction of thorium dioxide with HF is similar to the uranium reaction shown above.

#### PLANT 5 — METALS PRODUCTION

Conversion of  $UF_4$  to masses of uranium metal, called derbies, was accomplished in Plant 5. The derbies were then remelted and cast into ingots of metallic uranium. The reduction process in Plant 5 is described below:

 reduction: green salt was reacted with magnesium metal (Mg) in a steel pot lined with magnesium fluoride (MgF<sub>2</sub>) slag. The steel pot was heated in a furnace to a temperature between 650°C and 820°C for 3-4 hours before the reaction occurred. The metal product was a mass of uranium, called a derby, that weighed about 150 kg (~330 lb.). The reaction, which is exothermic, is:

 $UF_4 + 2 Mg \rightarrow U + 2 MgF_2$ . The internal temperature of the pot could reach 1650°C, well above the melting point of uranium metal (~1130°C).

After cooling, the derbies were transferred to casting area in Plant 5, to Plant 9, or shipped offsite. Activities in the casting area are described next. The processes in Plant 9 are described in the next section. The other principal activities in Plant 5 were:

• remelting and casting: uranium metal derbies and scrap uranium metal were vacuum melted in graphite crucibles, and the molten uranium metal (~1480°C) was flowed into heated graphite molds to produce ingots weighing up to 650 kg (1440 lb.).

The top 5 cm of each ingot was sawed off to remove cavities and impurities before the ingots were transferred to Plant 9 for drilling and machining. These croppings were subsequently remelted with derby metal.

#### PLANT 9 — SPECIAL PRODUCTS

Independent processes carried out in the plant included casting of large-diameter ingots from derbies and high-grade recycled metals, drilling and machining of uranium metal ingots for extrusion, and chemical decladding of rejected unirradiated fuel elements from Hanford. These processes are described below:

- casting: ingots that measured up to 33 cm (13 inches) in diameter and weighed up to 900 kg (~1980 lb.) were cast.
- drilling and machining: cropped billets were center drilled and machined, prior to shipment offsite for extrusion.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

**6**71

• chemical decladding: rejected unirradiated fuel elements from Hanford were immersed in dilute nitric acid to remove the outer layer of copper. They were then treated with dilute hydrofluoric acid to remove the Zircaloy-2 cladding from the uranium metal core of the element. The purified uranium metal was recycled to the ingot manufacturing process.

Machined billets were sent to Plant 6 for treatment and inspection before shipment offsite. Thorium metal was also processed in Plant 9 and thorium scrap metals were formed

into briquettes for recycle. These operations occurred during the period 1954–1955.

## PLANT 6 — METALS FABRICATION

Uranium metal billets and extruded tubes were heat treated, cut, and machined in this facility. Flat billets were also produced in a rolling mill. The feed stock of round billets was received from Plant 9; extruded tubes were received from offsite locations.

- heat-treatment: uranium metal billets from Plant 9 were heat treated in a neutral salt bath before shipment offsite for extrusion.
- cutting and machining: blanks were produced by lathe cutting extruded tubes to appropriate lengths. These were treated in a hot salt bath and quenched in oil before being automatically machined to specific tolerances. Machined fuel sections were degreased, pickled, rinsed, and dried before final inspection and shipment.
- rolling: a rolling mill was used to produce flat billets that were inspected and shipped offsite.
- recycling: chips and turnings were crushed, pickled, rinsed, dried, and formed into briquettes for use in the Plant 5 casting operation.

Scrap metal produced in Plant 6 was prepared for recycling through Plant 5.

PLANT 8 - SCRAP RECOVERY

Recycling of residues and metal scraps from production processes, at the FMPC and other sites, was designed to return a suitable material to the uranium production stream. Refinery preparation for high grade scraps employed various furnaces to oxidize the material. Low grade residues were processed to yield an ammonium diuranate cake. Initially, conversion of the cake to feedstocks that were acceptable for the refinery was accomplished by offsite contractors. After a plant expansion in 1955, the need for such offsite processing was eliminated. A rotary kiln and vertical hearth furnaces of various sizes were used in Plant 8. The enrichment of materials processed was limited to a maximum of 1.25% <sup>235</sup>U.

• refinery preparation: uranium metals, uranium octoxide  $(U_3O_8, called black oxide)$ , furnace salts, dust collector product, and floor sweepings were roasted in one of three furnace to dry them and to oxidize impurities such as metals, oil, and graphite.

• hydrometallurgical processing: conversion of various low grade residue forms to ammonium diuranate (ADU) cake or uranium ammonium phosphate (UAP) was performed in accordance with feed available and refinery requirements.

## Appendix B Equip Plant Processes and Wastes

Processing steps varied over the years of operation of Plant 8. The history of the recovery operations (Mead 1972) provides additional details on processing and the range of recovery operations undertaken at the FMPC.

Plant 8 was also involved in the production of thorium hydroxide and thorium oxalate and the calcination of sump cakes that contained thorium. These operations occurred between 1966 and 1971.

#### PILOT PLANT

Charles Reason

The Pilot Plant was used for numerous process testing and experimental operations. It was also employed as a production facility for various processes. In the early years, derbies were produced there, in the manner described above for Plant 5. Another process operated on a production scale was the direct conversion of uranium hexafluoride (UF<sub>6</sub>) to green salt (UF<sub>4</sub>). This production process was operated with UF<sub>6</sub> that contained as much as 2.5% <sup>225</sup>U. A two-step procedure was used:

- vaporization of  $UF_6$ : solid  $UF_6$  in large cylinders was heated in autoclaves at approximately 110°C to produce gaseous  $UF_6$ .
- reduction of UF<sub>6</sub>: gaseous UF<sub>6</sub> was mixed with hydrogen gas at 480-650°C in metal reactors to produce UF<sub>4</sub> powder. Hydrogen fluoride (HF) was a valuable byproduct of the reaction, which was: UF<sub>6</sub> + H<sub>2</sub>  $\rightarrow$  UF<sub>4</sub> + 2 HF.

Much of the thorium production activity at the FMPC took place in the Pilot Plant. Several processes were operated there, beginning in 1964. Thorium production activities continued until 1980.

#### PLANT 7 — URANIUM HEXAFLUORIDE CONVERSION TO GREEN SALT

Plant 7 utilized the process for conversion of  $UF_6$  to  $UF_4$  that had bee successfully employed and improved in the Pilot Plant. There were two sets of four reactors in the facility. One set was used for natural uranium; the other was used for depleted uranium. Each reactor was designed for greater capacity than had been available in the Pilot Plant. Normally, three reactors were in operation and one was held as a spare. Under these conditions, production capacity was six tons per day for natural and depleted uranium tetrafluoride production. Plant 7 produced green salt for only two years, from June 1954 through May 1956, before it was closed and subsequently dismantled.

#### THE K-65 STORAGE SILOS

The K-65 Storage Silos were constructed of concrete in the western portion of the FMPC site in 1951-1952. Their purpose was to store residues from the extraction of uranium from ore concentrates that were processed during the early years of FMPC operation. The residues, containing the daughter products of the uranium decay chains, were transferred to the silos as slurries, primarily between 1953 and 1955. Other waste materials were also slurried to the silos in later years.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

The slurried waste solids contain particulate radionuclides including radium (Ra). The nuclide <sup>226</sup>Ra decays to <sup>222</sup>Rn (radon gas), which can diffuse into the airspace of the silo and be released to the atmosphere. A detailed discussion of this process and of the changes to the silos that affect it is presented in Appendix J of this report.

## WASTE INCINERATORS AND BURNERS

An incinerator for solid waste materials was installed near the eastern facility boundary, outside the production area, in 1954. This incinerator was operated intermittently until 1979, when it was found to be out of compliance with applicable codes. In 1980, a new solid waste incinerator was installed in the same area. A detailed chronology is provided in Appendix K.

A graphite burner, an oil burner, and an incinerator for organic liquids were also operated for varying periods. Both the graphite burner and the oil burner were simple arrangements that operated for about twenty years. The graphite burner was operated from November 1965 to September 1984. The oil burner began operation at the end of March 1962 and operated until June 1979. The liquid organic waste incinerator was installed in April 1983 and has operated since that time. Appendix K contains more information about these facilities. Estimated releases from these sources are presented in that appendix.

#### THE GENERAL SUMP FOR LIQUID WASTES

Physically, the General Sump is a collection of tanks of various sizes, pumps, piping and valves where process wastes from the various plants were received and analyzed. Some liquid wastes were generated in almost every operation at FMPC. The major process areas had individual treatment facilities capable of pretreating the liquid wastes that were peculiar to that particular process step. These plant treatment facilities were simple installations which provided equipment and tanks to collect waste liquors, to adjust pH for precipitation of uranium, and to filter the resultant slurry. Filter cake that resulted from precipitation, was recycled as a process residue, while the filtrate was pumped to the General Sump System. Effluent slurries from Plant 8 were discharged directly to the pits if uranium concentrations were below the discard limit. If the concentration was higher, the slurry was recycled (Johnson et al. 1958, Calhane 1961).

In addition, the Plant 2/3 Refinery had a sump system in place for neutralizing and recovering process materials and effluents. Some wastes received at the General Sump required only settlement and movement through the various tanks prior to discharge of the supernatant liquid and sludges to the wet chemical waste pit. If certain wastes exceeded the discard specifications for the General Sump, however, it was recycled through the Refinery sump in Plant 2/3 for further treatment. Standard Operating Procedures (NLCO 1961) directed that all acidic uranium-bearing wastes be adjusted for pH to obtain maximum precipitation of the radioactive material before being pumped to the wet chemical waste pit.

After settling had occurred in the tanks of the General Sump, the effluent was pumped to the Clearwell. located near the waste pits (Figure B-3). From the clearwell, the effluent was combined with effluents from the storm sewer system, treated sanitary sewer system and water treatment plant effluent before being discharged through Manhole 175 and the

## Appendix B

#### Plant Processes and Wastes

main effluent line to the Great Miami River. See Appendix L for more information about liquid waste disposal.

In October 1986, the Storm Water Retention Basin (SWRB) went on-line to help lower the number of storm sewer overflow violations. Runoff from the waste pit 4 was collected in the SWRB and then discharge into the plant effluent via waste pits 5 and 6, and the clearwell. This system helps control the flow of runoff from the waste storage area into Paddy's Run Creek. The SWRB also resulted in a decrease in total uranium discharged to the Storm Sewer Outfall Ditch (SSOD) (WMCO 1988). In 1986, prior to the SWRB operation, there were 3 hexavalent chromium violations at the combined General Sump and clearwell; and 3 total suspended solids (TSS) violations at Manhole (MH)-175; in 1987 there were no violations (Reafsnyder 1987).

Several major changes in treatment of FMPC process wastes occurred in 1987. First, on February 23, 1987, Waste Pit 5 and the clearwell were taken off-line to protect the groundwater as mandated by the Ohio EPA Director's Findings and Orders (DFO). At that time, wastewater was routed from the General Sump to the Biosurge Lagoon (BSL), instead of to Pit 5. The DFO also required that an additional liner be placed in the BSL by September 1988. Consequently, wastewater was emptied from the lagoon, and a larger percentage of the process wastewater was discharged from the General Sump directly to MH-175 during the summer of 1987.

Since the Biodenitrification facility was on-line, the FMPC could meet the National Pollutant Discharge Elimination System (NPDES) discharge limits for nitrates 90% of the time. The biosurge lagoon was taken off-line in October 1987 to prepare for the upgrade of the liner. While the biosurge lagoon was out of service, flows were routed to two nearby temporary tanks designed to hold process waste water flows.

#### LIQUID AND SOLID WASTE DISPOSAL PITS

Several waste disposal pits have been utilized during the course of the operations at the FMPC. These pits were all located near the western boundary of the site, close to Paddy's Run Creek (see Figure B-3). There were six pits in all; three were used for disposal of dry solid wastes only and three were used to dispose of liquid wastes. The largest amount of waste was disposed in Pit 3, a liquid waste disposal pit. The periods of operation of each of the six pits are shown in Figure B-4. More detailed information about the sizes of the pits and their construction is given in Appendix K.

Wastes in the first four of the pits may have contributed to groundwater contamination. Even though three of these were used for disposal of solid waste, the presence of rainwater and collection of snow melt presented opportunities for downward migration of waste materials. The bottoms of Pits 5 and 6 were both lined with rubber and were therefore less likely to contribute to subsurface soil and groundwater contamination.



Figure B-3. Diagram of the FMPC showing the waste pits, the active and inactive fly ash pits and scrap materials area.

Appendix B Plant Processes and Wastes

ر نۇ

E.

inc.

11\_





Figure B-4. Historic use and current status of the waste pits, burn pit and clearwell at the FMPC.

Page B-12

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

ŗ.

## GASEOUS WASTE TREATMENT SYSTEMS

The two types of gaseous effluent treatment systems employed at the FMPC were dust collectors and scrubbers. Not all gaseous waste streams were treated by such systems. The incinerator and simple waste burners, building roof exhaust vents, and laboratory hood exhausts are examples of untreated gaseous discharges. Many important process exhausts discharged through dust collectors. Dust collectors employed bag filters to remove airborne particulates from an exhaust stream. A few exhaust streams passed through liquid scrubber systems. Scrubbers employed either acid or caustic solutions to scavenge particles from the air stream being discharged to the atmosphere. Each type of system is discussed below. More detailed information about performance of these systems is given in Appendices E, H, and I.

fastind, p

#### Dust Collectors

Many of the processes that operated in the FMPC facilities were served by dust collectors. In some cases a single operation, such as an area used for packaging of a solid product, would be ventilated through a collector to remove the airborne dust generated by the packaging process and recover the product material. In other situations, exhaust air from several operations was carried by ventilation ductwork to the dust collector. In some installations, the airborne dust passed through a cyclone separator prior to reaching the dust collector. In the cyclone, particles are removed from the air stream by impaction on the walls as the air flows along a path of circular cross section with constantly decreasing radius.

Although a variety of dust collection equipment was used at the FMPC, the designs shared many common features. Dust collectors contained numerous bag filters through which the air passed before discharge to the environment. The bag filters resembled an array of hollow vertical columns. The filter bags were clamped to supports at both the top and bottom. The collector intake routed the contaminated air into the inside of the columns formed by the filter bags. The air was drawn through the bag material and discharged to the atmosphere by the system's blower. The collector designs included a bag cleaning mechanism that dislodged dust deposited on the inside of the filter bags. The dust fell by gravity into a hopper which was periodically emptied into a drum. The recovered material was then recycled.

The filtration medium used most frequently at the FMPC was virgin wool felt; bags composed of this fabric were manufactured to FMPC specifications. Several different materials were studied and used at various times during the history of particular plants. These materials included other forms of wool felt; polyesters, and most recently Gore-Tex<sup>TM</sup>. Much of the testing of alternative filtration materials was undertaken to try to reduce failures of dust collector bags. Some dust collectors handled exhaust air which was at elevated temperatures and/or contained corrosive compounds, such as HF. Bags deteriorated under such conditions and failures of filter bags were often the reasons for elevated releases (see Appendix E). Such failures could be detected in several ways: by periodic inspection, by the elevated release rate determined by analyzing the effluent sample filter, or by measurements of the pressure drop across the filtration system. In later

## Appendix B Plant Processes and Wastes

years, radiation detectors were installed to monitor the filter that collected the effluent sample; the system would alarm when sufficient radioactive material collected on the filter to indicate that an abnormally large release had occurred. When such releases were detected, the exhaust system was shut down and the failed bags were replaced.

Most dust collector exhaust streams were sampled on a continuous basis. Measurements of the amounts of dust collected by the systems were also made when the material was drummed for recycling. The results of some of these operational measurements were reported by Ross and Boback (1971). The data showed that dust collection systems could be highly efficient. Measurements made on four collection systems in Plant 5 between May 1968 and September 1971 yielded estimated efficiencies of greater than 99.9%. However, available data on effluents from dust collectors (Appendix E) show that these systems were not consistently as efficient as they were during the period studied by Ross and Boback (1971).

#### Scrubber Systems

1

-----

While all of the FMPC facilities employed dust collectors, the use of scrubber systems for radioactive effluent control was predominantly at two facilities, Plant 2/3 and Plant 8. These systems were used for effluent streams that were corrosive and/or at high temperature. In Plant 2/3, the NO<sub>x</sub> fumes driven off during denitration and the airstream from the UO<sub>3</sub> gulping operation were passed through scrubbers that employed a nitric acid solution. The solution became more acidic as the NO<sub>x</sub> fumes were collected and was periodically diluted. The nitric acid produced was recycled for use in the Refinery. The uranium collected by the system was also returned to the digestion area. Before entering the scrubber, the particle-laden air stream from the UO<sub>3</sub> transfer operation was passed through a primary cyclone and a secondary cyclone to collect the UO<sub>3</sub> product. The material was stored in a surge hopper prior to grinding and packaging. Appendix H contains more information about the Plant 2/3 scrubbers.

In Plant 8, scrubbers were used to cleanse the exhausts from the rotary kiln, the primary calciner, and various other furnaces. The hot exhaust gases were forced to follow an extended path through the scrub liquor to maximize the contact between the gases and the solution. This arrangement is designed to cool the discharge and to increase the removal of particulates. The scrub liquor for these systems was sodium hydroxide solution. The Plant 8 scrubbers are described in more detail in Appendix I.

Because routine sampling of scrubber exhausts was not performed, periods of elevated releases cannot be identified directly. Measurements of the efficiency of the Plant 8 scrubber systems were performed periodically over the years, beginning in the late 1950s. Those measurements provide some historical evidence of system performance. Measurements of releases from the Plant 2/3 scrubbers were performed only recently. Because the system has changed little over the years, the recent data can be used to estimate releases from that source. The results of the scrubber efficiency evaluations and effluent release measurements are discussed in Appendices H and I.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

с. ×

- -

#### REFERENCES

1 .

a filmente de la compañía de la comp

· · · · ·

· . . ·

Calhane, R. W. The operation of the General Sump System, FMPC Manufacturing Standards; Cincinnati, OH: National Lead Company of Ohio; SOP 3C-501; 24 March 1961.

Cuthbert, F. L. Thorium production technology. Reading, MA: Addison-Wesley Publishing Company, Inc. 1958.

Harrington, C. D. and Ruehle, A. E. (Eds). Uranium production technology. New York: D. Van Nostrand Company, Inc.; 1959.

.

Johnson, E. R.; Rutenkroger, E. O.; Kreuzmann, A. B.; Doumas, B. C. General description of the hydrometallurgical system; Cincinnati, OH: National Lead Company of Ohio; Specification No. 8A-101; FMPC Manufacturing Standards; 15 September 1958.

Mead, J. C. History of FMPC residue recovery operations. Cincinnati, OH: National Lead Company of Ohio; NLCO-1096; 1972.

NLCO (National Lead Company of Ohio). Standard Operating Procudure — the refinery sump operations, production — plants 2 & 3; Cincinnati, OH: National Lead Company of Ohio; SOP 3C-206; 10 April 1961.

Reafsnyder, J. A. Trends in radioactivity in effluent water - Feed Materials Production Center (FMPC). Letter to L. C. Bogar; Cincinnati, OH: Westinghouse Materials Company of Ohio; 23 November 1987.

Ross, K. N.; Boback, M. W. The control and sampling of airborne contaminants from uranium production. Paper Prepared for Presentation at the 101st Annual Meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers. Cincinnati, OH: Westinghouse Materials Company of Ohio; 1971.

WMCO (Westinghouse Materials Company of Ohio). A closer look at uranium metal production, a technical overview. Cincinnati, OH: Westinghouse Materials Company of Ohio; 1988.

WMCO (Westinghouse Materials Company of Ohio). Feed Materials Production Center environmental monitoring annual report for 1987. Cincinnati, OH: Westinghouse Materials Company of Ohio; FMPC-2135; 1988.

LINTER EL MA

iy Buildening Build

i te kultur et a gana et

Sec. Bridge .

#### APPENDIX C

11

#### FMPC PRODUCTION INFORMATION

#### INTRODUCTION

The FMPC primarily processed uranium and its compounds, but thorium metal and compounds were also produced in relatively small quantities on several occasions. Production information for uranium and thorium provides a guide to the magnitude of FMPC activities over the years and, in the absence of other data, can be used as an aid in estimation of facility releases to the environment. Data on uranium processing by fiscal year are presented in the Annex at the end of this appendix.

Several types of data are presented in this appendix. Information on receipts of material at the FMPC and shipments from it provides a rough indication of production. When available, plant-specific production rates are also presented because they are more useful for estimating releases from specific facilities.

A variable factor during the course of uranium production was the  $^{235}$ U content of the uranium being processed. The concentration of  $^{235}$ U in a sample-or batch of uranium is generically referred to as the "enrichment" of the material. Three general categories of uranium enrichment based upon the concentrations of  $^{235}$ U present are defined as follows:

- natural uranium contains 0.72% <sup>235</sup>U; also called "normal" uranium
- depleted uranium contains significantly less than 0.72% <sup>235</sup>U, typically 0.14– 0.20% at the FMPC
- enriched uranium contains more than the natural concentration of <sup>235</sup>U, typically 0.95-1.25% at the FMPC

Data on the enrichment of processed uranium are presented using these categories in the figures and tables of this appendix.

While most of the enriched uranium was in the range shown above, some processing of 2% enriched uranium occurred in the 1960s. The capability to digest 5% enriched uranium was added to Plant 1 in 1970.

Some of the uranium received at the FMPC was recycled. That is, it had been recovered from reactor fuel prior to shipment to the FMPC. The enrichment of the recycled material was variable. Processing of the fuel separated the uranium from the bulk of the fission and activation products in the irradiated fuel. However, some of those radionuclides were detectable as contaminants in the uranium. Appendix D contains the results of recent measurements of fission and activation products in materials at the FMPC.

Thorium production at the FMPC was estimated to have been only about 0.4% of the uranium production. Processing was limited to a few facilities and to specific time periods.

Page C-2

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

#### URANIUM PRODUCTION

The following assessment of historic uranium production at the FMPC is divided into: (1) gross receipts and shipments of uranium, (2) plant-specific production data, and (3) shipments of specific uranium products.

#### **Gross Receipts and Shipments of Uranium**

A general indication of overall plant activity from fiscal year 1952 through fiscal year 1980 is provided by data on the receipt of uranium at the FMPC and the subsequent shipment of uranium products to other locations (FMPC 1988). The information available is generally tabulated on a fiscal year (FY) basis because FMPC budgets followed that schedule. The government's fiscal year changed in 1976 from a July-June to an October-September calendar. In the following data summaries, shipment and production activities during July-September 1976 are included in FY 1976. When making comparisons, it is necessary to remember that fiscal "year" 1976 contains 15 calendar months.

After FY 1980, the accountability system was changed to include onsite transfers between FMPC plants in the total quantities received and shipped. As a consequence, receipts and shipments listed in accountability reports after FY 1980 do not reflect overall FMPC activity and are not included here.

During the fiscal years 1952 through 1980, the FMPC received about 362 thousand metric tons (MT) of uranium and shipped about 358 thousand MT to offsite locations (Audia 1977; FMPC 1988). Approximately 54% of the receipts and shipments were natural uranium, about 20% were enriched uranium, and some 26% were depleted uranium. Table C-1 shows the total receipts and shipments for the three categories of material. Data for individual fiscal years are given in Table C1-1 in the Annex. (It should be noted that some material may have been counted twice, even in these tabulations. For example, billets manufactured at the FMPC were shipped offsite for extrusion, then shipped back for final processing before the finished reactor fuel was sent to the customer.) No detailed time history of the amount of uranium stored onsite at the FMPC has been found.

×	<u> </u>	· · ·	1 ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) (
Activity	Natural	Enriched	Depleted
Receipts	1.94 x 10 <sup>5</sup>	7.14 x 10 <sup>4</sup>	9.65 x 10 <sup>4</sup>
Shipments	$1.95 \times 10^5$	6.95 x 10 <sup>4</sup>	9.35 x 10 <sup>4</sup>

Table C-1. Quantities (MT) of Uranium Received by and Shipped from the FMPC Between July 1951 and September 1980

The distributions of uranium receipts and shipments among the three uranium enrichment categories were not constant with time. Figure C-1 shows the fractions of the uranium receipts that were natural, enriched, and depleted uranium during each of the fiscal years. Most of the uranium received at the FMPC during the first decade of operation was natural uranium. Some significant quantities of depleted uranium were received during FY 1955 and FY 1956. Enriched uranium receipts did not exceed 10% of the total until 1961, but then rose steadily until 1966. Following that time, the material received was a highly variable mixture of the three uranium enrichment categories.

# 

K.

ŧ.



.

in Steen

COLONIA STATE

1111

1

in the second second

•=



Uranium shipments from the FMPC (Figure C-2) tended to follow the pattern of receipts during most of the first 29 years of operation. This was particularly true for enriched uranium for the twenty years between 1955 and 1974; in only three of those years was the difference between the two quantities more than 30%. The ratios of shipments to

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

12

receipts for depleted uranium were highly variable between 1957 and 1967, but were more consistent before and after that time. For natural uranium, the quantity shipped was always within 30%, and usually within 20%, of the amount received between 1953 and 1966. After that time, there was much greater variability as the inventory that had been built up was converted to finished products and shipped. Comparisons of the data on receipts and shipments indicate that material was received, processing occurred, and products were shipped on a fairly regular schedule.

Figure C-3 is a plot of the total annual shipments, in metric tons of uranium (MTU), of all three categories of uranium. It is an indication of the magnitude of plant operations during the first 29 years of operation. The amount shipped during 1952, about 160 MTU, is not shown clearly in the figure. While the plot gives an idea of the overall site activity for the entire FMPC, it does not address the operation of specific processes. Data for individual plant operations are given in the next section.



FMPC during FY 1952-1980.

## Plant-Specific Uranium Production Data

Operation of the various facilities at the FMPC varied with time. Processing rates were increased or reduced because of changes in the demand for intermediate materials and finished metal products. Data on specific material production rates are more directly related to radionuclide releases from individual facilities. The data on uranium processing listed in the Annex and summarized in figures in this section come from several different sources at the FMPC (Audia 1977; Dunaway 1993; FMPC 1988; Rathgens 1985). The plots shown below illustrate the variations in operational histories of specific FMPC facilities.

Page C-4

÷

## Appendix C FMPC Production Information

Plant 2/3. Figure C-4 contains the production rates for uranium trioxide  $(UO_3)$  during the fiscal years 1952 through 1988. The plot shows two periods when the annual production of  $UO_3$  exceeded 4000 MTU as well as extended periods of lower production. Data for individual fiscal years are given in Table C1-2 in the Annex. These production rates are important for estimation of releases from the  $UO_3$  vacuum transfer and packaging activities.



Figure C-4. Annual production (MTU) of UO<sub>3</sub> in Plant 2/3 during FY 1953-1988.

Data on the distribution of the  $UO_3$  by enrichment category are shown in Figure C-5 for the period FY 1953-88. There was no production of  $UO_3$  during fiscal years 1953, 1963-1964, and 1978-1980. During FY 1965, when  $UO_3$  production resumed, only enriched uranium was processed. The fraction that was enriched exceeded 0.5 between FY 1965 and FY 1970, but then declined rapidly. The only identified  $UO_3$  production from depleted uranium was 41 MTU in FY 1970, 4.7% of the total production for that year. This fraction is not shown in Figure C-5, but is reflected in the data shown for that year. Of the approximately 111,000 MTU converted to  $UO_3$  during FY 1952-1976, nearly 94% was natural uranium.

Plant 4. Figure C-6 contains data on production of green salt (UF<sub>4</sub>) in Plant 4. The highest annual production, greater than 12000 MTU, occurred in FY 1958. In each of the fiscal years from 1957 to 1963, UF<sub>4</sub> production exceeded 9000 MTU. Production declined steadily during subsequent years. During the period FY 1971-1988, the production of UF<sub>4</sub> was less than 1250 MTU. Data for individual fiscal years are given in Table C1-2 in the Annex. Comparing the UF<sub>4</sub> and UO<sub>3</sub> production curves (Figures C-6 and C-4, respectively) suggests that an offsite source provided some UO<sub>3</sub> feed for Plant 4 prior to FY 1959 and a substantial amount of the feedstock between FY 1963 and FY 1968.



during FY 1953-1988.

The fractions of the UF<sub>4</sub> production from natural and enriched uranium are shown in Figure C-7. Before FY 1963, all the UF<sub>4</sub> was produced from natural uranium. After FY 1962, enriched UF<sub>4</sub> production began to increase. Enriched uranium was the dominant material for UF<sub>4</sub> production in the years following FY 1966. Depleted UF<sub>4</sub> (not shown in the

## Appendix C FMPC Production Information

in the second

المتانين

figure) was produced in only one year, FY 1970. It accounted for almost 20% of the total production in that year. During the period FY 1952–1976, UF<sub>4</sub> production in Plant 4 was ~89,000 MTU from natural uranium, ~20,000 MTU from enriched uranium, and only ~340 MTU from depleted uranium.





Plant 5. Figure C-8 contains the data on production of uranium metal derbies and ingots in Plant 5. The derby production plot indicates the amounts, in MTU, of  $UF_4$  that were reduced to uranium metal. The ingot production data show the throughput of the metal remelt furnaces and casting operations. Annual production for both processes was at a high level between FY 1956 and FY 1967. Then production declined to a relatively constant lower level until FY 1979 when it again increased. Data for individual fiscal years are given in the Annex in Tables C1-3 and C1-4.

The distribution of derby production by uranium enrichment category is shown for Plant 5 in Figure C-9. Depleted uranium derbies were produced only after FY 1964. Production of derbies from enriched uranium began in FY 1958.

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page C-7



principal form in FY 1969 and FY 1971–1988.



Figure C-10. Fractions of Plant 5 ingot production from natural, enriched, and depleted uranium during FY 1953-1988.

Plant 9. Casting of ingots was also accomplished in Plant 9 during FY 1958 and subsequent years. Figure C-11 shows the production data for that operation. Also shown in the figure is the throughput for the ingot and billet machining operations in Plant 9, which began in 1966. After peaking in the years FY 1964-1965, ingot production in Plant 9 was generally much lower after the start of the machining operations. Table C1-5 in the Annex contains the production data for individual fiscal years. The total production of core and target elements in Plant 9 during FY 1958-1971 was about 22,000 MTU. There was no production of enriched uranium cores and target elements during FY 1953-1957 or during FY 1972-1976.

In contrast with the <sup>235</sup>U content of materials handled in Plant 5, nearly all of the uranium processed in Plant 9 was enriched. Natural uranium was processed in Plant 9 only in FY 1973 and accounted for just 3 percent of the throughput during that year. Reactor cores and target elements produced in Plant 9 were also composed of enriched uranium.

Plant 6. Production data for Plant 6 are shown in two curves in Figure C-12. The first of these is the production of rods by the rolling mill. That operation began in FY 1953 and continued until FY 1971. The second curve shows the annual production of machined fuel elements. This activity also declined after FY 1964, but continued at a greatly reduced rate between FY 1971 and FY 1988. Data on production during individual fiscal years are shown in Table C1-5 in the Annex.



## Appendix C FMPC Production Information

1.1

-

Fractional distributions of the products from Plant 6 according to their  $^{235}$ U content are shown in Figure C-13. Prior to FY 1965, all the products were manufactured using natural uranium. During FY 1966-1968, enriched uranium was used for 15-31% of the cores and targets produced. Production of depleted uranium products began in FY 1967 and was the dominant material in FY 1969 and during FY 1971-1976. Table C1-6 in the Annex contains the data for individual fiscal years. This distribution of materials is similar to that for ingots produced in Plant 5 during the same period (Figure C-10). Approximately 107,000 MTU of core and target elements were produced in Plant 6 between FY 1952 and FY 1976. More than 88% of the total was produced from natural uranium; about 9% of the elements were made of depleted uranium. Distribution by enrichment category is not presently available for years beyond 1976.



Figure C-13. Fractions of Plant 6 core and target production from natural, enriched, and depleted uranium during FY 1953-1976.

Plant 7. Uranium tetrafluoride was produced by reacting  $UF_6$  with hydrogen in Plant 7 for two years, from June 1954 through May 1956. Its design capacity was 12 tons per day of uranium as  $UF_4$ , when six of eight reactors were operating. Depleted and natural uranium products were produced; each bank of four reactors included a spare. Little information on actual production has been found. During January-May 1956 the normal uranium bank of reactors produced 656 MTU of  $UF_4$ . During January-April of the same year, the bank handling depleted uranium produced 1114 MTU of  $UF_4$ . It may be presumed that all four reactors may have been operating or that three reactors operated well above the initial design capacity during this four-month period. The limited monthly data are given in the Annex.

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page C-11

Page C-1:

. :

**τ**:

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

9

Plant 8. The recovery of uranium from scrap material in various forms was accomplished in Plant 8. The recovered uranium then became feed for the Plant 2/3 Refinery. Figure C-14 shows the amounts (MTU) of uranium recovery by Plant 8 by fiscal year. During FY 1955-1969, uranium recovery exceeded 1000 MTU per year. During eight years of operation, uranium recovery exceeded 2000 MTU per year. Uranium recovery data for individual fiscal years are given in Table C1-7 in the Annex.



Figure C-14. Annual uranium recovery (MTU) from scrap during FY 1953-1988

Figure C-15 contains the fractions of the total uranium values recovered that were natural and enriched uranium through FY 1988. During the first nine years of operation, natural uranium was the only material recovered. Processing of scrap containing enriched uranium began in 1963. The fraction of the uranium recovered that was enriched was greater than 0.5 during nine of the eleven years during the period FY 1966-1976. A total of ~38,000 MTU was recovered through FY 1988. Approximately 78% of the uranium recovered through FY 1976 was natural uranium. There is currently no information concerning distribution by enrichment category for years from 1977 through 1984.

Depleted uranium comprised less than 0.2% of the total amount of uranium recovered by Plant 8 during the period FY 1953 through FY 1976. For the four years, 1985 through 1988, however, the percentage of depleted uranium was 21, 19, 80, and 69%, respectively (Table C1-7).

Mit an amitwik mit benefit,
Mit an amitwik mit benefit,
Mit an amitwik mit benefit,

with the lotter set.

and a construction of



Figure C-15. Fractions of material recovered by Plant 8 that were natural or enriched uranium during FY 1952-1988.

Pilot Plant. The FMPC Pilot Plant was used for production activities as well as process development and testing. Detailed data for the complete range of production campaigns have not yet been uncovered. However, data are available on the production of  $UF_4$  from  $UF_6$  in the Pilot Plant. Annual production figures are plotted in Figure C-16. The figure shows an increase to the peak production of about 3500 MTU in 1964 and the subsequent equally rapid decline in production in later years. Data for  $UF_4$  production during individual fiscal years are shown in Table C1-8 in the Annex. Information about the small quantities produced during the early years (1953-1956) came from Davis (1956). There was no  $UF_4$  production during the years 1968 through 1984, but production was restarted in 1985.

Much of the  $UF_6$  to  $UF_4$  conversion was performed using enriched uranium. The distribution of natural and enriched uranium employed for  $UF_4$  production in the PilotPlant is shown in Figure C-17. Initial production was primarily from enriched  $UF_6$ , but production was about evenly divided between the two forms between FY 1962 to FY 1965. Enriched uranium was then used almost exclusively as the feedstock during 1967  $UF_4$ production. Depleted uranium was used for  $UF_4$  produced during 1986, 1987, and 1988. It accounted for 53, 70, and 100% of total production in those years.

Detailed data on the enrichment of uranium employed in other work at the Pilot Plant has not been uncovered. The record of shipments of uranium to the FMPC indicates clearly that the earliest operations would have employed natural uranium. However, the material usage in later years may have been quite variable.



م. با هزار



Figure C-17. Fractions of Pilot Plant  $UF_4$  production using natural or enriched uranium during FY 1953-1988.

(a) A state of the state of

•

11.

## Appendix C FMPC Production Information

#### Shipments of Specific Uranium Products

A compilation of historic data on specific products (Rathgens 1985) provides additional information on the manufacture of products composed of uranium of varying <sup>235</sup>U content. Detailed data for individual fiscal years are given in Tables C1-9 and C1-10 of the Annex. Fuel cores and target elements were shipped to both the Richland Operation (RLO) and the Savannah River Plant (SRP) for reactors in operation there. Figure C-18 shows the total shipments of natural, enriched, and depleted uranium, in several configurations, for FY 1952 through FY 1976. These products were finished in Plants 6 and 9 at the FMPC. During the first decade of operation, most of these products were manufactured from natural uranium. Enriched uranium was employed in greater than 10% of the production of fuel and target elements between FY 1967 and FY 1971. During the years FY 1966-1969, enriched uranium fuel and target elements accounted for more than half of the total quantities shipped.



Figure C-18. Annual quantities (MTU) of fuel and target elements shipped during FY 1953-1976.

Intermediate products, principally  $UO_3$ , were also shipped from the FMPC. Data on the quantities shipped between FY 1971 and FY 1976 have been located. Figure C-19 summarizes the amounts and timing of the shipments of the two most important intermediate products from FMPC. Shipments of uranium trioxide were by far the largest of any intermediate products. Most of the  $UO_3$  was sent to the Paducah, KY plant but a small amount was sent to Allied Gulf Nuclear Services in South Carolina. About 97% of the  $UO_3$  shipped was natural uranium. The next largest category of intermediate product shipments was ingots of 0.95% enriched uranium. These ingots were sent to RMI

Radiological Assessments Corporation "Setting the standard in environmental health"

Page C-15

#### Page C-16

÷.,

i .

Company, Inc. in Ashtabula, Ohio for preparation of fuel elements for the RLO. The amounts shipped were in the range of 300-1000 MTU during the 6-year period. Depleted derbies and metal pieces were shipped to the Y-12 Plant in Tennessee, the Rocky Flats Plant in Colorado, and the Idaho National Engineering Laboratory. Enriched  $U_3O_8$  and  $UF_4$  were shipped to Goodyear Atomic during the period, but the amounts were small, less than 30 MTU.



products shipped during FY 1971–1976.

#### THORIUM PRODUCTION

Table C-2 lists the FMPC plants which processed significant quantities of thorium, the chemical form produced, the time period during which the processing was carried out, and the total quantity produced expressed as metric tons (MT) of thorium metal. There has been no thorium processing at the FMPC in more than 10 years, and most of the thorium processing equipment has been removed. Very little information is now available about the equipment which had been used, possibly because many of the records concerning thorium processing were destroyed in the early 1970s. Most of the information listed in Table C-2 came from an addendum (Hill and Dolan 1988; Clark et. al. 1989) to the FMPC radionuclide discharge report (Boback et al. 1987). Some of the information in the table came from production records located by Hill and Dolan which had not been destroyed in the early 1970s. These authors estimated other production information from interviews with past and present FMPC employees, product volume, and yield information.

Appendix C FMPC Production Information

Plant	Product	Period	Quantity (MT Th)
2/3	Testing	1968	None
4	Fluoride	1954	460 <sup>a</sup>
8	Hydroxide	1966	59
8	Oxalate	1969-1971	310
9	Metal	1954-1955	380
9	Briquetting	1954-1955	· 76
Pilot	Extraction	1964-1980	790
Pilot	Gel	1964-1970	689
Pilot	TNT Crystals	1966	0.4
Pilot ·	Metal	1967-1971	51
Pilot	Oxalate	1971-1976	153
Pilot	Gel	1977-1979	350 -

## Table C-2. Thorium Processing in FMPC Plants

#### REFERENCES

.....

L. L.L.

in which

1.17.19.1

Sec. 1

5

- Audia, S. F. Over-all accountability analyses report, plant startup through September 30, 1976. Letter to H. D. Fletcher, ERDA. Cincinnati, OH: National Lead Company of Ohio; 31 August 1977.
- Boback, M. W.; T. A. Dugan; D. A. Fleming; R. B. Grant; R. W. Keys. History of FMPC radionuclide discharges; Cincinnati, OH: Westinghouse Materials Company of Ohio; FMPC-2082; 1987.
- Clark, T. R.; L. Elikan; C. A. Hill; B. L. Speicher. History of FMPC radionuclide discharges, revised estimates of uranium and thorium air emissions from 1951–1987; Cincinnati, OH: Westinghouse Materials Company of Ohio; Addendum to FMPC-2082; March 1989.
- Davis, J. O.; W. E. Palmer; H. A. Kraus. Hydrogen reduction of slightly enriched uranyl hexaflouride in the NLO Pilot Plant. Cincinnati, OH: National Lead Company of Ohio. Estimated 1956.
- Dunaway, D. L. Summaries of specific FMPC plant production. Cincinnati, OH: Fernald Environmental Management Restoration Corporation. Personal communications with R. E. Moore; 1993.

Page	C-18
------	------

••• \_\_-

1.2

17.

<u>.</u> 4 .

27

\$

:1

8 4 N - 14 - 5

...

ψ,

14

۰.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

: ··

. **.** '

.

÷ . •

1.4

 $\mathbf{A}^{(1)}$ 

. •:

. :

Ċ.

.

:

·...

: \*\*

1.1

1.1.

Ľ

. .

1-1

:

Ċ.

e de la composition d La composition de la c

٠.

έ¥.

. . .

. :

- FMPC. FMPC uranium inventory records. Cincinnati, OH: Westinghouse Materials Company of Ohio; 1988.
- Hill, C. A.; Dolan, L. C. History of FMPC radionuclide discharges. Draft version of an addendum to FMPC-2082. Cincinnati, OH: Westinghouse Materials Company of Ohio; October 1988.
- Rathgens, L. Typed and handwritten summaries of product deliveries and unit costs for FY-1953 through FY-1976 and production tonnage compilations for FY 1953-1984. Cincinnati, OH: National Lead Company of Ohio; 11 January 1985.

51 - L Î

.)]

11

ы**л**, .

101 1

> . .

> > ŧ

۰.

1

• ;

•:

: ::

Ð

1250

;;'

. . . .

•		<i>r</i>	4 11 H	
•	· _	. `*		•
va stí s	, * .	•	Sec.	•
		÷	31 <del>3</del> -	
- t.	, ta u - t	•	Ċ	:
	· .	A.		
• •.	•	· ·	الاين مالي	
			r	
• • •		: 	2 6 2	
• •		1.5	1.1.2	
`. ·		2 1	$C^{+}$	
1.11	•			
C				

FMPC Production Information

Appendix C

لأشتحينا

£\_\_

## ANNEX TO APPENDIX C-DATA TABULATIONS

#### **RECEIPTS AND SHIPMENTS**

Table C1-1 contains the data on receipts and shipments of natural, enriched, and depleted uranium for the fiscal years from 1952 through 1980. These data form the basis for Figures C-1, C-2, and C-3.

Fiscal _	Amount	s received (M	TU)	Amounts shipped (MTU)		
Year	Natural	Enriched	Depleted	Natural	Enriched	Depleted
		_				•
1952	861	0	11	148	0	11
1953	3,221	19	106	2,993	12	43
1954	6,015	2	1,034	4,700	4	620
1955	9,124	40	2,996	9,458	30	2,837
1956	12,141	33	4,254	11,681	34	3,896
1957	13,699	179	40	13,246	91	526
1958	13,837	579	41	13,625	514	221
1959	14,740	1,086	97	13,040	760	64
1960	16,125	995	41	15,136	876	217
1961	İ3,744	1,825	11	13,802	1,501	172
1962	10,715	2,670	2	11,327	2,124	2
1963	14,201	3,727	1	12,399	3,003	2
1964	10,286	6,234	66	11,317	5,653	36
1965	6,325	5,698	0	8,060	5,486	7
1966	5,263	5,917	124	4,388	5,578	25
1967	17,538	6,036	839	3,784	6,236	379
1968	213	5,237	3,367	5,394	5,294	3,038
1969	204	4.381	3.613	1,055	3,257	3,333
1970	1.050	3.104	2,803	1,934	2,118	2,564
1971	518	1,099	2,522	683	1,597	2,827
1972	4.897	1.301	2,689	2,183	2,447	2,686
1973	35	2.157	4.998	3,536	2.111	5.290
1974	8.511	1.816	2,538	7,353	2,380	2,505
1975	8.148	172	2.097	8,119	678	1.521
1976	711	486	7.026	11.725	751	7.908
1977	1.785	5.442	17.366	3.859	5.604	11.938
1978	11	3.811	14.768	4	4.077	14.608
1979	69	3,726	9.835	Ō	3.589	11.414
1980	ĩ	3.546	13 229	Õ	3,659	14,785

Table C1-1. Receipts and Shipments of Uranium at the FMPC by Fiscal Year

Radiological Assessments Corporation "Setting the standard in environmental health"

Page C-19

11\_\_\_

٤.

#### PRODUCTION OF $UO_3$ AND $UF_4$

Data on the production of uranium trioxide in Plant 2/3 are presented in Table C1-2. The use of depleted uranium in production of  $UO_3$  occurred only during FY 1970. In that year, 41 MTU of depleted  $UO_3$  was produced. These data are the basis for Figures C-4 and C-5. Also shown in Table C1-2 is the production data for uranium tetrafluoride in Plant 4. The most recent compilations are given for FY 1952-88 in the column labeled "Total." It is the basis for Figure C-6. The data for production of natural and enriched UF<sub>4</sub> through FY 1976 were from an earlier tabulation. These earlier data in some cases disagree with those in the later tabulation. It is not presently known whether the difference is due to production of depleted UF<sub>4</sub> or to a revision of the production data for some years. The only year for which depleted UF<sub>4</sub> production has been specifically identified is FY 1970 when 343 MTU of that material was produced. Depleted UF<sub>4</sub> from Paducah was repackaged in Plant 4, but that activity is not reflected in the table.

#### **PRODUCTION OF DERBIES AND INGOTS IN PLANT 5**

Data on the production of uranium metal derbies and ingots in Plant 5 are presented in Tables C1-3 and C1-4. The total production amounts cover the period from FY 1952 through FY 1988. These data form the basis for Figures C-8, C-9, and C-10.

#### PRODUCTION IN PLANTS 6 AND 9

Table C1-5 contains information about the production of enriched uranium metal ingots and enriched uranium metal products that were machined in Plant 9. Enriched uranium was used almost exclusively in Plant 9. The only exception was the processing of 37 MTU of natural uranium in Plant 9 during FY 1974. Also contained in Table C1-5 are data on manufacture of rolled and machined uranium products in Plant 6. The distribution of uranium enrichments for Plant 6 products is shown in Table C1-6. These two tables form the basis for Figures C-11, C-12, and C-13.

## Appendix C FMPC Production Information

17

12

	Pro	Production (MTU) of			Production (MTU) of		
Fiscal	<u>Uranium trioxide in Plant 2/3</u>		<u>Uranium tetrafluoride in Plant 4</u>				
Year	<u> </u>	Natural	<u>_Enriched</u>	Total	<u>Natural</u>	<u>Enriched</u>	
1952	0	0	0	0	0	0	
1953	0	0	0	0	0	0.	
1954	642	642	0	1,568	1,568	0	
1955	3,288	3,288	0	. 3,314	3,314	• 0	
1956	5,329	5,329	0	5,029	5,029	0	
1957	8,370	8,370	0	9,358	9,358	0	
1958	10,039	10,039	0	12,117	11,577	0	
1959	11,540	11,540	0	9,454	8,459	0	
1960	12,187	12,187	0	11,388	10,426	0	
1961	11,039	11,039	0	10,642	8,966	0	
1962	6,288	6,288	0	9,468	7,849	0	
1963	0	0	0	10,482	7,928	1,075	
1964	0	0	0	7,203	4,145	997	
1965	543	· 0	543	6,797	3,117	2,888	
1966	· 1,347	196	1,151	6,174	2,052	3,381	
1967	1,835	832	1,003	6,263	2,632	3,283	
1968	3,251	1,555	1,696	4,809	1,219	3,588	
1969	2,028	665	1,363	2,821	494	2,326	
1970	880	259	621	1,923ª	666	914	
1971	809	574	235	580	55	525	
1972	2761	2,365	396	347	· <b>0</b>	347	
1973	3,534	3,533	1	<b>O</b>	· 0	0	
1974	7,114	7,114	0	342	0	342	
1975	8,189	8,189	0	634	0	633	
1976	9,752	9,752	0.	0	0	0	
1977	2,191	1673	518	0	0	0	
1978	. 0	0	0	0	. 0	0	
1979	0	0	· 0	0	0	0	
1980	0	0	0	479	0	479	
1981	103	0	103	562	0	562	
1982	203	0	203	366	0	366	
1983	319	0	319	1,145	. 0	1,145	
1984	306	<b>0</b> ·	306	1,240	0	1,240	
1985	145	. 0	145	1,146	60	1,086	
1986	2	0	2	1,068	0	1,068	
1987	170	0	170	280	0	280	
1988	93	0	93	388	0	388	
<sup>a</sup> Inclu	des productio	on of 343 MTU	of UF, using	depleted ura	nium.		

Table C1-2. Production of Uranium Trioxide and Uranium Tetrafluoride

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

.....

Acres 18

16

١

Fiscal	P	roduction (MTII) of 1	ranium metal derl	hies
. Year	Total	Natural	Enriched	Depleted
1952	0	0	0	0
1953	45	45	0	0
1954	2,099	2,099	0	• • 0
1955	5,824	5,824	· 0	· · · · O
1956	8,459	8,459	0	0
1957	6,113	6,113	0	0
1958	6,749	6,260	489	S 5 0
1959	7,759	6,881	878	<b>0</b>
1960	10,586	9,704	882	0
* 1961	8,470	7,052	. 1,418	. · · O
1962	8,563	6,782	1,781	0
1963	10,243	7,655	2,588	0
1964	7,648	4,080	3,568	. : <b>: 0</b>
1965	6,432	2,991	3,441	0
1966	5,166	2,018	3,054	: 94
1967	7,172	2,756	3,547	236
1968	5,339	1,255	3,435	
1969	4,017	<b>95</b>	2,578	1,344
1970	2,885	1,974	261	650
1971	1,344	172	205	967
1972	1,217	í • <b>O</b>	225	992
1973	2,139	0	170	1,969
1974	' 1,317	0	362	954
1975	1,121	· 0	325	797
1976	1,703	0	140	1,564
1977	1,780	35	219	1,525
1978	2,139	·) <b>0</b>	291	•1,848
1979	1,618	, <b>O</b>	272	1,346
1980	2,019	• 0	213	1,806
1981	2,608	· 0	588	2,020
1982	4,159	0	682	3,477
1983	4,802	0	1,085	3,717
1984	6,290	• 0	1,054	5,237
1985	5,075	218	1,111	3,746
1986	6,205	<b>215</b>	1,010	4981
1987	4,606	0	346	4,260
1988	2,667	(† <b>0</b>	305	2,362

# Table C1–3. Production of Uranium Metal Derbies in Plant 5

Page C-22

•
Appendix C FMPC Production Information

1000

1) 12-20-11-20

-----

Fiscal	Proc	luction (MTU) of u	ranium metal ingo	ots
Year	Total	Natural	Enriched	Depleted
1952	. 0	0	0	0
1953	90	90	0	0
1954	3,976	3,976	0	0
1955	9,528	9,528	0	· 0
1956	12,137	12,037	0	0
1957	12,680	12,680	0	0
1958	12,727	12,727	0	0.
1959	. 13,365	13,365	0	0
1960	16,708	16,708	0	0
1961	12,691	12,691	0	. 0
1962	12,865	12,865	0	0
1963	14,285	14,285	0	0
1964	11,655	11,655	0.	0
1965	10,234	10,234	0	0
1966	11,239	6,498	1,376	67
1967	10,969	5,266	2,451	432
1968	10,144	2,503	1,506	2,248
1969	6,638	191	0	2,540
1970 ·	5,425	3,762	0	1,269
1971	2,375	435	0	1,838
. 1972	1,683	0	0	1,633
1973	3,292	0	0	3,260
1974	1,711	5	0	1,525
1975	1,167	· 0	0	1,041
1976	2,142	0	0	2,080
1977	2,175	0	61	2,114
1978	1,963	0	53	1,910
1979	1,386	0	0	1,386
1980	1,989	0	0	1,989
1981 -	2,047	0	· 0	· 2,047
1982	3,732	0	0	<sup>-</sup> 3,732
1983	4,569	0	610	3,959
1984	3,933	0	239	3,694
1985	4,558	691	125	3,742
1986	4,310	206	0	4,104
1987	4,501	0	0	4,501
1988	3.109	0 .	0.	3,109

Table C1-4. Production of Uranium Metal Ingots in Plant 5

Radiological Assessments Corporation "Setting the standard in environmental health"

Page C-23

# Page C-24

. .

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

.

ن : نور :

È.

۰:

Fiscal -	Pl	ant 9 (1992-020).			Plant 6	
Year	Ingots	Machined	1837.	Rolled	Machined	-
1952	. 0	.0		0	0	-
1953	· 0	0	<u> </u>	1,966	1,608	
1954	0	0		5,679	3,581	••••
1955	0	0		9,973	6,752	
1956	. 0	0 .		12,470	8,086	
1957	. 0	0		15,074	8,629	
1958	732	0 .		13,665	8,378	•
1959	1,251	0		14,033	7,320	
1960	1,388	0	·	18,532	9,131	· · ·
1961	2,364	0	: `	15,370	7,552	
1962	2,663	0	i -	15,430	8,211	
1963	3,660	0		14,507	9,232	
1964	5,297	0		11,313	9,279	
1965	5,361	0	• .	12,310	8,674	
1966	1,197	3,296		7,683	6,987	
1967	1,258	3,753	:	7,576	5,837	•
1968	691	4,165	<u>.</u>	5,029	5,105	
1969	778	2,980	• •	3,380	3,227	
1970	499	1,720		3,309	2,882	
1971	422	2,182	·.· ·	1,068	1,413	
1972	599	1,839	•	0	922	
1973	452	3,067	• (.	0	1,881	
1974	1,031	2,221		0	870	
1975	1,189	·1,532		0	797	
1976	304	1,996	1'	0	1,065	
1977	381	2,074		0	1,110	
1978	480	1,932		0	1,172	
1979	604	1,558	•	. • <b>0</b>	900	•••
1980	380	1,788		0	999	•
1981	796	2,214		0	1,127	
1982	974	3,566		0	1,821	
1983	1,366	4,391	2 N 1	0	2,191	
1984	1,516	4,254		0	1,924	
1985	1,074	··· , 3,428 / 105		0	1,860	
1986	1,640	; 4,222	· ·	0	1,743	
1987	745	709	• • • •	0	. 426	
1988	394	338	· •	0	. 8	

Table C1-5. Production of Uranium Ingots and Machined Metal Products in Plants 9 and 6

.

· · · · · · ·

Fiscal	Uranium core and target production (MTU)							
Year	Natural	Enriched	Depleted					
1952	0	0	0					
1953	1,608	0	0					
1954	3,581	0	0					
1955	6,752	0	0					
1956	8,086	0	0					
1957	8,629	0	0					
1958	7,961	0	0					
1959	6,660	0	0					
1960	8,330	0	0					
1961	6,306	0	0					
1962	6,906	0	0					
1963	7,396	0	0					
1964	6,428	<b>0</b> ·	· 0					
1965	5,665	0	0					
1966	3,312	582	0					
1967	2,983	1,218	103					
. 1968	1,246	1,024	1,012					
1969	131	0	1,154					
1970	1,779	0	777 ·					
<b>1971</b> ·	410	0	941					
1972	0	0	922					
1973	. 0	0	1,881					
1974	0	0	870					
1975	0	0	797					
1976	0	<u> </u>	1,065					

## Table C1-6. Production of Uranium Fuel and Target Elements in Plant 6

### **RECOVERY OF SCRAP URANIUM**

Table C1-7 contains data on the recovery of uranium from scrap material in Plant 8 at the FMPC. The recovered uranium was then fed to the Refinery. Most of the material recovered was natural uranium. Recovery of depleted uranium was minimal. Data in the table are plotted in Figures C-14 and C-15.

**S** 

È.

.....

• 5.

TISCAL .	<u>I</u>	Network	Entiched	De-lete-
<u>rear</u>	10tai	Natural	Enriched	Depleted
1952	0	0	0	0
1953	0	0	0.	0
1954	266	266	0	0
1955	1,160	1,160	0	0
1956	1,764	1,764	0	0
1957	1,927	, 1,927,	0 ·	• • 0
1958	2,018	2,018	0	• 0
1959	2,568	2,568	0 ·	0
1960	3,188	3,188	0	0
1961	2,902	2,902	0	0
1962	2,820	2,820	0	. 0
1963	2,657	2,115	542	0
1964	3,505	2,380	1,125	0
1965	2,134	1,182	952	; 0
1966	1,617 ·	650	967	· 0
1967	1,837	855	982	0
1968	2,222	687 -	1,530	5
1969	1,036	256	759	21
. 1970	649	423	204	22
1971	307	128	172	7
1972 .	111	7	103	1
1973	66	21	45	0
1974	3	3	<b>0</b> ·	: <b>0</b>
1975	43	11	32	0
1976	51	12	39	. 0
1977	386ª		•	•
1978 ·	<u>122ª</u>			
··· 1979 ·	184ª			
1980	118ª		•	
1981	41ª		•.	,
1982	237ª			
1983	376ª			• •
1984	261ª			•
1985	188	5.	143	40
1986	176	<b>2</b>	141	<b>33</b> `
1987	1,106	0	223	. 883
1988	261	.10	· 69	181

1. 1. 1. 1. 1. 1.

strag is de

14

sette providence de la competition de la competitiva de la competition de la competi

. . .

. .

:.'

. .

.

:`

# Table C1-7. Uranium Recovered from Scrap Material in Plant 8

 $\langle \cdot \rangle$ 

1

.

Appendix C

5.0

L. South

#### FMPC Production Information

## PRODUCTION OF UF<sub>4</sub> FROM UF<sub>6</sub>

Table C1-8 contains information about the production of uranium tetrafluoride from uranium hexafluoride in the FMPC Pilot Plant. There was no production during the years 1968 through 1984. Enriched UF<sub>6</sub> was the primary feed for the process. No UF<sub>4</sub> was produced using depleted uranium in the Pilot Plant until 1986.

Fiscal _	Production	of UF <sub>4</sub> from UF <sub>6</sub> in the	e Pilot Plant
Year	<u> </u>	<u>Natural</u>	<u> </u>
1953	15		15
1954	~20ª	~20ª	
1955	26		26
1956	33		33
1957	0	0	0
1958	540	0	540
1959	995	0	995
1960	962	0	962
1961 ·	1,676	.0	1,676
1962	2,961	1,342	1,619
1963	2,676	1,197	1,479
1964	3,529	1,468	2,061
1965	1,450	658	792
1966	1,219	478	741
1967	361	13	348
1968-1984	· 0	0	0
1985	622	511	111
1986	462 <sup>b</sup>	92	125
1987	542°	0	160
1988	1,642 <sup>d</sup>	0	0
lstimate based on icludes 245 MTU	apparent capacity (I of depleted uranium	)avis 1956).	

#### Table C1-8. Production of Uranium Tetrafluoride in the Pilot Plant

dProduction was entirely of depleted uranium.

Conversion of  $UF_6$  to  $UF_4$  was also the purpose of Plant 7, which operated for only two years (from June 1954 through May 1956). Natural and depleted uranium were employed in separate sets of reactor banks in the facility. Production of  $UF_4$  from natural uranium feed was 71.3, 138, 104, 227, and 110 MTU during the first five months of 1956. Conversion of depleted  $UF_6$  during the first four months of that year was accomplished at a rate that exceeded the original design capacity of the plant. Monthly production amounts were 311, 230, 265, and 308 MTU, all well above an expected 180 MTU for that half of the plant. Higher than design feed rates, improvements in availability, or use of all four reactors are possible explanations of this high level of production. It is known that a number of improvements had been made to the plant to overcome initial operational difficulties.

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page C-27

#### Page C-28

## SHIPMENTS OF PRODUCTS FROM THE FMPC

Data on shipments of intermediate products from the FMPC have been located for the fiscal years 1971 through 1976. These shipment data are summarized in Table C1-9. The quantities of  $UO_3$  shipped offsite were larger than shipments of any other intermediate product during this period.

1	Shipments (MTU) of intermediate products								
Fiscal Year	UO <sub>3</sub> (natural)	Ingots (enriched)	Metal (depleted)	UF <sub>4</sub> and U <sub>3</sub> O <sub>8</sub> (enriched)					
1971	804	. 342	0	5					
1972	2,908	538	0	25					
1973	3,885	372	· 0	. 2					
1974	7,238	941	0	10					
1975	8,100	672	193	· 4					
<u>1976</u>	9,998	321	158	· 14					
		· · ·		· ·					

Table C1-9. Shipments of Intermediate Products from the FMPC, FY 1971-1976

Table C1-10 contains data on the shipments of fuel and target elements of varying <sup>225</sup>U content from the FMPC from FY 1952 through FY 1976. Natural uranium was the most important component of the total until the early 1960s, when enriched uranium began to comprise a significant fraction of the total amounts shipped.

Appendix C FMPC Production Information

Linkson

62

Fiscal	Shipments (	MTU) of fuel and targe	t elements
Year	Natural	Enriched	Depleted
1952	0	0	0
1953	1,476	1	0
1954	3,612	0	0
1955	6,544	0	0
1956	8,033	13	0
1957	7,705	65	0
1958	7,954	409	0
1959	7,332	626	0
1960	9,325	791	· 0
1961	7,116	1,344	0
1962	8,530	1,414	0
1963	8,062	1,837	0
1964 ·	6,395	2,693	0
1965	5,791	3,033	0
1966	3,312	3,102	0
1967	3,229	3,081	86
1968	1,246	3,170	934 -
1969	139	2,357	1,161
1970	1,774	655	<b>709</b> ·
1971	357	318	982
1972	0	28	893
1973	0	· 0	1,846
1974	0	· 0	912
1975	0	0	365
1976	0	0	1,496

Table C1-10. Quantities of Fuel and Target Elements Shipped from the FMPC

Radiological Assessments Corporation "Setting the standard in environmental health"

Page C-29

n

## APPENDIX D

#### OTHER RADIONUCLIDE RELEASES

Processing of uranium was the principal function of the FMPC. Thorium processing was a secondary activity. Radioactive decay of uranium and thorium isotopes produces series of other radionuclides that are collectively referred to as decay products. The initial decay products for the three decay series of greatest interest are shown in Figures D-1, D-2, and D-3. The first of these illustrates the decay products of uranium-238 ( $^{238}$ U), including another important uranium isotope,  $^{234}$ U.

Kin C

.....



Figure D-1. Decay products of uranium-238, from thorium-234 to radon-222.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page D-2	The Fernald Dosimetry Reconstruction Project	
· -	Tasks 2 and 3, Source Terms and Uncertainties	

In most of the feeds received by the FMPC, the uranium had previously been separated chemically from the other decay products. As a result, the facility's effluents consisted primarily of uranium and other radionuclides were generally present in small quantities. Radioactive decay of uranium after the initial chemical separation from the daughter radionuclides also produced those same nuclides as trace contaminants.

However, early processing campaigns treated ores that contained near equilibrium amounts of the daughter radionuclides through radium. As shown in Fig. D-1, the decay product that follows radium is radon, a gas. The wastes from that early processing were placed in the K-65 Storage Silos (see Appendix J). Releases of radon and other nuclides from the silos are a special case that is treated in Appendix J.

Some thorium was processed at the FMPC. Fig. D-2 shows a comparable sequence of the decay products of thorium-232 (<sup>222</sup>Th), which includes thorium-228 and two radium isotopes. This sequence also leads to a gaseous radon isotope. Processed thorium would include both thorium isotopes and small residuals of the other solid elements. Radioactive decay after processing would also produce trace contaminants in the thorium.



# Radium-224

Radon-220 (gas)

1. 1. **1. 1. 1.** 1. 1. 1.

Figure D-2. Decay products of thorium-232, from radium-228 to radon-220.

The third decay chain of interest is that of uranium-235, which is present (0.72%) in natural uranium and in increased amounts (generally less than 1.5%) in enriched uranium processed at the FMPC. This decay sequence (Fig. D-3) also includes an isotope of radon. Appendix D Other Radionuclide Releases



Radon-219 (gas)



In addition to decay products, other radionuclides were released during FMPC operations. These originated in nuclear reactors, where finished uranium fuel and target elements, produced at the FMPC, were used. Fissioning of the uranium atom produces other radionuclides, called fission products. Absorption of neutrons by uranium and other materials present in the reactor produces radioactive activation products. When spent fuel from the reactors was processed at fuel reprocessing plants (not at the FMPC), the uranium was not completely separated from fission and activation products. As a result, recovered uranium that was recycled to the FMPC introduced small amounts of fission and activation products into the process streams at the FMPC.

Receipts of recycled uranium began at the FMPC in fiscal year (FY) 1961. All of the recycled uranium that was received during FY 1961–1963 was in the form of enriched uranium trioxide  $(UO_3)$  from Hanford (Spenceley 1985). Production of enriched uranium tetrafluoride  $(UF_4)$  from  $UO_3$  in Plant 4 did not begin until FY 1963 (Rathgens et al. 1985), so releases of fission and activation products would not have occurred prior to July 1962. Plant staff involved in the processing of the recycled  $UO_3$  have identified October 1962 as the time that processing of that material began at the FMPC (Bonfer 1991). Measurements of the amounts of these radionuclides, relative to uranium, were not performed until years

Radiological Assessments Corporation "Setting the standard in environmental health" Page D-4

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

8

2

<u>.</u>

later. At that time, concentrations of fission and activation products were probably higher than those present in the early years of processing of recycled uranium at the FMPC. However, the later measurements are presently the only guide to the concentrations of those contaminants in effluents. Results of the measurements are discussed below.

#### AIRBORNE RADIONUCLIDES

In 1985, measurements of fission and activation products in particulate material trapped in scrub liquor and by dust collectors were performed (Boback et al. 1987). Single grab samples were taken from a wide variety of locations and analyzed for fission and activation products. The results of these measurements are presented as radionuclide concentrations per kilogram of uranium in Table D-1. Absence of an entry in the table, as in the column for ruthenium-106 (<sup>106</sup>Ru, shown in this table as Ru-106), for example, indicates that no result was reported for that radionuclide.

For most radionuclides, the variability, both from one dust collector to another in any particular plant and among plants, was substantial. This can be seen from the arithmetic means and standard deviations that have been computed using the results for each plant. Sampling and analytical uncertainties for these results were not reported in Boback et al. (1987). Only the short-lived daughters of <sup>238</sup>U were found in consistent concentrations. The concentrations of thorium isotopes and their radium (Ra) daughter products were found to be consistent in samples from some plants but not from others. The concentrations of fission products — cesium (Cs), strontium (Sr), and technetium (Tc) — were highly variable. For some analyses, <sup>90</sup>Sr was not detected; upper bound concentrations are included in Table D-1, but were not considered in the statistical analysis of the <sup>90</sup>Sr concentrations. The fission product <sup>106</sup>Ru was reported for only one of the samples: 0.084  $\mu$ Ci (kg U)<sup>-1</sup> in dust from collector G4-2.

Transuranic elements neptunium (Np) and plutonium (Pu) were also measured. The nuclides <sup>237</sup>Np, <sup>238</sup>Pu, and <sup>239/240Pu</sup> were detected in all of the samples analyzed. The relative amounts of <sup>239</sup>Pu and <sup>240</sup>Pu cannot be determined by alpha spectrometry (the common analytical technique) because the alpha particles emitted by the two nuclides have very similar energies. The observed concentrations varied over a wide range within individual plants and from plant to plant. An important radionuclide that has not been identified, but would be expected to be present, is <sup>241</sup>Am. The energy of the alpha particle emitted by <sup>241</sup>Am is virtually the same as that emitted by <sup>238</sup>Pu. Because the special chemical separation needed to isolate <sup>241</sup>Am was apparently not performed, the results reported for <sup>238</sup>Pu no doubt include a contribution from <sup>241</sup>Am. Because concentrations of individual transuranic nuclides were not determined, these nuclides have been grouped and referred to as TRU, short for transuranic.

Concentrations of fission and activation products observed in 1985 could have been among the highest ever present because recycled uranium had been processed over a long time period. However, plant operations just prior to the measurements could also have had a substantial effect on the measurements. The annex contains a tabulation of data on the quantities of recycled uranium and the associated plutonium that were shipped to the FMPC for processing. Average plutonium concentrations in the various forms of recycled uranium compounds differed substantially, with plutonium/uranium (Pu/U) ratios that 38.32

_				Ra	dionuclide C	oncentratio	n (µCi/kg ol	l'uranium)							Uranium	Chemical	U-235	U-236
Source of Sample	Pu-239,240	Pu-238	Np-237	Th-234	Pa-234m*	Th-232	Th-230	Th-228	Ra-228	Ra-226	C+137	Ru-106	Tc-99	Sr-90	(gUperg)	Form**	Percent	Percent
Plant 1 Dust, G2-1	0.10	0.011	0.051	438	438	0.12	0.23	0.079	0.012	0.009	0.030		<b>1.1</b> ·		0.708	UTT, UOa	0.95	0.01
Plant 1 Dum, G2-64	219	8.7	12	381	381	19	3685	8.7	11	39	12		56	2.3	0.160	UOct	0.71	0.01
Plant 1 Dum, G2-76	6.1	0.58	0.79	975	975	1.4	30	1.5	0.79	2.0	30		7.9	24	0.028	UOct	0.84	0.02
Plant 1 Dust, G2-172	1.6	0.29	0.33	629	629	8.8	26	5.5	5.5	3.5	0.031		503		0.218	UOct	0.67	0.02
Plant 1 Dust, G2-235	0.18	0.11	0.077	496	496	0.32	9.3	1.3	0.12	0.50	0.22		5.4	0.30	0.626	UDi, UOct	3.43	0.04
Plant 1 Mean	45	1.9	2.6	584	584	6.0	760	. 35	3.4	9.1	6.5		115	13				
Std. Dev.	97	3.8	5.2	237	237	8.3	1641	3.6	4.6	17	- 13	-	218	15				
Plant 4 Dust, G4-1	0.30	0.029	0.22	722	722	0.098	0.30	0.27	0.018	0.16	1.6		59	1.2	0.73	UTri	0.83	0.06
Plant 4 Dust, G4-2	0.054	0.0063	0.10	277	277	0.061	0.090	0.053	0.0026	0.0037	0.026	0.084	82	0.070	0.76	VTI	0.84	0.07
Plant 4 Dust, G4-4	0.19	0.017	0.064	536	536	237	0.42	0.25	0.0072	0.0051	0.032		52	0.044	0.75	ודט	0.51	0.02
Plant 4 Dust, G4-5	0.11	0.018	0.14	605	605	0.077	0.32	0.30	0.015	0.0083	0.28		97	0.20	0.71	UTI	0.80	0.05
Plant 4 Dum, G4-7	0.63	0.047	0.15	610	610	0.17	0.28	0.31	0.0041	0.0047	0.067		106	0.028	0.51	UDi -	1.11	0.05
Plant 4 Dust, G4-12	0.013	0.0023	0.0035	293	293	0.035	0.052	0.049	0.0027	0.0012	0.097		2.1		0.75	UTI	1.78	< 0.01
Plant 4 Dust, G4-13	0.048	0.0086	0.17	783	783	0.22	0.31	0.33	0.0053	0.013	0.062	•	93	0.032	0.82	UOct	0.90	0.02
Plant 4 Dust, G4-14	0.0010	0.0036	0.0070	726	726	0.077	0.13	0.033	0.0044	0.0028	0.038		0.046		0.76	UTI	0.20	< 0.01
Plant 4 Dust, G4-15	0.46	0.039	0.085	721	721	0.16	0.54	0.22	0.0050	0.015	0.020		5.3		0.74	ហោ	0.84	0.07 .
Plant 6 Mean	0.20	0.019	0.11	586	586	26	0.27	0,20	0.0072	0.024	0.25		55	0.27				
Std. Dev.	0.22	0.016	0.073	187	187	79	0.16	0,12	0.0055	0.052	0.52		43	0.47				
Plant & Dust, G5-247	3.1	0.52	1.4	1223	1223	1.6	6.3	15	1.9	0.55	11		18	94	0.014	UOci	0.78	0.05
Plant & Dust, G2-67	5.2	0.47	1.5	1983	1983	3.6	11	9.5	1.4	0.21	13	•	34	78	0.023	UOct	0.81	0.05
· Plant & Dust, G5-248	0.40	0.10	0.25	32653	32653	1.2	1.2	6.3	0.15	0.14	5.6		- 2.3	1.1	0.015	UOcl	0.23	< 0.01
Plant 5 Dust, G8-249	0.015	0.0030	0.015	880	880	0.073	0.17	0.071	0.0071	0.0052	0.054	•	0.45	1.2	0.47	UTI	0.22	< 0.01
Plant & Dust, G8-250	0.0093	0.0028	0.018	1162	1162	0.10	0.35	0.21	0.0058	0.014	0.041		0.17	0.38	0.34	UTI	0.20	0.01
Plant 5 Dust, G5-251	0.90	0.084	0.60	23913	23913	0.30	6.0	1.4	0.13	0.13	4.9		8.7	4.1	0.037	UOct	0.43	0.01
Plant & Dust, G5-253	0.57	0.062	0.22	25478	25478	0.61	23	0.27	0.18	0.11	10		1.3	76	0.016	UOct	0.39	0.01
Plant 5 Dust, G5-254	0.65	0.093	0.33	18961	18981	0.79	L1	0.93	0.19	0.069	18		3.0	79	0.022	UOct	0.28	0.01
Plant 5 Dust, G5-256	1.3	0.13	0.53	17004	17004	0.97	1.9 .	1.1	0.21	0.13	21		4.9	4.5	0.025	UOa	0.27	0.01
Plant 5 Dust, G5-260	0.030	0.011	0.022	34364	34364	0.020	0.26	0.12	0.0055	0.0034	0.024		0.28		0.49	UOci	0.20	< 0.01
Plant 5 Dust, G5-261	0.033	0.0037	0.015	9185	9185	0.0047	0.069	0.060	0.0041	0.0041	0.017		0.28	0.013	0.75	UOct	0.21	< 0.01
Plant 5 Dust, G5-262	1.0	1.0	3.9	4727	4727	<b>58</b>	45	136	1.6	0.90	66.		34	•	0.0011	UOct	0.25	< 0.01
Plant & Dust, G&A-100	0,17	0.062	0.33	2913	2913	· 2.3	27	9.3	0.12	0.058	3.1		17		0.052	UOcL	0.31	0.01
Plant & Dust, G6A-101	0.32	0.074	0.24	24233	24233	1.9	1.8	6.5	0.11	0.053	4.2		· 1.3	3.9	0.062	UOct	0.22	< 0.01
Plant 5 Dust, Bldg. \$5	0.18	Q.029	0.25	23558	23558	2.7	4.0	· 5.3	0.077	0.15	3.3		4.8	1.2	0.021	UOct	0.21	< 0.01
Plant 5 Mean	0.92	0.18	0.64	14817	14817	5.6	5.6	13	0.44	0.17	11		8.7	29				
Std. Dev.	1.4 -	0.28	1.0	12216	12216	17	11	34	0.71	0.24	17		12	39				

Table D-1. Results of Analyses for Specific Radionuclides and Uranium in Dusts and Scrubber Liquids at the Feed Materials Production Center in 1985

Appenaix D Other Radionuclide Releases

. . .

Radiological Assessments Corporation "Setting the standard in environmental health"

.

.

പനക്സം

	<u> </u>	•		·· Re	dionuclide C	oncentratio	n (uCi/kg ol	'urenium)					•		Uranium	Chemical	U-235	U-23
Source of Semple	Pu-239,240	Pu-238	Np-237	Th-234	Pa-234m*	Th-232	Th-230	Th-228	Ra-228	Ra-226	C=-137	Ru-106	Te-99	Sr-90	(gU per g)	Form**	Percent	Perce
Plant 8 Dust, G43-27	4.7	0.24	0.64	257	- 257	1.1	101	1.7	0.25	0.18	0.14		36	0.26	0.11	UOrt	0.93	0.05
Plant 8 Dust, G43-29	0.64	0.083	0.36	38	38	0.23	1.9	0.81	0.035	0.036	0.022	-	32	0.041	0.69	UOct	0.91	0.05
Plant 8 Dust, 8035	0.16	0.037	0.067	409	409	0.28	0.59	0.30	0.058	0.0059	0.26	•	13	0.028	0.54	UOct	0.42	0.02
Plant 8 Dusta Mean	· 1.8	0.12	0.36	234	234	0.54	34	0.92	0.11	0.075	0.14		27	0.11				
Std. Dev.	2.5	0.11	0.29	186	186	0.49	58	0.68	0.12	<sup>^</sup> 0.095	0.12		12	0.13				
· · · · · ·			•••		•		••			÷		•			•			
	-			•						•						•		
Scrub Liquor Samples			•	-	·.			t.							• •			• .
Plant 8, Box Purnace	7.1	0.95	1.5	320	320	23	- 30 -	23	0.53	1.1	13		71		0.0017	UOct	. 0.63	. 0.03
Plant 8, Rotary Kiln	3.0	0.33	0.70	607	. 607	7.7	<b>17</b> :	6.2	0.22	0.12	0.65	•	39	3.4	0.0067	UOct	0.92	0.0
nt 8, Oxidation Furnace #1	0.036	0.012	0.036	94	94	1.0	1.2	3.6	0.15	0.016	1.3		5.8	0.27	0.036	UOct	0.22	< 0.0
Plant # Liquids Mean	3.4	0.43	0.74	341	341	11	36	$-\mathbf{n}$	0.30	0.40	5.0	5	39	1.8	_a,			
Std. Dev.	<b>3.6</b> 🤅	0.48	0.72	257	257	11	38	10	0.20	0.58	7.0		33	2.2				
						•	:	•••••			•	• .				· · ·	•	7
о <sup>с</sup> с			•		•••				•		•			• •		•	-	
Plant 9 Dust, G9N1-1039	1.7	0.13	0.46	13858	13858	0.060	0.27	1.8	0.013	0.44	0.73		_ 69.3	0.22	0.55	UOct	0.93	0.05
					.*							•						
	· .	•	•• -						•					•	*			
Pilot Plant Dust, G-1	0.0023	0.0023	0.0048	81	81	0.073	0.35	0.13	0.0023	0.0036	. 0.20		0.096	. ·	0.75	UTI	0.78	< 0.
Pilot Plant Dust, G-2	0.0017	0.0035	0.0099	123	123	0.11	0.19	0.13	0.0028	0.0019	0.21		0.17		0.75	UTI	0.74	< 0.0
ot Plant Dust, 735-13-7050	0.62	4.9	0.18	. 782	- 782	11	9.1	8.6	6.6	0.45	6.2		21		0.024	UDi, UOa	0.62	< 0.6
Pilot Plant Mean	0.21	1.6	0.064	329	329	3.8	3.2	3.0	2.2	0.15	2.2		0.78		•			
Std. Dev.	, 0.36	2.8	0.096	393	393	6.4	5.1	4.9 .	3.8	0.26	3.4	· ·	. 1.1		•	•		

 $\mathcal{M}^{(s)}$ 

....

103.71

5.5

<u>.</u>

•••••

\_

.

.

47

•;

1.0

÷

..

∵.

۰,

·· .

·

. .

•

. ....

.

÷...

÷ 1

1

•

.

гаге п-о

.

Tasks 2 and 3, Source Terms and Uncertainties

•	•
Appendix D	Page D-7
Other Radionuclide Releases	

ranged from about 0.3 parts per billion (ppb) for receipts of offsite  $UO_2$  to more than 1100 ppb for  $UO_3$  received from Paducah in 1980. Except for the 1980 shipment, the Pu/U ratios of incoming materials, while variable, were less than 10 ppb.

Part of the material from Paducah was repackaged, from hoppers to drums, in Plant 4. To reduce the Pu concentration, it was blended with sump cake in the rotary kiln in Plant 8 and converted to calcium uranate, which was subsequently used as feed for the refinery. Production of  $UO_3$  from this feed stock appears to have begun in May 1982 and 110 lots had been produced by May 1985. The Pu content of each lot was measured and Pu/U ratios ranging from 4 to 46 ppb were found (Spenceley 1985). The ratio generally increased with time, but not monotonically, as the feed with higher Pu content became incorporated into the refinery inventory. Samples of uranyl nitrate hexahydrate (UNH) from 14 tanks in the refinery were analyzed for Pu in April 1985. The measured Pu/U ratios in samples of UNH ranged from 6.5 to 81 ppb.

Processing of the Paducah material was performed in the years just prior to the time concentrations of plutonium and other transuranic nuclides were measured in various samples of dusts and scrub liquors. In Plant 8, where the Paducah material was blended, ratios of Pu/U in samples of scrub liquor averaged about 60 ppb. Dust from primary dust collector for that facility was found to have a Pu/U ratio of about 80 ppb. Samples of dusts collected in Plant 4, which presumably represent historically more typical Pu/U ratios, averaged about 5 ppb. A similar low concentration ratios were also found in the dusts collected from the Pilot Plant. A somewhat higher average Pu/U ratio was found in dusts from Plant 5, but the results appear to be highly dependent upon the specific process exhaust treated. The highest Pu/U ratio was found in a sample of dust from Plant 1; it was about 3600 ppb in dust from collector G2-64. This finding apparently reflects dust from grinding and homogenization of samples of the original Paducah  $UO_3$ .

#### OTHER RADIONUCLIDES IN LIQUID WASTES

•

Various FMPC monthly reports, environmental monitoring reports, and analytical data sheets have been found to contain data on the presence of radionuclides other than uranium in liquid waste discharges. These data are tabulated in Appendix L to which the reader is referred for a more detailed discussion. Measurements of releases of thorium and <sup>226</sup>Ra were made in the mid-1950s. However, monitoring of the two radium isotopes (<sup>226</sup>Ra and <sup>228</sup>Ra) does not appear to have been performed consistently until 1968. Data from measurements of activation and fission products beginning in 1976 have been identified. Concentrations of activation products (<sup>237</sup>Np, <sup>238</sup>Pu, and <sup>229/240</sup>Pu) and of fission products (<sup>137</sup>Cs, <sup>106</sup>Ru, <sup>99</sup>Tc, and <sup>90</sup>Sr) have been documented in liquid wastes. Other decay products of <sup>238</sup>U and <sup>232</sup>Th were also present as shown by the data in Table D-1. The releases of other radionuclides in liquid wastes have generally not been related to specific facilities at the FMPC or to particular operations within the plants.

Because the measurements of other radionuclides were not made in every year, it was necessary to develop correlations between the releases of uranium and those of the other radionuclides. Ratios of releases, expressed for example as  $\mu$ Ci <sup>226</sup>Ra per kg U, were computed for years when measurements were made. These ratios, compiled in Tables L-12 and L-13, provide a basis for estimating releases of the other radionuclides for years when they were not measured. Substantial year to year variability is common for these

> Radiological Assessments Corporation "Setting the standard in environmental health"

	T	ne Fe	ma	ald Dosi	metry R	econs	truction	Project
'asks	2	and	3.	Source	Terms	and	Uncert	ainties

ē

5. GA 14

7.

ratios; the standard deviations are typically larger than the mean values. This variability was considered when deriving the uncertainties associated with the estimated releases of other radionuclides.

ំពេះកំហេតុន សូរីក

4 ( **1** 1 1 1 1 1

## RELATIVE IMPORTANCE OF RELEASES

Page D-8

The relative importance of releases of radionuclides to the environment depends upon comparison of three factors. These are the quantities released, the potential for concentration in the environment, and the relative toxicities of the radionuclides, as measured by their dose conversion factors for the several possible modes of exposure. Differences in dispersion and dilution of uranium and the other radionuclides in the atmosphere and in the river are not expected to be significant.

A methodology developed by the National Council on Radiation Protection and Measurements (NCRP) (NCRP 1989) was used to assess the relative importance of the identified radionuclides as potential contributors to offsite radiation dose. The NCRP screening methodology was primarily intended to evaluate compliance with environmental standards. However, the screening factors that were developed for many radionuclides and a variety of exposure pathways can also be used to assess the relative importance of radionuclide releases to the environment. The referenced methodology has been expanded to include liquid pathways; formal publication of that work is expected in 1995.

The screening factors for radionuclides released to the atmosphere or to fresh water address two of the three factors listed above. The potential for concentration in the environment is evaluated by considering environmental pathways that reflect important transport mechanisms. These are buildup of radionuclides in soils and sediments and uptake into the terrestrial and aquatic food chains. The relative toxicity of each radionuclide (and any other radionuclides that may be produced by its radioactive decay) is also reflected in the NCRP screening factors. Data for the third comparison differences in the quantities released—were available from direct measurements of releases of uranium and other radionuclides and from the measurements of the relative concentrations of other radionuclides in collected dust and scrub liquors presented above:

The relative importance of a particular radionuclide is defined as the fraction that it contributes to the total potential radiation dose from all radionuclides. This parameter was evaluated for releases to the atmosphere and for releases to water. Both surface water and groundwater were considered in the latter category. Mathematically, the relative importance of a particular nuclide  $(RI_i)$  is

 $RI_{j} = \frac{Q_{j} SF_{j}}{\sum_{j=1}^{n} Q_{j} SF_{j}}.$ 

where  $Q_j$  and  $SF_j$  are the quantity discharged and the screening factor, respectively, for releases to the atmosphere or to water. The summation in the denominator of the equation

en rende su

extends over all (n) of the radionuclides released to the medium of interest.

#### Appendix D Other Radionuclide Releases

-

The relative importance of the radionuclides in FMPC discharges to air and water were evaluated using Monte Carlo techniques. Measured and estimated uranium releases were used, together with data on correlations of releases of other radionuclides to releases of uranium, to develop release estimates for the other radionuclides. The transuranic nuclides were treated as a group, rather than individually, because all individual contributions were not defined. The environmental behavior and toxicity for the TRU group were approximated by parameters applicable to the plutonium isotopes.

Uncertainties in the uranium releases were derived as part of the source term estimates and those uncertainty estimates were used in the present calculations. The concentration ratios obtained for airborne release locations were assumed to be medians of lognormal distributions whose geometric standard deviations were estimated to be 1.5. For the liquid releases, the observed means and ranges of release ratios were used to define triangular distributions for the calculations.

Because the NCRP screening factors were developed to assess compliance with standards, their cautious approach tends to overestimate potential exposures. For the present calculations of RI, it was assumed that a triangular distribution with the most probable value equal to the SF could be used to define a range of possible estimates. In most cases, the upper bound of the distribution was taken to be 2 times SF and the lower bound was 0.1 times SF.

The Monte Carlo calculations made to assess the relative importance of radionuclides released to the atmosphere considered inhalation, direct radiation, and ingestion pathways. The results of these calculations are shown in Figure D-4. The most important releases are clearly those of uranium, with an estimated median RI of 0.85. The thorium isotopes <sup>232</sup>Th and <sup>230</sup>Th had median values of RI of 0.051 and 0.039, respectively. Median values of RI for other nuclides were < 0.02.

The figure clearly illustrates the relative unimportance of other radionuclides compared to uranium. The other nuclides deserve correspondingly less attention in the dose assessment process. Inhalation was the most important exposure pathway, accounting for 91% of the potential uranium dose and about 70% of the doses from thorium isotopes even assuming, as the calculations do, that persons consumed only foods produced near the plant. The contribution of inhalation to the total would have been even greater for persons with typical food supplies.

Three different exposure scenarios were evaluated to ascertain the relative importance of various radionuclide releases to water. The first of these considered all potential exposure pathways. Although rainfall in the Cincinnati area is frequent, some irrigation was considered possible for a demanding crop, such as corn, during crucial growth periods. Based upon a review of precipitation records in the 1960s, it was assumed that supplemental irrigation would be provided for three weeks during July and August to assure adequate moisture for the crop. Some use of river water for irrigation has been reported by nearby residents who were interviewed.

Because exposure from all pathways would be limited to at most a few individuals, alternative calculations were performed for two other exposure scenarios. Table D-2, shows the pathways considered in each case. Scenario 2 considers all pathways but drinking water, a situation that may have been realized along the river near the FMPC. The third scenario considered only drinking water and is relevant for individuals who ingested contaminated groundwater or river water downstream of the plant.

Radiological Assessments Corporation "Setting the standard in environmental health"





Figure D-4. Contributions of radionuclides released to the atmosphere to the potential dose.

. · .

Appendix D Other Radionuclide Releases

Ζ.,

	Table D-2. Se	creening Calcula	tions Perform	ed for Liquid Efflue	nts
_	Pathways	considered in ca	alculations	Most	
Exposure scenario	Drinking water	Fish consumption	Irrigation water use	important nuclides	Results presented in
1	yes	yes	July, Aug.	<sup>226</sup> Ra, <sup>228</sup> Ra, U, <sup>232</sup> Th, <sup>234</sup> Th	Fig. D–5
2	no	yes	July, Aug.	<sup>226</sup> Ra, <sup>228</sup> Ra, <sup>232</sup> Th, U	Fig. D–6
3	yes	no	no	<sup>226</sup> Ra, <sup>234</sup> Th, <sup>228</sup> Ra, U	Fig. D-7

In the first scenario it is assumed that river water is used for drinking, fish from the river are used for food, and river water is used for irrigation of human food crops and plants used for feed for animals that are used in turn for human food. Under these assumptions, the calculations indicate that 226Ra and 228Ra are the most important nuclides with median values of RI of 0.60 and 0.19, respectively. Next in order of importance is U, followed by two thorium isotopes; median values of RI for these nuclides were between 0.042 and 0.050. Contributions of other nuclides to potential dose for this scenario can be seen in Fig. D-5 to be even smaller.

Figure D-6 contains the results of calculations that address the situation when river water is not used for drinking but the other pathways identified above are assumed to be operative. For this scenario, the same nuclides are identified as important but the rankings are changed somewhat. The radium isotopes 226Ra and 228Ra are again predominant (median values of RI were 0.62 and 0.19, respectively); median values for the other three nuclides were in the range 0.025-0.048.

Figure D-7 shows the results for exposure scenario 3 when drinking water is the only complete pathway. Because the groundwater was contaminated by the liquid effluents from the plant, this calculation indicates the relative importance of radionuclides that could be consumed as a result of drinking contaminated groundwater. In these calculations, the lower bound for the triangular screening factor distribution was taken to be 0.5 times SF and the upper bound was taken to be 1.1 times SF. The most likely value was assumed equal to SF. These choices reflect the fact that the average tap water intake is about  $1.1 \text{ L} \text{ d}^{-1}$ . compared with the 2.2 L d<sup>-1</sup> assumed in derivation of the screening factors. Ninety-five percent of a representative population would be expected to consume tap water at a rate < 2.4 L d<sup>-1</sup> (Roseberry and Burmaster 1992). For the drinking water pathway, <sup>226</sup>Ra is again the primary contributor to the dose (median RI = 0.34), followed by <sup>234</sup>Th (median RI = 0.23), <sup>228</sup>Ra (median RI = 0.16), and uranium (median RI = 0.15).

These calculations show that releases of the radium isotopes are quite important for all three scenarios, accounting for roughly 50–80% of the potential dose. The contributions of the uranium and thorium isotopes vary for the three scenarios but are consistently important contributors.

> Radiological Assessments Corporation "Setting the standard in environmental health"

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

6

•7

٩,

Š



Figure D-5. Contributions of radionuclides released to water to the potential dose from all pathways. Appendix D





Radiological Assessments Corporation "Setting the standard in environmental health"

## Page D-13

Other Radionuclide Releases

. .

54

Page	D-14
------	------

00000

ç

X \ 11.74

1990 - D



Figure D-7. Contributions of radionuclides released to water to the potential dose from drinking contaminated groundwater or water from the river.

· . · · · ·

Appendix D Other Radionuclide Releases

#### SUMMARY

Uranium was the principal material processed at the FMPC and, on a mass basis, was the primary contaminant released. Thorium was the second largest contaminant on a mass basis. The facility also released a number of activation and fission products that reached the plant as contaminants of recycled uranium. The annex contains a tabulation of receipts of recycled uranium. Effluent monitoring data and the results of special sampling were used to estimate the quantities of other nuclides that were released and their relative importance for dosimetric purposes. The special case of releases of radon and other nuclides from the K-65 silos is treated in Appendix J.

Monte Carlo calculations were used to estimate the relative importance of radionuclides released to the atmosphere and in liquid wastes. The procedure was based upon the screening approach developed by the NCRP. The calculations show that the release of uranium was by far the most important contributor (~85%) to the potential dose from releases to the atmosphere. Estimated to be next in importance for atmospheric releases were <sup>232</sup>Th and <sup>230</sup>Th. Inhalation was found to be the dominant exposure pathway.

The calculations for liquid releases were more complex. Three exposure scenarios were addressed to reflect various possible water usage patterns. In all scenarios, <sup>226</sup>Ra was the most important nuclide; <sup>228</sup>Ra was second or third in importance in each case. Overall, the radium isotopes accounted for 50–80% of the potential dose from liquid releases. Specific isotopes of uranium and thorium were found to be of varying importance for the three scenarios, but as a group they accounted for most of the potential dose not attributed to radium.

#### REFERENCES

- 5

.

Boback, M. W.; Dugan, T. A.; Fleming, D. A.; Grant, R. B.; Keys, R. W. History of FMPC Radionuclide Discharges. Cincinnati, OH: Westinghouse Materials Company of Ohio; Document Number FMPC-2082 (Revision to FMPC-2058); 1987.

Bonfer, D. C. Personal communication with Paul G. Voillequé. 1991.

- NCRP. Screening techniques for determining compliance with environmental standards, releases of radionuclides to the atmosphere. Washington, DC: National Council on Radiation Protection and Measurements, NCRP Commentary No. 3; 1989.
- Rathgens, L. et al. Typed and handwritten summaries of product deliveries and unit costs for FY-1953 through FY-1976A and production tonnage compilations for FY 1953-1984. Cincinnati, OH: National Lead Company of Ohio; 11 January 1985.
- Roseberry, A. M.; Burmaster, D. E. Lognormal distributions for water intake by children and adults. Risk Analysis, 12: 99-104; 1992.
- Spenceley, R. M. Joint task force on recycle material processing. Letter to J. A. Reafsnyder, Department of Energy. Cincinnati, OH: NLO, Inc.; 1 May 1985.

. \$

#### ANNEX TO APPENDIX D

The analysis of the relative importance of other radionuclides to radiation doses from releases to the atmosphere at the FMPC showed that uranium was by far the dominant source of dose and that only thorium and transuranic nuclides could make potentially significant contributions to the total dose. In this annex, the results of further investigations into releases of these radionuclides are presented.

#### RELEASES OF TRANSURANIC NUCLIDES

The FMPC began to receive recycled uranium as enriched  $UO_3$  during the last half of 1961 (Gessiness 1985). Processing of this material in Plant 4 could have occurred during the last half of 1962, but may not have started until FY 1964 or 1965.

Table D1-1 shows the quantities of recycled uranium and plutonium (Pu) received by the FMPC. The quantities of plutonium received in 1961-1964 were estimated using the mean concentrations measured during 1965-1970. The recycled uranium was shipped to the FMPC from several sources and in a variety of forms (Gessiness 1985). The plutonium concentrations in the table are relative to the amount of uranium.

The data show that about half of the plutonium was received in 1980. This material was  $UO_3$  received from Paducah that had originated at the Hanford reservation. The high concentrations of Pu measured in samples from Plants 1, 2/3, and 8 in 1985 (Table D-1) were affected by the processing of the Paducah shipment and are not reflective of processing of the recycled uranium in earlier years. However, concentrations in other facilities appear more representative of historic operations and perhaps a gradual buildup of Pu concentrations over time.

Releases of transuranic nuclides to the atmosphere were estimated using the data in Tables D-1 and D1-1 together with estimates of the uranium releases from particular effluent paths. Except as noted above, the concentration ratios measured in 1985 were taken to be representative of earlier years of operation. The relative amounts of recycled uranium and uranium that had not been previously irradiated were considered, but not on a year by year basis because it was not possible to track when particular batches of material were actually processed.

#### **RELEASES OF THORIUM**

Releases of thorium as a contaminant of uranium were based upon the 1985 concentration ratios that were given in Table D-1. Some of these ratios may have been influenced by thorium processing campaigns, but it was not possible to isolate events as specific as the Paducah shipment of high plutonium content that was discussed above and in the main text of the appendix.

un district for de la cue

Appendix D		
Other Radionuclide	Releases	

<u>.</u>

فرجة

2

	Recycled		Plutonium
Fiscal	Uranium	Plutonium	Concentration
Year	Received (MTU)	Received (g)	(parts per billion)
1961	· 40	0.21ª	
1962	453	2.4 <sup>a</sup>	
1963	367	1.9ª	
1964	780	4.1 <sup>a</sup>	
1965	8.2	0.019	2.318
1966	103	0.698	6.746
1967	413	1.938	4.693
1968	150	0.994	6.624
1969	120	0.805	6.710
1970	1,302	5.305	4.075
1971	<b>68</b>	0.448	6.631
1972	5.8	0.008	1.377
1973	15 .	0.011	0.737
1974	49	<b>0.123</b>	2.528
1975	37	0.099	2.678
1976	10	0.047	4.526
1977	23	0.007	0.290
1978	15	0.084	<b>5.533</b> .
1979	397	2.161	5.439
1980	124	25.512	205.183
1981	423	2.197	5.197
1982	639	3.631	5.680
1983	479	2.207	4.604
1984	838	1.025	1.222
1985	321	0.322	1.002
Total	7,184 <sup>b</sup>	56.2ª	

Table D1–1. Plutonium Received by FMPC in Recycled Uraniu	m
from Various Sources (Data from Gessiness 1985)	

 \* Estimated using average plutonium concentration between 1965 and 1970.
<sup>b</sup>This total may be compared with 403,000 MTU received during the same period that did not contain plutonium.

Releases of thorium from the processing campaigns are difficult to estimate because of the general lack of information about those activities. The information and production data assembled by Hill and Dolan (1988) was used in making estimates of thorium releases. Normalized release rates for uranium from similar activities were used in calculations of thorium releases. Estimates for the most important activities are shown in Table D1-2. The broad ranges of estimates indicates substantial uncertainty.

> Radiological Assessments Corporation "Setting the standard in environmental health"

11\_

Page D–18	The Fernald Dosimetry Reconstruction Project
· · · · · · · · · · · · · · · · · · ·	 Tasks 2 and 3, Source Terms and Uncertainties

Particle sizes for the thorium releases are believed to be comparable to those observed for uranium. A median diameter of about 7  $\mu$ m with a GSD of about 3 is considered · · · · . · . reasonable. 10

Table I	01–2. Estimated	Parameters for	the Significant Thor	ium Releases
FMPC Facility	Period of Operation	Chemical Form	Estimated Release Rate (kg Th y <sup>-1)</sup>	Range of Release Rates (kg Th y <sup>-1)</sup>
Plant 9	1954-1956	$ThF_4$ , $ThO_2$	100	50-200
Plant 4	1954	ThO <sub>2</sub> , ThF₄	5	0-10
Pilot Plant	1964–1980	Th(NO <sub>3</sub> )2	15	7–30
🗸 Pilot Plant 👘	1964–1970 🚊	Th(OH)₄	50	20-100
Pilot Plant	1969-1971	ThO <sub>2</sub>	15	10-30
Pilot Plant	1971	$Th(C_2O_4)_2$	10	5-25
Pilot Plant	1977–1979	Th(OH)₄	60	20-100
Plant 8	1966	Th(OH)4	150	50-250
Plant 8	1969-1971	Th(OH) <sub>4</sub>	400	200-800
	•			

#### REFERENCES

• :

1.4

. ......

<u>,</u>

10 x 1 1 1

50° .

Gessiness, B. Plutonium content of NLO feed materials (revision 1). Internal memorandum to W. J. Adams. Cincinnati, OH: NLO, Inc.; 10 April 1985. • • • :

.

· · · · · · · ·

• • •

and a second second

.

Letting the second state of the second state

(statistic statistic st

1.12 1.1

•.•

í

 $e^{-2}e^{-$ 

•.

Spenceley, R. M. Joint task force on recycle material processing. Letter to J. A. Reafsnyder, Department of Energy. Cincinnati, OH: NLO, Inc.; 1 May 1985.

The Constant of the second

and the second second second second second

and we may protect and a second second second second A CONTRACTOR SALES AND A SALES AND A SALES AND A

e al construction operations and

· . .

## APPENDIX E

#### EFFLUENTS FROM DUST COLLECTOR EXHAUSTS

#### INTRODUCTION

Many of the plant processes that were expected to generate airborne particles were serviced by dust collectors. Process area ventilation air was ducted to the collectors where airborne particulate material was removed before discharge. The dust collectors recovered valuable uranium that would otherwise be lost and worker exposure in the process areas was reduced.

A general description of dust collector operation is given in Appendix B. More information is available in pollution control and ventilation handbooks such as Danielson (1973) and CIV (1980). Detailed descriptions of some of the specific systems that were in use at the FMPC are available in ventilation system evaluation reports for the various plants; for examples, see Boies (1965).

When operating as designed, the systems could be quite efficient (Drinker and Hatch 1956, Ross and Boback 1971). However, the effluent sampling program identified many occasions when dust collector performance at the FMPC was not optimal. These cases were documented using sampling systems installed to estimate losses of uranium to the environment. The set of effluent sampling systems and the data they produced are of primary importance in any estimation of effluent releases from the dust collector exhausts. Accordingly, the first sections of this appendix are devoted to a description and analysis of those systems.

The following aspects of the effluent sampling systems that were utilized for FMPC dust collector exhausts are discussed below:

- description of the sampling systems
- operating procedure
- sample analysis
- reports of results

After this introductory information, the historic dust collector effluent measurement results, taken from monthly reports, are presented. The reported releases based on those sampling systems were sometimes incomplete. The reasons for those deficiencies and remedies to them are discussed. Simple interpolation was sufficient to estimate releases when results were unavailable for short periods. Normalized release rates were employed for periods prior to implementation of a routine program of effluent monitoring.

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page E–2	•	The Fernald Dosimetry Reconstruction Project
-	. ·	Tasks 2 and 3 Source Terms and Uncertainties

While the design of the sampling systems was generally well conceived, there are possible biases in the results that were given in routine reports. The potential biases are described and methods for estimating the magnitudes of the biases are discussed.

The sizes of particles in the effluents being sampled have an important bearing on the degree of bias in the reported results. Particle size distributions for some of the effluent streams were measured in 1985. Those data and information about other uranium processing facilities have been used to estimate particle size distributions for the dust collector exhausts; the results of that effort are presented. In addition, the chemical forms of materials discharged from the dust collectors are summarized. The chemical form is a determinant of particle density and affects the sampling bias. The transport and deposition of released uranium and the estimation of the radiation dose due to uranium inhalation are also dependent upon particle size and density.

Even with estimates of the particle size distribution and chemical form of the effluent, there is currently insufficient information to make definitive adjustments for sampling bias. The overall sampling bias was estimated using Monte Carlo techniques. These were used to make release estimates for this study. Those estimates, together with the associated uncertainties, are presented in the last section of this appendix.

.

Š.

14.1.1

#### DUST COLLECTOR EFFLUENT SAMPLING SYSTEMS

The sampling systems installed in the dust collector stacks were simple in concept. Air was drawn from the exhaust duct to a pleated filter for collection of particulate material in the sample of discharged air. The filters were periodically changed and submitted for analysis. Details of the design and operation of these systems and of the sample analysis and data reporting are given below.

14 N. P

Sampler Design and Installation

Design of the sampling systems was generally well conceived and consistent with guidance for good sampling practices. Important features of sampler design and installation (Starkey 1956, Boone 1956b, Bipes 1961) were:

• isokinetic sampling — the air velocity through the sampling probe was designed to be the same as that in the exhaust duct at the sampling location to avoid over- or under-sampling particles of various sizes

• proper location — sampling probes were to be installed 7 to 10 stack diameters downstream of the exhaust fan or major bend with 2 to 3 stack diameters of straight ductwork beyond the sampling point

• short sample lines — the filter holder was located outside the stack at an elevation near that of the sampling probe, so total line lengths were generally less than one meter.

A simple schematic diagram of the sampling system is shown in Figure E-1. It is only intended to illustrate the basic components of the system.

the provide and the provide

Appendix E Effluents from Dust Collector Exhausts Wall of Stack Wall of Stack discharge flow

8

.

Figure E-1. Schematic diagram of dust collector stack sampling system. Not shown are the support piping outside the stack or the rain caps that were atop stacks.

The design features identified above were all consistent with consensus guidance for stack sampling installations (ANSI 1969). Initially, a preference for sampling locations in laminar flow was indicated (Boone 1956b); however, the feasibility of satisfying that criterion was limited and it was not present in the later installation procedure (Bipes 1961). Other probe location goals may not have been achieved in practice. The September 1956 procedure recognized that compromises may be necessary with regard to sampling location. It guided the installer to approach the optimal location "as nearly as possible" (Boone 1956b). Earlier guidance circulated by Starkey (1956) indicated that it would rarely be possible to satisfy the probe location guidance without locating the sampling probes on the roof. Some samplers were located outside, but the majority were not. The implied limitation on probe placement would likely mean that the probe was closer to the air mover or to a bend in the stack than was recommended.

The initial sampling probe design included a tapered inlet nozzle that had an internal diameter of 0.95 cm (Starkey 1956). Recent investigations (ORAU 1985) revealed that not all of the inlets were tapered, which may have added to impaction loses in some sampling lines. The initially suggested sampling line diameter appears to have been modified to 0.62 cm at an early stage in the development (Boone 1956a, Boone 1956b).

Prior to installation of the probe in the duct, a pitot tube traverse of the stack was performed to determine the air velocity at several points in the stack. Traverse data were obtained periodically after installation as well. This information was necessary to

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page E-4	The Fernald Dosimetry Reconstruction Project
·	Tasks 2 and 3, Source Terms and Uncertainties

Prior to installation of the probe in the duct, a pitot tube traverse of the stack was performed to determine the air velocity at several points in the stack. Traverse data were obtained periodically after installation as well. This information was necessary to determine the proper flow rate for isokinetic sampling and for the calculations of releases from the sampling data (Starkey 1956, Boone 1956b, Bipes 1961).

A valve in the line to the vacuum source was provided to make adjustments to the sampling flow rate. Such adjustments were normally made when samples were changed but there was no mechanism for assuring a constant flow rate during the sampling period.

#### **Operating Procedures**

Some effluent sampling was performed in the Pilot Plant in 1953, but a routine program for measuring discharges from the facilities was not begun until 1955. Distribution of the initial stack sampling procedure to all the plants occurred in February 1956 (Starkey 1956). Later that year a formalized procedure was promulgated (Boone 1956b). Initial sampling frequencies were weekly, biweekly, or monthly depending on the magnitude of the previous effluent measurements. Pleated "Type S" cellulose filters were used to collect the particulate material. The procedure called for measurement and documentation of the flow rate at the end of the sampling period prior to removal of the filter. The exposed filter was taken from the filter holder, placed in a marked bag, and sealed for delivery to the laboratory. A new pre-weighed filter was placed in the holder. The flow rate was set to the value required for isokinetic sampling and the system was reassembled.

volie.

14.2

.

بالأمدار المراد

é.

1.19

#### Sample Analysis

Tare weights of filters were determined before they were placed at sampling locations. Exposed filters were weighed to determine the total mass of material collected. If sufficient mass was present, the sample was analyzed for uranium content. Otherwise, the uranium fraction of the total mass was estimated using previous measured uranium fractions for the same exhaust. Laboratory results were provided to the Industrial Hygiene and Radiation (IH&R) group on standard analytical data sheets. If an exposed filter was wet, the normal procedure appears to have been to analyze it for total uranium content. The total amount of material releases and the uranium fraction were not reported in such cases.

51 1

#### **Reports of Results**

Monthly reports of releases were made to plant management by the IH&R group. These reports usually included results for all the measurement periods during the month. Estimates of releases from the dust collector exhausts at the FMPC relied on isokinetic sampling of the stacks. When the probe velocity  $(u, \text{ cm } s^{-1})$  and the stack fluid velocity  $(v, \text{ cm } s^{-1})$  are equal, there is a very simple relationship between the mass of material released from the stack and the mass of material collected on the filter. That relationship, which involves the flows through the sampling probe and the stack, was used to estimate releases from the dust collector exhausts. Because the flow through a tube is the product of the fluid velocity and the cross-sectional area, one way to express the relationship is as follows: Appendix E Effluents from Dust Collector Exhausts

$$Q_r = [v_a / v_b] [A_s / A_p_b] M_f$$
 (E-1)

where  $Q_r$  is the amount of material released (g),  $v_a$  is the average fluid velocity (cm s<sup>-1</sup>) in the stack, v is the fluid velocity at the stack centerline (the point of sampling),  $A_s$  and  $A_p$  are the areas (cm<sup>2</sup>) of the stack and the probe, respectively, and  $M_f$  is the amount of material (g) found on the filter. Implicit in Equation (E-1) is the assumption that u = v, which reflects the fact that the effluent sampling systems were designed to operate isokinetically. An equivalent expression for  $Q_r$  is

$$Q_r = [F_s^* / F_p^*] M_f$$
 (E-2)

where  $F_s^*$  and  $F_p^*$  are the current "standard" flow rates in the stack and sampling probe, respectively. That is,  $F_p^*$  is the computed sampling flow rate that would provide isokinetic sampling for a stack whose measured flow rate was  $F_s^*$ . The value of  $F_p^*$  for a given stack was adjusted when a new value for  $F_s^*$  was obtained from pitot tube measurements in the stack.

When a sample weight was determined but the uranium content was not, it was common practice to assume the last measured value of the fraction of the dust that was uranium to convert the mass released to the amount of uranium released. Sometimes grab samples of the collected dust were analyzed to determine the uranium fraction of the dust.

The monthly reports, which are still available, also contained\_comments regarding the operation of the facilities, the dust collectors, and the sampling systems. These notes indicate the difficulties that were encountered by the IH&R staff in implementing the sampling program. The discussions related to plant operating conditions are very useful for reconstructing the history of a particular release point.

#### Early History of the Sampling Program

The sequence of monthly reports documents the onset and growth of the dust collector effluent sampling program. Periodic sampling of some stacks was performed as early as 1953; however, the continuous sampling program did not begin until April 1955. Initiated in seven stacks in Plants 4 and 5, the sampling program grew fairly rapidly to encompass thirty stacks six months later. Subsequent growth was more gradual, as is shown in Figure E-2. Small changes from month to month may reflect either sampling problems or changes in plant operations. The sharp increase early in the second year was due to the installation of more sampling systems in Plant 8. The following month, operation of Plant 7 was terminated and those sampling systems were taken out of service. During the next two years the sampling program grew gradually to a maximum of 50 sampling systems in May 1958. The decline in number of systems after that time was due to the shutdown of systems in Plant 1 and in the Pilot Plant.

> Radiological Assessments Corporation "Setting the standard in environmental health"

> > 1.150





Page L-

Figure E-2. Growth of the dust collector exhaust stack sampling program during the first years of operation.

At the start of 1960, there were 44 dust collector exhaust sampling systems in operation at the FMPC. At that time, the most common sampling interval was one month, although a few stacks were sampled more frequently. Typically, the time resolution of the data varied from 3-7 days for exhausts with the highest release rates to approximately four weeks for systems with the lowest release rates. When the staff were trying to determine whether a malfunctioning dust collector had been repaired, sampling periods as short as a few hours were used. In the 1960s, sampling intervals were occasionally as long as six weeks for discharge points that were minor contributors to plant uranium releases.

Both plant production and staff were reduced in later years. Intervals between sample analyses were greater and routine reports contained less detail. Filters were no longer changed and analyzed regularly. Instead, sampling systems and filters were inspected routinely, but filter changes and analysis occurred primarily when the filter had collected a visually detectable amount of particulate material.

#### PARTICLE SIZE DISTRIBUTIONS AND CHEMICAL FORMS OF RELEASES

The chemical and physical characteristics of the uranium that was released to the atmosphere are important for four reasons. In the present context, particle size and density, which is related to chemical form, are important determinants of the transmission factors and of the magnitude of anisokinetic sampling bias. In addition, the chemical form determines the mobility of uranium inhaled by humans and affects its distribution in and clearance from the body. Physical characteristics, primarily particle size, affect two important processes. The size and shape of the particles are both parameters that affect the deposition of discharged radionuclides. In addition, aerodynamic particle size is an important determinant of the fate of an inhaled aerosol in the human respiratory tract. PV2-274

# Appendix E

· · ·

Contraction and the second

#### Effluents from Dust Collector Exhausts

Larger particles are collected in the upper regions while very small particles penetrate further along the bronchial airways. Many of the larger particles will be swallowed and enter the gastrointestinal (GI) tract from which the radionuclides may be absorbed into the blood. The smaller particles are cleared from the lung directly to the blood and to the GI tract where uptake to blood may also occur.

The only measurements of the particle sizes of stack emissions from the FMPC were conducted in 1985 by Northern Kentucky Environmental Services (NKES) (Reed 1985). In the NKES study, measurements were made for both the inlet ducts and the outlet ducts of 15 major uranium-emitting stacks with dust collectors. The particle-size distributions determined in the study were reported by Boback et al. (1987).

Particle-size distributions for the stack emissions measured in 1985 are included as a part of the source-term characterization for stacks because the plant processes served by the stacks have not changed significantly since the start of FMPC operations. The hydrofluorination process for producing  $UF_4$  (green salt), for example, has remained basically the same over the years with respect to conditions which might affect the particle size distribution of the product. Similarly, the various plant operations which produce  $U_3O_8$  particles also have not changed in a manner which would significantly alter particle size distributions.

The particle size data given in Boback et al. (1987) for inlets to and outlets from the dust collectors have been consolidated in Appendix F, which contains plots of the reported measurement results. Some of the distributions deviate substantially from the expected lognormal shape. For convenience in calculations, polynomial functions have been fit, using least squares techniques, to the reported distributions. These functions, also given in Appendix F, permit computer calculation of the portion of the aerosol in a particular size interval. Particle size distributions for the outlet ducts (or emission stacks) are representative of emissions from dust collectors with intact bag filters. However, when bag failures permit unfiltered air to escape to the atmosphere, the distributions of particles in the inlet ducts would be more representative of the releases.

The predominant uranium species released from each stack was identified from FMPC reports and engineering drawings of process equipment. In some cases more than one uranium species was determined to be emitted from a stack. Nearly all of the dust collector exhaust stacks evaluated by NKES emitted either  $UF_4$  or  $U_3O_8$ . One of the stacks studied discharged a mixture of  $UO_2$  and  $UO_3$ .

To verify them, results presented by Boback et al. (1987) were compared against original NKES data. That process and resolution of the questions that arose from it are discussed below.

#### Verification of Particle-Size Measurements

Verified particle size measurements are those for which the reported results are consistent with the original data and which meet the test of physical reality. The latter test is simply the question of whether, as expected, the particle size for the outlet duct of a specific dust collector is less than that for the inlet duct over the entire range of measurements.

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page E-8	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3 Source Terms and Uncertainties

Most of the particle sizes listed in Boback et al. (1987) were verified in accordance with these criteria, but discrepancies and omissions were found in some cases. Unverified values were not considered representative of specific stack emissions.

Discrepancies were found for the outlet ducts of G5-251, G5-253, and G5-260. The particle size distributions as reported by Boback et al. (1987) for these cases are not consistent with the original NKES data sheets. The reported distributions were derived from modified data sheets of uncertain origin.

Measured particle sizes for the outlet ducts of G4-5 and G43-27 were greater than those for the corresponding inlet ducts, which is physically unrealistic. The particle size data for the inlet duct of G5-251 were also difficult to accept because they indicated smaller particles than those for the outlet duct for the same collector. However, the latter values were not verified (see above). It was also found in the verification process that reported values (Boback et al. 1987) for the larger particle sizes in the distributions in inlet ducts of G5-254 and G5-256 seem to contain relatively small systematic errors (5-10%). These errors have been corrected and the revised values are included in the verified results.

NUMBER OF STREET

ź.

**F** 

Table E-1 contains the results of particle size measurements that were verified as part of this study. The calculations of sampling bias employ ten distinct particle sizes — the 5th, 15th, 25th, . . ., and 95th percentile values — to represent the distribution for the dust collector exhaust of interest. These are given in the table. The same calculations also require information on particle density, so the chemical form of the discharged uranium is also of interest. This information has been included in Table E-1 for each duct. The same chemical form assignment applies to both the inlet and outlet ducts.

It should be noted that the bag filters of the dust collectors for FMPC stacks were not all made from the same material during the 1985 NKES study. Some of the dust collectors had wool felt bags, but a change to Gore-Tex bags was in progress over the period of years which included 1985. There were too few stacks with the same uranium species and different bag types to draw definite conclusions about differences in bag collection efficiencies for specific particle sizes ranges.

## Inferred Particle Sizes for Other Stacks

The particle size distributions for emissions from some stacks for which no measurements had been made were inferred from the results obtained by NKES (Reed 1985). This was accomplished by relating the uranium chemical species and plant operation(s) serviced by an unstudied exhaust to those of exhausts for which measurements had been made.

The particle size distributions of the stacks which emitted UF<sub>4</sub> produced by the hydrofluorination process were averaged, and this average distribution was assumed to apply to all stacks emitting UF<sub>4</sub> also produced by hydrofluorination but for which reliable measured values are not available. Estimation of the average distributions for UF<sub>4</sub> and a similar average for  $U_3O_8$  are described in a subsection below.

# Appendix L Effluents from Dust Collector Exhausts

· .:

. . .

ŝ.

12.27

:•

•			•			· .		· 11	. :			•	
Tabl	le E-1. S	um	mary of	f Verifie	ed Info	mation	on Pa	rticle Si	ize for l	Dust Co	llectors	5	
· · ·				Equ	uiválen	t diame	ter (µm	) at spe	cified p	oercenti	le ·		
Stack	Form	a	5	15	25	. 35	45	55	65	75	85	95	_
G4-2	UF <sub>4</sub>	Õ	1.5	4.3	6.1	7.6	. 9.0	10	12	14	16	20	
	-	I	2.6	4.2	5.3	6.3	7.3	8.3	9.5	11	13	17	
		-					<b>F</b> A	<b>.</b>	10		01	00	
G4–5	$\mathrm{UF}_4$	0	0.56	1.4	2.5	3.8	5.4	7.4	10	14 10	21 15	.30	
		1	1.0	- 1.9	2.7	3.6	4.0	5.9	1.1	10	لانز	21	
G4 .7	110-	0	0.80	16		47	73	11	15	20	27	41	
u	002	v	0.00	<b></b> 0	2.0				~				
G4-12	UF₄	0	2.5	4.5	5.8	6.9	8.0	9.0	10	12	13	17	
		Ι	3.4	5.5	6.9	8.1	9.2	10	11	13	15	18	
<b>-</b>		-		~ .		·		10	10	15	10	04	
G4–14	UF4	0	.0.92	3.1	5.0	6.7	8.4	10	12	10 19	<u>مر</u>	24 05	
	•	ł	5.4	8.1	9.9	12	وبر	14	. 10	סנ	20	20	
G5_249	UF.	0	0.13	0 29	2.4	4.6	6.4	8.0	10	12	15	19	
00-245		ĭ	2.7	5.2	6.9	8.3	9.7	11	13	14	17	21	
		-											
G5-250	$UF_4$	0	0.66	2.4	4.1	5.8	7.5	9.3	11	14	18	25	
		I	5.9	8.8	11	12	14	15	17	19	22	21	
C5 951	TTE	T	0.28	0.35	0.40	0.45	0.51	0.58	0.69	0.85	12	6.0	
00-201	014	1	0.20	0.00	0.40	0.40	0.01	0.00	0.00	0.00	4,-	0.0	
G5-253	UF	Ι	0.89	3.4	5.4	6.9	8.4	9.7	11	13	15	19	
	Ŧ												
G5–254	U <sub>3</sub> O <sub>8</sub>	0	0.63	1.4	2.5	3.7	4.8	5.9	7.2	8.7	11	14	
·		I	1.7	<b>3.0</b> ·	4.2	5.5	7.0	8.8	11	15	21	37	
C5 950		0	0.49	0.64	16	3.0	46	61	77	9.5	12	16	
<del>G0-</del> 200	0308	U T	0.40	3.2	4.8	6.2	7.4	8.6	9.8	11	13	17	
		•	0.70	0.2	•			0.0	210		-		
G5–260	$U_3O_8$	I	1.5	3.1	4.2	5.3	6.4	7.6	9.0	11	13	18	
	5.5	;						•	_				
G5–261	U <sub>3</sub> O <sub>8</sub>	0	1.1	2.9	4.2	5.4	6.5	7.7	8.9	11	13	. 16	
		I	2.9	5.3	7.0	8.6	10	12	. 14	16	19	20	•
C12 07	ПO	T	1 1	96	10	. 5 3	67	83	10	13	16	93	
G40-21	0308	1	1.1	2.0	4.0	0.0	0.7	0.0	10	<u>cu</u>	IV.	20	
G9N1-	U202	0	0.34	0.47	0.61	0.79	1.1	1.9	3.8	6.0	8.7	· 13	
	~3~8	•				÷•••							

.•

<sup>a</sup> Distributions are given for the outlet (O) and inlet (I) of the dust collector.

-

Radiological Assessments Corporation "Setting the standard in environmental health"

×\*.

Page E-9

11 .

140000

Airborne  $U_3O_8$  is produced in the FMPC as a result of the oxidation of uranium metal surfaces by air. There are two general types of plant operations which can produce airborne  $U_3O_8$  particles:

- foundry operations such as melting and casting of uranium metal, breakout of the uranium derbies and ingots from crucibles, and cleaning of metal surfaces
- the machining of uranium derbies and ingots.

Lake D-IA

The NKES study included only stacks which served foundry operations in Plant 5. The average particle size distribution based upon the  $U_3O_8$  emission points that were evaluated was assumed to apply to all stacks exclusively serving foundry operations for which no measurements had been made. Surface oxidation of uranium scrap in high-temperature furnaces such as took place in Plant 8 was assumed to be in the same category as foundry operations.

Distributions of particle size for machining operations were inferred from other sources of particle size data. These are presented in a the second subsection. Particle sizes for emissions from dust collectors in Plants 1 and Plant 2/3 were also inferred from other sources and are discussed separately below. In the last subsection, the issue of particle sizes for UF<sub>4</sub> produced by reduction of UF<sub>6</sub> is addressed.

Calculation of Average Distributions for UF<sub>4</sub> and U<sub>3</sub>O<sub>8</sub>. The average particle-size distributions for both the inlet ducts and the outlet ducts for stacks emitting UF<sub>4</sub> and U<sub>3</sub>O<sub>8</sub> were derived from the data in Appendix F. Table E-2 gives the verified particle size distributions for UF<sub>4</sub> in six outlet ducts. The average distribution derived from the six sets of measurements of this type is also shown. Table E-3 contains the verified distributions of UF<sub>4</sub> measured in the inlets to seven dust collectors and the average distribution derived from those measurements. Tables E-4 and E-5 contain the verified and derived average distributions for U<sub>3</sub>O<sub>8</sub> in three outlet and four inlet ducts, respectively. In all four tables, results are given in terms of the equivalent aerodynamic diameter, defined as the diameter of a sphere of unit density (1 g cm<sup>-3</sup>) that has the same gravitational settling velocity as the particle (also assumed to be spherical).

Table E-6 contains the median particle sizes for the inlets and outlets of dust collectors handling UF<sub>4</sub> from hydrofluorination in Plant 4 and  $U_3O_8$  from foundry operations in Plant 5. Also shown in the table are particle sizes of  $U_3O_8$  in air measured during foundry operations at Los Alamos (Hyatt et al. 1959) and at two facilities in the United Kingdom (Vallis 1991; Fishwick 1991). These results agree reasonably well with dust collector inlet values from Plant 5 at the FMPC.

As noted previously, the measured distributions deviate from lognormality and the composite distributions are also not truly lognormal. However, if the central portion of the distribution is used to make an estimaté, geometric standard deviations (GSDs) of the composite distributions for the FMPC are about two. A GSD of two was quoted by Fishwick (1991) as typical of the measurements at Springfields.

# Appendix E Effluents from Dust Collector Exhausts

.

Table E-2. Size Distributions for UF <sub>4</sub> in Dust Collector Outlet Ducts									
	_	Percentage of particles in specified size range (µm) <sup>a</sup>							
Plant	Stack	0-2.5	2.5-5.0	5.0-7.5	7.5-10	10-15	15-20	20-40	
4	G4-2	8.0	12	15	16	29	15	5.0	
	G4–5	25	· 17	14	8.0	13	7.0	16	
	G4-12	5.0	15	22	23	25	8.5	1.5	
	G4-14	12	13	15	15	21	14	10	
5	G5–249	25	13	15	<b>13</b> . :	19	<b>10</b> 1	4.5	
	G5–250	16	14	15	14	16	14	10	
Average		_15	14	16	15	20	12	7.8	
<sup>a</sup> Ran	ges are gi	ven for e	quivalent a	erodynami	c diameter	s of parti	cles.		

Table E-3. Size Distributions for UF<sub>4</sub> in Dust Collector Inlet Ducts

۲.,

		Percentage of particles in specified size range (µm) <sup>a</sup>							
Plant	Stack	0-2.5	2.5-5.0	5.0-7.5	7.5–10	10-15	15-20	20-40	
4	G4-2	5.0	17	26	22	22	5.5	2.5	
	G4–5	23	27	14	10	11	5.0	10	
	G4–12	3.5	8.5	18	24	29	14	3.0	
	G4-14	0.8	3.2	8.0	14	34	22	18	
5	G5-249	4.5	9.5	15	20	29	15	7.0	
	G5-250	0.7	2.8	6.5	. 12	28	30	20	
	G5-253	12	10	17	18	27	12	4.0	
Average		7.1	11	15	17	26	15	9.2	
a Rai	nges are giv	ven for ec	uivalent a	erodynami	: diameter	s of partic	cles.	• •	

Table E-4. Size Distributions for U<sub>3</sub>O<sub>8</sub> in Outlet Ducts of Dust Collectors Serving Foundry Operations

	Percentage of particles in specified size range (µm) <sup>a</sup>						
Stack	0 - 2.5	2.5-5.0	5.0-7.5	7.5–10	10-15	15-20	20-30
G5-254	24	22	21	15	10	7.2	0.8
G5-256	32	16	16	13 .	17	5	1
G5-261	13	18	23	. 19	19	6	2
Average		19	20	16	15	6.1	1.3
	Stack G5-254 G5-256 G5-261 rage	Stack     02.5       G5-254     24       G5-256     32       G5-261     13       rage     23	Percentage       Stack     0-2.5     2.5-5.0       G5-254     24     22       G5-256     32     16       G5-261     13     18       rage     23     19	Percentage of particle       Stack     02.5     2.5-5.0     5.0-7.5       G5-254     24     22     21       G5-256     32     16     16       G5-261     13     18     23       rage     23     19     20	$\begin{tabular}{ c c c c c c c c c c c c c c c c c c c$	Percentage of particles in specified size r       Stack     0-2.5     2.5-5.0     5.0-7.5     7.5-10     10-15       G5-254     24     22     21     15     10       G5-256     32     16     16     13     17       G5-261     13     18     23     19     19       rage     23     19     20     16     15	$\begin{tabular}{ c c c c c c c c c c c c c c c c c c c$

• •

Radiological Assessments Corporation "Setting the standard in environmental health"

3
		,			3				
		· ·	Table E-5	. Size Dist	ributions	for U <sub>2</sub> O2	in Inlet Duc	s	
			of Dust	Collectors	Serving I	Foundry	Operations	1	
	-			Percentag	e of partic	les in sp	ecified size r	range (µr	n) <sup>a</sup>
<u>. Pl</u>	ant	Stack	0-2.5	2.5-5.0	5.0-7.5	7.5-1	0 10-15	15-20	20-35
	5	G5-254	16	22	19 (14 <u>1</u>	14	14	8.0	12
	<u></u>	G5-256	5.0	16		17	26	<b>10</b> '	2.0
		G5-260	11	20	22		18	6.5	4.5
		G5-261	4.0	10	13	16	27	16	14
;	Avera	age	9.0	17	* ~ <b>18</b>	16	21	10	. : 8.1
	<sup>a</sup> Rang	es are gi	ven for eg	uivalent a	erodynam	ic diame	ters of parti	cles.	<u> </u>
				· ,		· . ·	,		· .
. :					s da mas	-	.1		
•		• • •		s. (		· · ·			
		Table	E-6 Con	nnosito Ma	dian Part	iclo Sizo	s in Plants A	and 5	·
	:			d Some Da	ita From (	ther Fac	ilities		· .
	· · · · ·			21				,	Median
Sr	pecies		So	urce	<u></u>	<u>!</u>	Location		size (µm
١	UF4	Hydrofi	uorinatio	n in Plant	4	Inlet to d	lust collector	·	9.5
						Outlet fr	om dust coll	ector	8.1
τ	J <sub>2</sub> O.	Foundr	v operatio	ns in Plan	t 5 <sup>-23</sup> -22	Inlet to d	lust collector		8.3
•	5 6		· · ·			Outlet fr	om dust coll	ector	6.0
		Los Ala	mos foun	drv		Airborne	narticles		73
		Alderm	astón IIK			Airborne	dust in wor	kshon	· 97
			$\omega = \omega = \omega = \omega$	s iounui V	· · •	THING	, 4436 111 1701	ranob	<i></i>

Tacke

The particle size distributions for dust collector stacks for which no measurements are available were inferred from the available data. Dust collectors handling  $UF_4$  produced by hydrofluorination were assigned the composite distribution for that species. Stacks serving foundry operations were similarly assigned the distribution for  $U_3O_8$  from Table E-6. Estimates for uranium machining operations are discussed below.

Inferred Particle Sizes for  $U_3O_8$  Produced During Machining. Machining operations such as cutting and milling of uranium metal ingots and derbies were conducted in Plant 6 and Plant 9. Studies in other facilities have estimated particle size distributions for releases from machining operations. Hyatt et al. (1959) reported an AMAD of 6.7  $\mu$ m with a geometric standard deviation (GSD) of approximately 2.7 for uranium machining operations at Los Alamos. A median particle size of 6.9  $\mu$ m was reported for similar operations at Aldermaston in the United Kingdom (Vallis 1991). The GSD for the Aldermaston distribution was stated to be approximately 3. The distributions are quite consistent considering the great differences in time and location.

Particle size measurements were made for one stack in Plant 9 in 1985. The inlet median diameter was 5.4  $\mu$ m for dust collector G9N1-1039. The reported median particle

size for the outlet was about 1.5 µm, which was atypical of the FMPC results. The reason for the large reduction in size between inlet and outlet of this dust collector is not known.

For other discharges from dust collectors in Plants 6 and 9, a median diameter of 6.8  $\mu$ m was assumed to apply to inlet ducts for dust collectors serving machining operations in Plant 6 and Plant 9 at the FMPC. A median diameter of 5.1  $\mu$ m is estimated to apply to the outlet ducts for those operations. This reflects the nominal 25% reduction in median particle size seen in most of the FMPC measurements.

Inferred Particle Sizes for Emissions from Plant 1 and Plant 2/3. A mixture of particles of  $U_3O_8$ ,  $UO_3$ , and  $UO_2$  is assumed to be present in the discharges from dust collector stacks in Plant 1 and Plant 2/3. Those collectors serve areas handling ores and various other feed stocks for the digestors. Because the 1985 NKES study did not include any stacks for these plants, particle-sizes for these emissions must be inferred from measurements made for similar operations elsewhere.

A study of particle sizes of uranium-containing dust from mining and milling operations was performed in the Elliot Lake Area of Canada (Duport and Edwardson, 1985; Duport and Horvath, 1989). Those authors reported AMADs of mill atmosphere aerosols for several processes as shown in Table E-7.

Table E-7. Results of Particle Size Measurements						
for Uranium Milling Processes						
	Median					
Process	size (µm)					
Jaw crushing	9.5					
Cone crushing	9					
Screening	7.5					
Grinding	<b>8</b> ·					
Acid precipitation	6					
Filtering	10					
Concentrate drying	. 8					
Concentrate packing	7.5					

The average AMAD for mills (possibly a weighted average) was reported to be about 7  $\mu$ m. The GSDs for the particle size distributions given in Table E-7 ranged between 3 and 5 (Duport and Hovarth 1989).

On the basis of the data cited above, a median particle diameter of 7  $\mu$ m with a GSD of 4 is assumed for the U<sub>3</sub>O<sub>8</sub> dust emitted from Plant 1 and Plant 2/3 as a result of ore handling. This inferred value applies to inlet ducts of the dust collectors. For the exhaust stacks, a median value of 5.3  $\mu$ m is assumed. As before, this reflects a nominal 25% reduction in the median particle size due to filtration in the collectors.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page E-13

## Tasks 2 and 3, Source Terms and Uncertainties

Particle Sizes for  $UF_4$  Produced by Reduction of  $UF_6$ . There were two sources of releases of  $UF_4$  produced by reduction of  $UF_6$ . This process was developed and modified in the Pilot Plant (Davis et al. 1956). During a 2-year period of operation, Plant 7 produced  $UF_4$  in larger reactor vessels that were modeled after the one in the Pilot Plant. Dust collectors in both facilities released product material during operations.

Process particle size measurements were made during the development process (Davis et al. 1956). The system to remove HF from the offgas employed two cyclone collectors, two filters, and a KOH scrubber. Particle size data from the two cyclones indicate median particle sizes between 9 and 11  $\mu$ m. These measurements are consistent with the median of the composite UF<sub>4</sub> size distribution for dust collector inlets (Table E-7), indicating that the particle size of airborne UF<sub>4</sub> is not strongly dependent upon the production process. The composite particle size distributions for UF<sub>4</sub> were used for the Pilot Plant and Plant 7 dust collector systems that handled UF<sub>4</sub>.

Summary of Inferred Particle Size Distributions. As noted previously, it is convenient to summarize information on both particle size and chemical form together. Table E-8 contains the information for the composite and inferred particle size distributions just discussed. Two particle size distributions are given, one for the inlet (I) to the dust collector and one for the outlet (O). The chemical form is the same for both the inlet and the outlet. The dust collectors to which the composite distributions were applied are listed in the footnotes to the table. Particle size distributions that were derived from other sources are given for the machining operations in Plants 6 and 9 and for operations with uranium feed stocks that generated airborne dusts in Plant 1 and Plant 2/3.

		Equivalent diameter (µm) at specified percentile										
Stack	Form	a	5	15	25	35	45	55	65	75	85	95
Comp-	UF <sub>4</sub>	0	1.0	2.6	4.2	5.8	7.5	9.4	11	14	17	22
osite <sup>b</sup>	_	I	2.0	4.2	6.0	7.8	9.4	11	12 ·	15	17	23
• • •		. '	-			. ::: ·					· • .	
Comp-	<sup>.</sup> U <sub>3</sub> O <sub>8</sub>	0	0.6	1.2	2.8	3.9	5.1	6.5	7.9	9.6	12	16
ositec	•	Ι	1.8	3.4	4.9	6.3	7.8	. 9.2	. 11	14	17	´ <b>2</b> 4
Plant 6	U <sub>3</sub> 08	0	0.82	1.6	2.4	3.3	4.4	5.8	7.8	11	<b>16</b> 2	32
Plant 9	00	I	1.1	2.2	3.3	4 <b>.4</b> 1	6.0	7.8	10	15	· <u>22</u>	43
Plant 1	IL-O-	0	0.63	1 3	91	21	45	61	0.1	14		50
Pl. 2/3	0308	· I ·	0.7	1.7	2.8	4.2	6.0	8.5	12	18	30	72

Table E-8. Composite and Inferred Particle Size Distributions

\* Distributions are given for the inlet (I) and outlet (O) of the dust collector.

<sup>b</sup> Composite UF<sub>4</sub> distribution applied to dust collectors G4-1, G4-4, G4-5(I), G4-8, G4-13,

G4–15, G4–7001, G5–251(I), G5–252, G5–253(O), G20–20, G4–2507, G4–2508, G4–2509, G4–2510.

<sup>c</sup> Composite  $U_3O_8$  distribution applied to dust collectors G5-247, G5-248, G5-258, G5-259, G5-260(O), G55-E100, G5A-100, G5A-101, G43-27 (O) and other  $U_3O_8$  discharges from Plant 8 and the Pilot Plant.

そうないという

### Effluents from Dust Collector Exhausts

•:

# PREVIOUS RELEASE ESTIMATES

In this section, previous release estimates, based primarily on routine operational measurements, are presented. The deficiencies in these estimates and possible biases in the reported values are discussed.

### **Routine Measurements**

Results of the measurements described above were reported routinely by the IH&R staff at the FMPC. Although monthly reports were prepared, the period for which data were presented did not correspond to the beginning and end of the calendar month. Typical reporting periods began and ended between the 20th and 25th day of the month. The results presented in a particular report could cover sampling periods with greater variation in start and stop times, depending upon which analyses were completed by the date of report preparation. Copies of many of those reports have been retained to the present day.

Previous FMPC release estimates for the dust collection systems gave annual totals that were largely based upon those reports. Table E-9 contains the annual releases from dust collector exhaust presented by Boback et al. (1987). The reported releases for each plant reflect samples collected from as many as eighteen different dust collector exhausts.

About 35% of the uranium discharges from dust collectors reported by Boback et al. (1987) came from Plant 4. Plant 5 was estimated to contribute about 28% of the total. Although it operated for only two years, Plant 7 was estimated to have released about 14% of all the uranium discharged by dust collectors. Plant 8 (with 11%) was the only other facility estimated to contribute more than ten percent of the total. The other five facilities were estimated to have made minor contributions. None accounted for as much as 4% of the total and the group was estimated to contribute about 12%.

### Deficiencies in Reported Release Estimates

There are two major deficiencies in the tabulations of reported releases in the monthly reports that form the basis for Table E-9. The first and most important is that the data are incomplete. In the early years of operation, no release estimate for a particular duct was made until a sampler was installed. Annual totals for those years must therefore be viewed with caution. There were also no estimates for times when the sampler malfunctioned during the sampling period. In later years, when production declined from the peak years in the early 1960s, the level of detail in the monthly reports was greatly decreased. Sample filters were changed much less frequently and detailed information about the sampling program was no longer included.

The second deficiency in the tabulations was the failure to account properly for undetected releases. If no material was detected on the filter from a dust collector exhaust sample, the reported release was shown as zero. Actually, the release was between zero and an upper bound computed using a variant of Equation (E-1):

$$Q_{rm} \leq [v_a/v][A_s/A_p]MDA_f \tag{E-3}$$

Page	E-16
------	------

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

Diskop og Evisiet

ĨĊ,

			Repor	ted in FI	MPC-20	82 (Boba	<u>ck et al. 1</u>	987)		_ <u>,</u> ,
Veer			Kepo	rted rele	ases (k	g U) from	n FMPC	facilities	D:1-4	<u> </u>
1051		0	- <u>4</u>	<u> </u>	0	<u> </u>	<u> </u>	9	102	102
1059	Ó	0.	0	0	U		U		402	400
1952	0	. U'	1470	0	0		0		493	499
1905	4	0	1473	90	12	. 4001	0		450	2,010
1904	40	/1 / 1000	5,890	4,119	28	4,201	201		211	14,007
1955	. 40	000	12,400 E 145	10,410	23	1,208	8/1 -	•••••••••••••••••••••••••••••••••••••••	443	31,910
1900	40	220	0140	3,001	27 .	1,743	1,310	0.4	ンム 10	12,000
1050 · ·	49	900	. 014	3,004	30		(91	0.4	य 70	0,002
1050	401	110	1 400	110	101		000	019	21	0,140
1909	40	119	1,420	4/8	127		200	· 417	, 30 710	2,911
1001	20 50	213	, 212	203	209	1. • • • • • • • • •	, 298	219 ,	174	2,152
1901	23	. 01	202	10	118	n e i. A de	209	D/ 105	114	1,020
1902	14 '	10	1.00	- 300	. 11 :	: · · · · · · · · · · · · · · · · · · ·	019	150	1/4	2,144
1903	83 :	U	1,469	783	163	•	994.	159	52	3,702
1904	24 )	0	545	330	34	5. <b>.</b> .	1,051	252	کل ۱۵	2,249
1962	4 .	13	335	226	<b>43</b> _2		390	68	10	1,089
1966	16 ;	54	-228	77	$\mathbf{n}_{ij}$	N	328	. 49	. 18	781
1967	26	27	280	148	<b>3</b> ∈ ∖		417	76,	12	.989
1968	1.	10	267	· 88	30	1 . J	900	121	4	1,421
1969	35	. 8	- 49	:119	3,	S. L. L	424	13	4	655
1970	6′∶⊹	47	. 30	<u>:</u> 53	_;;, <b>0</b>	11. I	569	<b>14</b> . ,	, <b>O</b>	718
1971	11 _	. 26	· 0	0	0 · .	· · ,	91	0	. <b>0</b>	128
1972	<b>56</b> )	· 410	-, <b>9</b>	33	· 0		5	24	• • 0	537
1973	2	186	57	- 79	0	•••	14	15	<u>.</u> , О	353
1974	1	15	24	<b>40</b> ·	0		11 .	<b>38</b> ,	. 0	130
1975	6	65	120	19	0		2	0	0.4	212
1976	3	9	26	14	2		8	3	. 0	65
1977	1	6	12	53	0		÷2	0	. 10	87
1978	2	0	12	29	0		. 0	72	2	117
1979	1.	0	46	12	0		0	2	0	62
1980	13	3	134	90	· 0		5	0	. 3	247
1981	1	0	432	135	0		0	0	<b>`</b> 0	568
1982	2	2	<b>21</b>	122	0.5		81	5	0	234
1983	6	0	43	. 41	0		25	0	0	115
1984	· 12	. 4.	40	84	1.		8	171	ີ 3	323
<u>Total</u>	1,042	<u>3,218</u>	33,217	26,189	1,204	13,272	10,774	2,599	3,133	94,646

Table E-9. Releases of Uranium from Dust Collectors

in which  $Q_{rm}$  is the maximum release for the sampling period (g),  $MDA_f$  is the minimum detectable amount of material on the filter (g), and the other terms are as defined previously.

A review of the analytical sheets for dust collector effluent sampling has indicated that the smallest reported amount of material on a filter was 0.1 g. No indication of the MDA<sub>f</sub> has been found on those forms reviewed. In the absence of other information, a value of 0.05 g has been used for  $M_f$  in Eq. (E-1) to estimate of the release during a sampling period when no release was detected. This is equivalent to assuming that the filter could have

.

.

100

contained any amount of uranium between zero and  $MDA_f$  and, in the long-term, the sum of such release estimates will be an unbiased approximation of the true release.

An example in which undetected releases were important for some dust collectors is shown in Table E-10. The measured releases for Plant 6 during 1960 were primarily from the South Precipitron. (Plant 6 employed some electrostatic precipitators; releases from them are included in the dust collector releases). That stack was sampled more frequently

		Estimated		,			
	•.	release			•		
		from South		• • •	Estimat	ed release	s from
Samplin	g Period	Precipitron	Samplin	g Period	G6-6057	G6-86	G6-88
Start	Stop	(kg U)	Start	Stop	(kg U)	(kg U)	(kg U)
12-15-59	1-21-60	11 <sup>a</sup>	12-15-59	1-21-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
1-21-60	2-16-60	11 <sup>a</sup>	1-21-60	2-16-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup> .
2-16-60	3-6-60	12	2-16-60	3-22-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
3-6-60	3-15-60	11 <sup>a</sup>	3-22-60	4-20-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
3-15-60	3-22-60	11 <sup>a</sup>	4-20-60	5-14-60	33.5	0.17 <sup>b</sup>	0.19 <sup>b</sup>
3-22-60	4-4-60	11	5-14-60	6-24-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
4-4-60	4-12-60	10	6-24-60	7-22-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
4-12-60	4-20-60	25	7-22-60	8-23-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
4-20-60	4-29-60	20	8-23-60	9-23-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
4-29-60	5-14-60	39	9-23-60	10-24-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
5-14-60	5-17-60	· 1.0 <sup>b</sup>	10-24-60	11-30-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
5-17-60	6-2-60	6.5	11-22-60	12-5-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
6-2-60	6-9-60	1.0 <sup>b</sup>	12-5-60	12-30-60	1.0 <sup>b</sup>	0.17 <sup>b</sup>	0.19 <sup>b</sup>
6-9-60	6-20-60	9.1		Total	46	2.2	2.5
6-20-60	7-5-60	1.1 <sup>b</sup>					
7-5-60	7-18-60	16					
7-18-60	7-26-60	7.1					
7-26-60	8-3-60	. 1.1 <sup>b</sup>					•
8-3-60	8-8-60	4.1					
8-8-60	8-19-60	9.1					
8-19-60	9-6-60	9.1					•
9-6-60	9-22-60	<b>6.1</b>					
9-22-60	10-13-60	2.0					•
10-13-60	10-24-60	1.1 <sup>b</sup>					
10-24-60	11-4-60	-1.1 <sup>b</sup>					
11-4-60	11-14-60	13					
11-14-60	11-22-60	1.1 <sup>b</sup>					
11-22-60	11-30-60	1.1 <sup>b</sup>					
11-30-60	12-5-60	2.0		•			
12-5-60	12-30-60	1.1 <sup>b</sup>					
	Total	250					

Table E-10. Measured and Estimated Releases from Plant 6 in 1960

<sup>a</sup> Estimated release based on operational data.

<sup>b</sup> Estimated release for period when no release was detected.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page E-17

than the other three release points, whose discharges were generally not detected by the samplers. Estimates for the undetected releases vary because the exhaust flows from the four ducts are different.

When sampling equipment was not installed or failed to operate or if no analytical result was available, interpolation, using releases measured during previous and subsequent sampling periods, was used to estimate the release. This was necessary for four of the sampling periods for the South Precipitron.

For the period shown, inclusion of estimates for periods of unmeasured and undetectable releases led to a total of 305 kg. This may be compared with the reported total of 269 kg in Table E-9; the difference between the two estimates is about 13%. The relative importance of undetected and unmonitored releases depends upon the magnitude of facility releases. Releases from Plant 1, which were relatively small, were underestimated by about 30% because of unmonitored and undetected releases during 1960-1962. However, underestimations for most facilities were smaller, comparable to those for Plant 6 during that period.

Table E-9 shows several years when the stated releases for various facilities were zero. In some cases, this occurs because processes were not operating. Plant 2/3 was closed throughout 1963 and, as noted, Plant 7 operated for only a brief period. On the other hand, Plant 6 is reported to have produced no less than 800 MTU of rolled or machined uranium during each of the years between 1970 and 1986, but annual releases were reported to be about 2 kg U or less. For times when sampling of dust collector exhausts was less complete, or less frequent and poorly described in the routine records, plant releases were estimated using release rates normalized to production rates, described in the next major section of this appendix.

Initial estimates of releases, including those corrected for unmonitored and undetected releases and those based upon normalized release rates and production rates, are subject to further revision to account for biases in the effluent measurements themselves. The potential biases that have been identified and quantified are discussed next.

Possible Biases in Release Estimates

12 - .....

Assessing the magnitude of biases in the sampling results is a difficult and important problem. Although much information was recorded about dust collector operation and the associated sampling, detailed records of stack and sampler flow rates are not available. Assessments of sampling losses have not been found in plant archives, although anecdotal information about problems with plugged sampling lines was recorded. However, revision of the previous release estimates requires quantification of the biases in sampling the dust collector exhausts and of the uncertainties associated with the revised estimates.

Three types of deviations from ideal sampling conditions may have biased the dust collector discharge estimates. These are inhomogeneous distribution of effluent particles in the exhaust duct, mismatch of sampling flow and duct flow, and losses of material in the sampling line. Each is discussed briefly in a subsection below.

Nonrepresentative Sampling. One design feature that was not consistent with standard guidance for sample collection from exhaust ducts was the use of a single sampling probe in larger ducts. The ANSI (1969) guide recommends multiple sample

and the second 
1

withdrawal points for ducts greater than 15 cm in diameter. The reason for multiple probes is to provide assurance that the samples will not be biased because of a nonuniform distribution of the contaminant in the stack. The sample extracted from the center of a dust collector exhaust stack would be representative if the particles were uniformly mixed in the exhaust or if the concentration on the centerline happened to be equal to the average concentration in the stack. When this is not the case, the sample is not representative of the material being discharged. The bias introduced may be positive or negative, depending upon the actual relationship between the centerline and average concentrations. Quantitative assessment of this question requires tracer measurements in the exhaust stacks. Such an effort is well beyond the scope of this work and is not feasible for many of . the exhausts. A qualitative assessment was made and is presented in Appendix G.

Anisokinetic Sampling. The second type of sampling bias that may have occurred is that due to anisokinetic sampling; that is, when the fluid velocity in the sample probe (u,cm s<sup>-1</sup>) differs from the fluid velocity in the exhaust stack  $(v, \text{ cm s}^{-1})$ . The samplers were set up to obtain isokinetic samples of the stack exhausts, by adjusting the sampling flow to the rate that would make u = v. However, the samplers were not equipped with constant flow rate control mechanisms and, as a result, sampler flow rate could vary during the sampling period. The stack flow rate may also vary from the most recently measured value, which was used to determine the isokinetic sampling rate for the stack.

The effect of deviations from isokinetic conditions depends not only upon the ratio of the fluid velocities (u / v), but also on the size and density of the particles (see above and Appendix F), the sampling probe diameter, and, to a lesser degree, on the air temperature and pressure. Anisokinetic conditions can also be produced by misalignment of the sampling probe.

The possible effects of anisokinetic sampling conditions were calculated using the methods described in Appendix G. That appendix contains example calculations and the basis for parameters used in Monte Carlo calculations of bias due to anisokinetic sampling. Anisokinetic sampling can produce either a positive or negative bias in sampling results depending upon whether u < v or u > v. The upper bound value for the bias depends upon the aerodynamic diameter of the particle, but can be as great as (v / u) for large particles.

Losses of Particles in the Sampling Lines. Two processes lead to losses of particles in the sampling lines. These are deposition of particles on the walls of the line and impaction of particles due to the presence of bends in the lines. The transmission factor for an aerosol through the sampling line is the ratio of the concentration at the outlet of the line, the sample collection point, to that at the inlet in the stack. A low transmission factor indicates large losses due to deposition and impaction. Unlike the biases due to nonrepresentative and anisokinetic sampling, losses due to deposition and impaction of particles in the sampling line lead only to underestimates of the effluent release. The magnitudes of such losses depend upon particle size and density (see above and Appendix F), the configuration of the sampling line, and the operating conditions for the line. These relationships are described in Appendix G, which contains example calculations and the basis for parameter values used in Monte Carlo calculations of sampling bias due to these processes.

### Page E-20

· · · · · · · ·

### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

Application of Monte Carlo Techniques to Assess Sampling Bias

,

۰. and the second seconds. The Monte Carlo calculational procedure that was used to estimate sampling biases and their uncertainties is summarized briefly in this subsection. The basis for the calculations is given in Appendix G to which the reader is referred. The calculations employed the measured and inferred particle size distributions described in a previous

section of this appendix. There are several parameters relevant to the estimation of sampling bias for a particular exhaust duct. None of these parameters is known with certainty. The Monte Carlo procedure utilizes information about the expected values and distributions of possible parameter values to make a series of estimates of quantities that depend upon the parameters. The calculations considered the three sources of bias identified above to obtain a measure of overall sampling bias.

The following steps were performed to apply this calculational technique. Distributions of the relevant parameters were developed that reflect the uncertainties associated with the parameters. The distributions were then sampled and the selected parameter values were used to estimate the overall sampling bias for a particular dust collector exhaust. This process was performed repeatedly to obtain a distribution of estimates of the overall sampling bias; the distributions obtained were approximately lognormal. The central values, medians or geometric means (GMs), of the distributions and the associated geometric standard deviations (GSDs) were used to generate revised release estimates and their uncertainties.

Median estimates of overall bias for individual stacks ranged from 0.82 to 0.98, with GSDs ranging from 1.4 to 1.6. The 90% confidence intervals for the estimates of overall bias indicate that, in general, releases may have been underestimated by as much as a factor of two or overestimated by as much as a factor of 1.6. The bounds of possible over- or underestimation are somewhat greater for the very large diameter ducts, notably in Plants 6 and 9. For those exhausts, underestimation by a factor of about 2.5 was possible as was overestimation by a factor of about 1.8. These estimates of overall bias differ from those made in the draft report, primarily because a better treatment of the attachment fraction was developed (see Appendix G).

Major contributors to the uncertainty were the velocity of air in the sampling probe and in the duct, the bias due to nonrepresentative sampling, and a parameter used in computation of the attachment fractions. There is no simple way to reduce the largest uncertainties, which principally reflect the absence of information about conditions of past operations and sampling. 

Section of the sector of the s

RELATIONSHIPS BETWEEN REPORTED RELEASES AND PRODUCTION

. . .

a no pair e tal tra

Because there are periods when routine sampling data are not available, it is useful to determine whether there are relationships between reported releases and plant production that could be used to make preliminary discharge estimates for those times. Dust collector releases reported by Boback et al. (1987) (Table E-9) and the plant production data, in metric tons of uranium (MTU), given in Appendix C were used. The period examined was 1956-1984. As shown in Figure E-1 installation of effluent samplers was incomplete N 364 · · ·

. .

0

12 11 21

ģ

Aries 142

before 1956. The plant total release estimates were used because release rates for individual exhausts were interpolated for some years by Boback et al. (1987) and because the utilization of specific dust collectors varied over the years of operation.

Figures E-3 and E-4 show annual production (P, MTU) and reported dust collector releases (Q, kg U) for Plants 4 and 8, respectively. These figures show that, while there is substantial variability in the reported releases for a given level of production, the values were lower during periods of reduced production.



ACT:

Figure E-3. Plant 4 production data (P, MTU) and reported releases from dust collectors (Q, kg U).

The ratio of the reported release for the year to the plant production during the same period is termed the normalized release rate. This ratio, (Q/P), has units kg U MTU<sup>-1</sup> and is useful for estimating releases for periods when data are incomplete or unavailable. In Figure E-5 the normalized release for Plants 4, 5, and 6 are plotted as functions of time. Lines connecting the points are provided only to aid the eye of the reader, not as interpolations for years when the reported releases were zero and no points are plotted.

Figure E-6 contains normalized release estimates for Plants 8 and 9. The normalized release estimates for Plants 8 drop rather sharply during the first few years, suggesting that efforts to reduce the dust collector releases were succeeding. However, the normalized releases returned to higher levels in the 1960s. After an initially low value for the first year of uranium production, a general downward trend is shown for Plant 9. Similar patterns are shown for the early years of operation of Plants 4 (Figure E-5).



Figure E-4. Plant 8 production data (P, MTU) and reported releases from dust collectors (Q, kg U).





7

オズンド

1

1.53

11111111



Figure E-6. Normalized release rates (Q/P) for Plants 8 and 9.



Figure E-7. Normalized release rates (Q/P) for Plants 1 and 2/3.

Figure E-7 contains normalized release estimates for Plants 1 and 2/3. The amount of uranium received by Plant 1 during a year was used as a surrogate for production in calculations of (Q/P). The normalized releases from Plant 1 show a generally declining trend but with some oscillations. Normalized releases for Plant 2/3 periodically returned to values near those of 1956-1959; normalized releases from Plants 4 and 8 show similar patterns. In contrast, normalized releases from Plants 5, 6, and 9 were generally lower in

The Fernald Dosimetry Reconstruction Project
 Tasks 2 and 3, Source Terms and Uncertainties

..

1 7

٠.

1

1000

2

ż,

H

i.

the later years. Because there is evidence that normalized releases often decreased with time, the entire distribution of estimates cannot be used to make estimates of releases prior to 1956.

Normalized release rates for Plant 7 and the Pilot Plant have not been estimated because production data are not well defined, missing, or incomplete. It would be expected that normalized release rates for Plant 7 and the Pilot Plant would be relatively high. In both those facilities, as in Plants 4 and 8, hydrofluoric acid fumes and high temperature exhausts were constant threats to the integrity of some of the dust collectors.

A to Bar Sec.

a 2008 11

 $(\mathbf{j})$ 

**REVISED RELEASE ESTIMATES** 

• •

,**.** .

• • • •

Introduction

Page E-24

The process of developing revised estimates of releases from the FMPC dust collectors is complex. Reported releases were incomplete because sampling was not initiated when production began. The reported releases do not include estimates of releases that were undetected by the analytical procedure or because a sampling system was temporarily out of service. Three sources of possible bias in the reported results, discussed above, have been estimated as part of this effort. Details are provided in Appendix G.

The first step in the approach adopted was to return whenever possible to the original release reports that were prepared routinely by the IH&R department. In the early years of full operation of the effluent sampling program, these reports contained a great deal of information about sample collection and about operational problems in all the plants. These detailed reports made it possible to estimate the magnitudes of undetected releases. Later reports of results, when production rates and releases were lower, were not as detailed and were much less helpful in this regard. In general, inclusion of undetected releases does not have a large effect on the estimates for early years when releases were large. In plants whose releases were relatively small (tens of kilograms of uranium per year) the relative contribution of estimates of releases that had gone undetected was greater.

The reported releases, together with production data, were used to compute normalized releases that offered some guidance for making initial estimates of releases when no effluent sampling was performed. However, such estimates necessarily reflect the biases in reported releases that were identified above and also require correction for them.

Aronagen 1

1 to start!

1 \*\*\*\* 25 \$ 25 4

**Calculational Procedure** 

5.

a strategies a

٠.

Summation of measured or estimated releases, such as those in Table E-10, can be performed using ordinary arithmetic. However the estimates of overall bias in the sampling are approximately lognormally distributed, which introduces complexities into the calculations. The special procedures required are described below.

A particular release measurement  $(E_1)$  was assumed to be upon a sample from a normal distribution. The one-sigma uncertainty for that measurement is designated  $S_1$ . Parameters of the equivalent lognormal distribution are the median or geometric mean  $(GM_1)$  and the geometric standard deviation  $(GSD_1)$ . These were computed using the following equations:

$$GM_{1} = \exp[u_{1}]$$
 in which  $u_{1} = \ln [E_{1}/(1 + (S_{1}/E_{1})^{2})]$ 

$$GSD_1 = \exp[\sigma_1] \text{ in which } \sigma_1 = \sqrt{\left[\ln\left(1 + (S_1/E_1)^2\right)\right]}$$

The central estimate of the lognormal distribution of computed values of overall sampling bias characteristic of the exhaust being sampled is designated  $GM_{ob}$ . The distribution of such estimates is characterized by the value of the  $GSD_{ob}$ . To make the correction for biases, we define  $\mu_{ob} = \ln GM_{ob}$  and  $\sigma_{ob} = \ln GSD_{ob}$ . The geometric mean revised release estimate is: exp ( $\mu$ ) = exp ( $\mu_1 - \mu_{ob}$ ) and the corresponding geometric standard deviation is: exp ( $\sigma$ ) = exp ( $\sqrt{(\sigma_1^2 + \sigma_{ob}^2)}$ ).

Composites of these revised release estimates cannot be obtained by simple addition because the central estimates are medians of lognormal distributions. The correct procedure for determining the median of a sum of such distributions is described below (Dunning and Schwarz 1981, Hoffman and Gardner 1983).

First, each geometric mean revised estimate was used to compute the corresponding arithmetic mean value (m) using the following equation:

$$m = \exp(\mu + 0.5 \sigma^2)$$
 (E-6)

where  $\mu = \ln GM$  and  $\sigma = \ln GSD$  for the distribution of revised estimates. The variance (s<sup>2</sup>) associated with a particular value of m was computed using

$$s^{2} = [exp(2\mu + \sigma^{2})][exp(\sigma^{2}) - 1]$$
 (E-7)

The means and variances of the revised releases to be summed are denoted by  $m_i$  and  $s_i^2$ , respectively. The arithmetic sums  $M = \Sigma m_i$  and  $S^2 = \Sigma s_i^2$  were computed. These were then used to calculate the geometric mean composite release (GM<sub>a</sub>) and its geometric standard deviation (GSD<sub>a</sub>) using Eqs. E-8 and E-9.

 $GM_a = \exp{[\mu_a]}$  in which  $\mu_a = \ln{[M/\sqrt{1 + (S/M)^2}]}$  (E-8)

 $GSD_a = \exp [\sigma_a] \text{ in which } \sigma_a = \sqrt{[\ln (1 + (S/M)^2)]}$  (E-9)

The same basic procedure was used to composite results from multiple time periods for an exhaust point, to obtain a median estimate of the releases from many ducts in a single plant, and to obtain median release estimates for the collection of individual plants. Uncertainties associated with the geometric mean total releases are generally smaller than those associated with the individual contributions to the total.

Estimates for Plant 1

Plant 1 was not a production facility in the classical sense. As an alternative, receipts of uranium have been used to indicate the level of activity. Figure E-8 shows the increase

Radiological Assessments Corporation "Setting the standard in environmental health"

(E–5)

(E-4)

Page E-26	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3, Source Terms and Uncertainties

in uranium receipts in the early years. Uranium was received prior to startup of Plant 1 operations, which did not begin until December 1953.



Figure E-8. Receipts of uranium in Plant 1.

Figure E-9 shows the median annual release estimates developed in this study. In the earliest years of operation, releases were not monitored. The average monthly releases measured during the period September-December 1955 were used to make initial estimates of releases during the years 1953-1955. Releases were variable from year to year, being highest in 1958. Releases from Plant 1 were not a large fraction of the total FMPC releases during that year. The median release from Plant 1 for the entire period was estimated to be 1,300 kg U oxides (GSD = 1.2).

### Estimates for Plant 2/3

Plant 2/3 also began production late in 1953. Figure E-10 shows the substantial variability in  $UO_3$  production over time in that facility. Effluent sampling systems were not in place until August of 1955. Initial estimates of releases for that year were obtained by scaling the results for the 5-month period for which data were available. The average normalized release rates for 1955-1957 were used to make initial release estimates for 1953 and 1954 when no effluent measurements were made.

The estimated median annual releases, shown in Figure E-11, generally follow the pattern defined by the changes in production, but there is additional variability. The highest releases from the Plant 2/3 dust collectors were in 1958. Over the entire period of operation, the median estimate of releases from Plant 2/3 dust collectors was about 4,000 kg U oxides (GSD = 1.2). This contribution to overall dust collector releases is about three times larger than that from Plant 1, but nonetheless is not a major fraction of the total.

1971年1月1日,1986年1月日,1987年1月1日,1987年1月1日,1987年1月1日,1987年1月1日,1987年1月1日,1987年1月1日,1987年1月1日,1987年1月1日,1987年1月1日,19

1000

1.1.1



÷

81

Figure E-10. Production of uranium trioxide in Plant 2/3.

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

変が強

112215

See ....

CLAR

14043



Figure E-11. Estimated median annual releases from Plant 2/3 dust collectors.



Figure E-12. Production of uranium tetrafluoride in Plant 4.

### **Estimates for Plant 4**

<u>,</u>2

5

Production of  $UF_4$  in Plant 4 increased sharply to more than 10,000 MTU in the first four years after startup in October 1953. It fell below 1000 MTU in 1971 and was slightly above that level for three years in the 1980s. Figure E-12 shows the time history of Plant 4 production.

Partial monitoring of Plant 4 effluents was established in April 1955; more samplers were installed in August of that year. Total releases for 1955 were estimated from the measurements and the normalized release rate for that year was used, together with production data, to estimate releases during 1953 and 1954. The estimate for 1953 was in good agreement with measurements made in November and December of that year.

Estimated median annual releases for Plant 4 dust collectors are shown in Figure E-13. Estimated releases were very high during the 1950s with a peak in 1955. Relatively high releases occurred early in the 1960s, but declined sharply toward the end of that decade. Releases in more recent years were quite variable, with a peak in 1981. For the entire period, the median release from the Plant 4 dust collectors was about 41,000 kg U (GSD = 1.2), about 80% of which was uranium oxides. Plant 4 was one of three primary contributors to total dust collector releases.



Figure E-13. Estimated median annual releases from Plant 4 dust collectors.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page E-29

14.783

31 U.V. 35

λ.

### **Estimates for Plant 5**

Uranium metal and ingot production in Plant 5 is shown in Figure E-14. After startup in May 1953, production rose sharply initially and remained at a high level until the late 1960s. A secondary peak in production occurred in the 1980s.





Partial effluent monitoring coverage was initiated in April of 1955 and a more complete program was in place by October of that year. Initial estimates of releases for 1955 were based upon extrapolations of the partial data for that year. The estimate of the normalized release for 1955 and production data were used to project releases for 1953 and 1954.

The estimated median annual release for all years are shown in Figure E-15. As was the case with Plant 4, the highest releases from Plant 5 occurred during the 1950s and were relatively high during the 1960s before declining to the much lower levels of the 1970s and 1980s. Plant 5 was another of the principal contributors to total releases from the FMPC dust collectors. The median estimate of release from Plant 5 for the entire period was about 38,000 kg U oxides (GSD = 1.2). This release is somewhat lower than but comparable to the amount estimated for Plant 4.

### **Estimates for Plant 6**

Machining operations in Plant 6 were initiated in July of 1952 and the rolling mill began production the following month. Combined production figures from the two operations are plotted in Figure E-16. Production rose rapidly after startup and remained high for many years, exceeding 20,000 MTU for all years between 1956 and 1964. Production levels were

. .

much lower after 1970, with maximum levels of about 2,000 MTU for three years in the 1980s.



Figure E-15. Estimated median annual releases from Plant 5 dust collectors.



Figure E-16. Production of machined and rolled uranium in Plant 6.

Page E-31

Page	E32
------	-----

.

51 (V) (L)

1

Į.

たいいい

5

Although effluent sampling was initiated in Plant 6 in August 1955, a full complement of sampling systems was not in place until mid-1957. The average normalized release rate in 1958 and 1959 was used, together with production data, to estimate uranium releases from Plant 6 for the years 1952 through 1957. Figure E-17 shows median annual release estimates for all years. The releases follow the general pattern of the production levels in Plant 6 with peak values during the years of highest production and low values after 1970.



Figure E-17. Estimated median annual releases from Plant 6 dust collectors.

The figure shows that Plant 6 was not a major contributor to total FMPC dust collector releases. After 1970, estimated releases were all less than 10 kg U and some were less than 1 kg U. (Some exhausts from Plant 6 were treated by electrostatic precipitators. Releases from those stacks are included in these totals in the "dust collector" category). The median estimate of the total Plant 6 release was about 2,100 kg U oxides (GSD = 1.1), about 1.5 times the release from Plant 1.

### **Estimates for Plant 7**

Plant 7 was turned over to the Production Division in late June of 1954. Initial operations were completed in the third quarter of that year. The plant ceased operation in May 1956. Although the capacity of Plant 7 is known, operational data for the facility appear to have been lost or destroyed.

Effluent monitoring began in Plant 7 in September of 1955. All four dust collector exhausts were sampled during the next eight months (until shutdown). Results for about

## Appendix E

## Effluents from Dust Collector Exhausts

one-third of the samples collected in 1955 were considered unreliable because of trouble with the vacuum system which pulled air through the samplers and because some sampling lines were plugged with  $UF_4$ . Sampler operation in 1956 was satisfactory and the improvement was noted in the sampling data record.

Whenever possible, measurement data were used as the initial estimates of releases from Plant 7. For other periods, two operating scenarios and corresponding release rates were developed for each of the dust collectors. One scenario reflected relatively good performance of the collectors while the other was used for periods when degraded performance was identified or suspected. During initial startup operations, when the systems were being tested and checked, and for the remainder of 1954 it was assumed that the first scenario applied. However, in July 1955 there were identified problems with loss of materials from Plant 7 (Cuthbert 1955). It was presumed that these difficulties began at the start of the 1955 and that the higher release rate estimates applied from January to late September (when actual sampling data were available).

Figure E-18 shows the estimated median annual releases from the Plant 7 dust collectors. Even though it operated for only two years, the observed and projected releases from the plant made a major contribution to the total FMPC dust collector releases. The median estimate of Plant 7 releases was about 35,000 kg U, primarily  $UF_4$ , (GSD = 1.4), which is lower than but still comparable to the estimate for Plant 5.



Figure E-18. Estimated median annual releases from Plant 7 dust collectors.

174 J.Y.

1000000

147. Ja 11.

ç

¥.

### **Estimates for Plant 8**

Uranium recovery operations in Plant 8 began in November 1953. Figure E-19 shows the history of that work over time. As was the case for other facilities at the FMPC, the highest activity occurred during the late 1950s and the 1960s. Annual uranium recovery increased rapidly during the first three years of operation and exceeded 1500 MTU for all years during the period 1957-1968. Uranium recovery during later years was substantially lower, but did rise to nearly 900 MTU in 1987.





Effluent monitoring was initiated in Plant 8 in July of 1955, but comprehensive monitoring was not established until the following year. Results from 1955 and 1956 were used to establish a normalized release rate that was used, together with production data, to make initial estimates of releases in late 1953 and during 1954 and 1955.

Estimated median annual releases from the dust collectors in Plant 8 are shown in Figure E-20. The highest estimated releases occurred between 1955 and 1970. Releases in later years were generally below 50 kg U with the exception of 1982. Because of the early releases — estimated to exceed 1000 kg U in each of ten years before 1971 — Plant 8 is one of the major contributors to total dust collector releases. Overall, the median Plant 8 dust collector release was about 14,000 kg U oxides (GSD = 1.1), lowest of the four major sources of releases.

15:11



Figure E-20. Estimated median annual releases from Plant 8 dust collectors.

### Estimates for Plant 9

<u>.</u>

Plant 9 began uranium operations in 1957. Production for that facility, shown in Figure E-21, includes both ingot production and machining of uranium metal. The production rate plot for Plant 9 is somewhat unique among the FMPC facilities because the production in later years was comparable to that in the mid-1960s.

Effluent monitoring had already been started in 1957 but was more complete in 1958. The normalized release rate for 1958 was used with production information to estimate the releases in 1957. Median annual release rate estimates for all years are shown in Figure E-22. Releases were highest during the early years but were estimated to exceed 100 kg U twice after 1975. Overall, the median release estimate for Plant 9 dust collectors was about 3,300 kg U oxides (GSD = 1.1), a contribution to the total roughly comparable to that from Plant 2/3.

### Estimates for the Pilot Plant

Work was started in the Pilot Plant in October 1951. Many different operations were performed there, not all of which were documented in terms of "production." Conversion of  $UF_6$  to  $UF_4$  was an initial production activity as was the reduction of UF4 to metal. Data on the first process were available but the metal production information was not as well preserved. Tests run to evaluate operational problems and recommend changes also had some attributes of production runs, but no accessible chronicle of these efforts was found.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page E-35



ř.

ţ

÷.....

11.1.1.1

Carl Marsh

÷

Appendix E		
Effluents from	Dust Collector	Exhaust

There was early monitoring of effluents from the Pilot Plant. Releases from the  $UF_6$  to  $UF_4$  production area were monitored during June-August 1953. Routine monitoring was started in the last quarter of 1955 and the normalized release rates estimated from the two sets of data were consistent. The mean value was used with production data to estimate releases from this part of the plant for the years 1952–1955.

Releases from the metal production area were also measured in 1953 and were found to be about 80 kg U per year. Routine monitoring in 1955 and 1956 showed that these releases had been reduced to about 3 kg U per year. The higher rate was used to estimate releases from October 1951 through 1952. Lower releases were estimated for 1953, when Plant 5 production was started, and releases during 1954 and 1955 were assumed to decline further.

Most of the releases during years when monitoring was only occasional were estimated to be due to the production of  $UF_4$ . Estimated median annual releases for all years are shown in Figure E-23. Annual releases are estimated to have exceeded 1000 kg U during four early years, but were less than 50 kg U in all years after 1963. Overall, the median Pilot Plant contribution to the total FMPC dust collector releases was estimated to be about 3,900 kg U (GSD = 1.2), approximately the same as the Plant 2/3 dust collector releases.



Figure E-23. Estimated median annual releases from the Pilot Plant dust collectors.

#### Summary of Dust Collector Releases

š.,

Estimated median annual releases from all FMPC dust collectors (including, as noted previously, the releases from stacks treated by electrostatic precipitator in Plant 6) are

Radiological Assessments Corporation "Setting the standard in environmental health"

Page E-37

Page E-38		The Fernald Dosimetry Reconstruction Project
	•	Tasks 2 and 3, Source Terms and Uncertainties

shown in Figure E-24. The plot shows that the highest releases were in 1955, with dominant contributions from Plants 7, 4, and 5. The figure illustrates the relative importance of releases during the early years of FMPC operations. Median annual releases exceeded 1000 kg U in only three years of the decades of the 1970s and 1980s, whereas they were consistently above that level during all but one of the years from 1954 to 1968.

17 A.

. <u>Avasu</u>

Real Property



Figure E-24. Estimated median annual releases from all dust collectors.

Table E-11 contains the best (median) estimates of the releases from FMPC dust collectors for each year of operation. These values, which have been rounded to two significant figures, were computed (as were the sums for individual plants) using the special procedure described earlier in this appendix. Also shown in the table are the geometric standard deviations for the lognormal distributions of release estimates.

Table E-12 contains the estimates of releases for each decade during which operations occurred. In addition to the median estimates, values for various percentiles of the distributions are shown. The table shows clearly the predominance of releases during the early years of operation of the facility.

11 .

i). ?'

### CONCLUSIONS

Many exhaust stacks at the FMPC were served by dust collectors that recovered uranium that would otherwise be lost. Routine sampling of the dust collectors was begun in April 1955 and expanded rapidly during the next two years. The results of these measurements form the basis for initial estimates of releases from the dust collectors.

<u>, </u>

	Table E-11.	<u>Median Annual I</u>	Release Esti	mates for FMPC D	Just Collectors
	Median	÷.		Median	•
	estimate	Geometric		estimate	Geometric
	of release	Standard		of release	Standard
Year	(kg U)	Deviation	Year	(kg U)	Deviation
1951	22	1.5	1970	850	1.4
1952	273	1.5	1971	160	1.4
1953	5,300	1.3	1972	640	1.4
1954	23,000	1.3	1973	440	1.3
1955	54,000	1.3	1974	170	1.2
1956	18,000	1.3	1975	270	1.3
. 1957	8,300	1.3	1976	85	1.2
1958	4,600	1.2	1977	120	1.3
1959	3,600	1.3	1978	·150	1.3
1960	2,600	1.2	1979	90	1.4
1961	1,800	1.2	1980	320	1.3
1962	- 2,400	1.2	1981	680	1.4
1963	4,600	1.3	1982	280	1.3
1964	2,700	1.3	1983	160	1.3
1965	1,300	1.3	1984	360	1.3
1966	950	1.3	1985	140	1.3
1967	1,200	1.3	1986	. 71	1.3
1968	1,700	1.3	. 1987	48	1.3
1969	780	1.3	1988	3	1.2

	Best estimate of release	Other percentiles in distribution of release estimates (kg U)				
Period	(kg U)	5th percentile	25th percentile	75th percentile	95th percentile	
1950s	120,000	96,000	110,000	130,000	150,000	
1960s	21,000	18,000	19,000	22,000	24,000	
1970s	3,100	2,500	2,800	3,400	3,800	
1980s	2,100	1,700	1,900	2,400	2,700	
1951–						
1988	140,000	120,000	130,000	160,000	170,000	

Physical and chemical parameters of the releases are important to the dispersion and dose calculations. Extensive review of measurements of particle size made in 1985 was performed and information was obtained from other facilities. Particle size distributions have been assigned to the various stacks based on direct measurement results or

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page E-39

Page E-40	The Fernald Dosimetry Reconstruction Project	
	Tasks 2 and 3, Source Terms and Uncertainties	

similarity of function to other stacks or areas in which measurements were performed. In spite of some substantial variations from stack to stack, it can be stated that the particles were relatively large. Plant processes have been reviewed to evaluate the chemical forms that would be released from the various stacks. About three-fourths of the releases from the dust collectors were in the form of uranium oxides.

Previous estimates of releases from individual dust collectors at the FMPC were tabulated from original records. In the early years, there were monthly reports of the measurements. Review of the reported results revealed periods when samplers were not in operation and other times when the releases were too low to be detected. Estimates were made for these periods based on other sampling results and information about the sampling and analysis procedures. Estimates were also made for years before monitoring was established as a routine procedure. These estimates were based either upon normalized release rates soon after routine monitoring was established or representative measurements during the mid- to late-1950s. In some cases, evaluations of unmonitored effluents led to significant increases in release estimates.

į.

11-00-1-1-

و برورد الرو

Possible biases in the sampling results were investigated and a Monte Carlo procedure was developed to estimate their magnitudes (see Appendix G). The procedure was applied to each of the dust collector exhaust sampling systems. The estimates of bias were used to compute revised release estimates for the dust collector exhausts. The magnitudes of the estimates of overall bias varied among the stacks from 0.82 to 0.98. Corrections for unmeasured releases and for sampling bias led to revised release estimates that were about 50% higher than previous estimates of dust collector releases.

The median estimate of total releases from the FMPC dust collectors was about 140,000 kg U. The preponderance of the releases occurred during the 1950s. Principal contributors to the releases during that decade were Plants 4, 7, and 5. Plant 8 also contributed significantly to the total, but most of those releases occurred over a longer period of time. Although releases from the other facilities were not small, those releases were not major fractions of the total release. However, some of the releases from plants that were lesser contributors to the total were important in individual years.

### REFERENCES

,

QF (

- 1

- Hidiney e ANSI (American National Standards Institute). Guide to sampling airborne radioactive materials in nuclear facilities. New York: American National Standards Institute, Inc.; 1969. The state of a period of the
- Bipes, R.L. Stack sampler installation. Cincinnati, OH: National Lead Company of Ohio; 24 October 1961. beer store I t

o e peder V Boback, M. W.; Dugan, T. A.; Fleming, D. A.; Grant, R. B.; Keys, R. W. History of FMPC radionuclide discharges. Cincinnati, OH: Westinghouse Materials Company of Ohio; Document FMPC-2082 (Revision to FMPC-2058); May 1987.

- ,\* <del>\*</del> .

The destable

••••

. .

N.

Effluents from Dust Collector Exhausts

- Boies, R. B. Heating and exhaust survey, Plant 5. Internal letter report to P. G. DeFazio, Engineering Project G-324. Cincinnati, OH: National Lead Company of Ohio; 21 April 1965.
- Boone, F. W. Drawing of stack sampler (unnumbered). Fernald, OH: National Lead Company of Ohio; 3 August 1956 (1956a).
- Boone, F. W. Stack sampling procedure. Fernald, OH: National Lead Company of Ohio; 5 September 1956 (1956b).
- CIV (Committee on Industrial Ventilation). Industrial ventilation, a manual of recommended practice. 16th Ed. Lansing, MI: American Conference of Governmental Industrial Hygienists; 1980.
- Cuthbert, F. L. Physical loss of SF material in Plant 7; internal memorandum to C. M. Walden. Cincinnati, OH: National Lead Company of Ohio; Document NLCO-1087; 18 July 1955.

Danielson, J. A. (ed.) Air pollution engineering manual. 2nd Ed. Research Triangle Park, NC: U. S. Environmental Protection Agency; 1973.

Drinker, P. and Hatch, T. Industrial dust. New York: McGraw-Hill Book Company; 1956.

- Duport, Philippe J.; Edwardson, E. Determination of the contribution of long-lived dust to the committed dose equivalent received by uranium mine and mill workers in the Elliot Lake Area. Ottawa: Atomic Energy Control Board of Canada; Document INFO-0167-1; 1985.
- Duport, P.; Horvath, F. Practical aspects of monitoring and dosimetry of long-lived dust in uranium mines and mills - determination of the annual limit on intake for uranium and uranium/thorium ore dust. Radiat. Prot. Dosim. 26: 43-48; 1989.
- Dunning, D. E., Jr.; Schwarz, G. Variability of human thyroid characteristics and estimates of dose from ingested 1311. Health Phys. 50: 661-675; 1981.

Fishwick, A. H. Personal communication with P. G. Voillequé. 1991.

- Hoffman, F. O.; Gardner, R. H. Evaluation of uncertainties in radiological assessment models. In Till, J. E.; Meyer, H. R., eds. Radiological assessment, a textbook on environmental dose analysis. Washington, D. C.: U. S. Nuclear Regulatory Commission; Document NUREG/CR-3332; 1983.
- Hyatt, E. C.; Moss, W. D.; Schulte, H. F. Particle size studies on uranium aerosols from machining and metallurgy operations. AIHA Journal 20: 99-107; 1959.

Radiological Assessments Corporation . "Setting the standard in environmental health"

Page E-41

Page E-42	The Fernald Dosimetry Reconstruction Project	
	Tasks 2 and 3, Source Terms and Uncertainties	

- NLCO (National Lead Company of Ohio). Monthly reports of effluent releases measured by the Industrial Hygiene and Radiation (and successor organizations). Cincinnati, OH: National Lead Company of Ohio; 1955-1989.
- RAC (Radiological Assessments Corporation). The Fernald dosimetry reconstruction project, task 1: identification of release points. Neeses, SC: Radiological Assessments Corporation; January 1991.
- Reed; K. P. A study of the particle size distribution of the stack emissions at Fernald. Unpublished report by Northern Kentucky Environmental Services; 1985.
- Ross, K. N.; Boback, M. W. The control and sampling of airborne contaminants from uranium production. Cincinnati, OH: National Lead Company of Ohio; Document NLCO-1087; 15 November 1971. .

Starkey, R. H. Stack sampling procedure (Attachment to monthly report of estimated stack losses). Cincinnati, OH: National Lead Company of Ohio; 3 February 1956.

> 12.2

·. . . . . .

20 - 20 - 20 - 20

. Se et el a

5 Mar

. . . . . . . .

(139) Adams

n Solotta por din sol

2 States Base 28

ن د ..

.

. . .

1.1

-

.

. '

r

· ,

•••

• •

· · · · ·

۰,

.

· ; • • •

Ξ.

14. X.

.

the set of the Vallis, D. G. Personal communication with P. G. Voillequé. 1991.

in the second 
to be a present of the

· · · · ·

.

### APPENDIX F

### FITTING PARTICLE-SIZE DISTRIBUTIONS FOR FMPC DUST COLLECTORS

### INTRODUCTION

The distributions of particle size in releases of particulate radioactive material from a nuclear facility are important in two particular respects for estimating transport and radiation dose. First, atmospheric deposition processes are sensitive to particle aerodynamic properties determined by size, shape, and density, and thus successful estimation of the rate of depletion of the plume depends on making reasonable assumptions about these distributions. Second, the use of the respiratory model of the International Commission on Radiological Protection (ICRP) requires the assumption of activity median aerodynamic diameters (AMAD) appropriate to the material.

In 1985, the Feed Materials Production Center (FMPC) and subcontractor Northern Kentucky Environmental Services (NKES) performed sampling operations on the inlet and outlet ducts of 15 dust collectors. Uranium particle-size distributions and isotopic fractions for these samples are presented by Boback et al. (1987), by NKES in an unpublished report (Reed 1985), and in the original data sheets. These data provide essentially all of the usable information on distributions of particle size in FMPC stack emissions that has come to light at the date of this writing (September 11, 1991), and this information will have to be taken as the basis of generic representations of particle size in the source term for purposes of transport simulation and dose reconstruction.

Each measured diameter is reported as an equivalent aerodynamic diameter, which is the diameter of a sphere of unit density ( $\rho = 1 \text{ g cm}^{-3}$ ) that has the same gravitational settling velocity as the particle. Physical diameter is equal to equivalent aerodynamic diameter divided by the square root of the density (expressed in units of g cm<sup>-3</sup>) of the particular compound of uranium for diameters in the ranges encountered in these tables. We confine this presentation to equivalent aerodynamic diameters.

In order to make use of the distributions, some extrapolation is necessary, because some of the distributions leave 30% or more of the probability unaccounted for in the region of the largest particles. Some degree of smoothing will be required for some of the distributions. And in all cases it will be necessary to interpolate between the tabular values. The large number of release points at the FMPC may also make it desirable to consolidate the particle-size distributions into a smaller number of "generic" distributions that can be applied to the simulations of release, transport, and uptake by inhalation. These requirements point to the need for a method of fitting a cumulative distribution function (CDF) to the empirical distributions. Such needs clearly are not new, and methods have been discussed in the literature (e.g., DallaValle et al. 1951).

In only a few of the cases are the data adequately represented by a lognormal distribution. Of the remainder, some but not all are of bimodal form (i.e., the density or frequency function has two maximum points).

The purpose of this appendix is twofold:

- to explain a method that we have found satisfactory for fitting cumulative distribution function (CDF) curves to empirical particle size distributions with small numbers of observed cumulative mass fractions
- to present the results of applying the method to those empirical particle-size distributions for inlet ducts and emission stacks given by Boback et al. (1987) as corrected, in two instances, with data from the original worksheets.

Figures F-1 through F-15 show plots of the distributions. For each dust collector, plots of the distributions for the inlet duct and the emission stack are shown on the same chart relative to log-probability axes; the observed cumulative mass fractions are plotted as discrete points, and the fitted CDF functions are shown as curves. Accompanying each plot is output from the plotting program that shows the input distribution, the fitting parameters determined by the method, the observed and predicted cumulative probabilities, summary statistics of the fitted distribution, and the diameter corresponding to each extreme value of the density function. These data are shown side-by-side for the inlet duct and the emission stack.

<sup>6</sup> PLEASE NOTE: The empirical distributions discussed here are mass distributions. We frequently substitute the word "probability" because it is the usual term in mathematical discussions. Also, the density (or frequency) function (PDF) is the derivative of the cumulative distribution function.

### **REGRESSION FUNCTION AND DETERMINATION OF PARAMETERS**

The method of regression is based on the application of a one-to-one transformation  $z = T(\zeta)$  to the domain of the standard normal cumulative distribution function

$$P(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-t^{2}/2} dt$$
 (F-1)

If the transformation T is increasing for all  $\zeta$ , the composite function  $P(T(\zeta))$  is also a cumulative distribution. For distributions that may be considered distortions of the lognormal, it is reasonable to try the further substitution

## $\zeta = \ln(x)$

and seek to determine the transformation  $T(\zeta)$  so that the composite function

$$\Phi(x) = P(T(\ln(x)))$$

(F-2)

Ň

.

.

represents the data as closely as possible by some chosen criterion of fit.

By choosing  $T(\zeta)$  to be a cubic polynomial and determining the coefficients by nonlinear least-squares regression, we have found that the resulting regression function (Eq. F-2) gives qualitatively appropriate representations of the empirical distributions. Algorithmically, the procedure is as follows. We are given diameters  $x_i$  and cumulative probabilities  $p_i$ , i = 1, ..., N. The regression is

 $t_i \approx T(\zeta_i)$ 

(F-3a)

Appendix F

.....

<u>د</u>ي.

: :

Fitting Particle Size Distributions for FMPC Dust Collectors

where the transformed data points  $(\zeta_i, t_i)$  are

$$t_i = P^{-1}(p_i), \quad \zeta_i = \ln x_i, \quad i = 1, \dots, N$$
 (F-3b)

We note that Eqs. F-2 and F-3 depend on numeric evaluation of the functions P(z) and  $P^{-1}(p)$ , where P is the standard normal CDF and  $P^{-1}$  is its inverse. Rational approximations to these functions are provided by Abramowitz and Stegun (1968; Eqs. 26.2.18 and 26.2.23, respectively).

One might begin by requiring that  $T(\zeta)$  have the general cubic polynomial form

$$\Gamma(\zeta) = c_0 + c_1 \zeta + c_2 \zeta^2 + c_3 \zeta^3 \tag{F-4}$$

so that the regression problem is to determine the coefficients  $c_0, \ldots, c_3$ :

$$\sum_{i=1}^{N} [t_i - T(\zeta_i; c_0, \dots, c_3)]^2 = \text{minimum}.$$
 (F-5)

Because the coefficients enter the expression for  $T(\zeta)$  linearly, the polynomial least squares regression problem posed by Eq. F-5 is linear. Once the coefficients  $c_i$  are determined, Eq. F-2 gives the distribution function  $\Phi(x)$ .

But this procedure is invalid if the polynomial  $T(\zeta)$  fails to represent a one-to-one increasing transformation. For the cubic, a simple test may be derived and applied after the coefficients have been determined. The necessary criteria are met if and only if

$$c_2^2 - 3c_1c_3 \leq 0 \text{ and } c_1 > 0.$$
 (F-6)

Unfortunately, the data from several of the inlet ducts produce linear regressions that fail to satisfy the criterion of Eq. F-6; the polynomials produced in these cases fail to be everywhere increasing. An alternative procedure is necessary to avoid this difficulty.

By rewriting Eq. F-4 as

$$\Gamma(\zeta;\alpha,\beta,\gamma,\delta) = \alpha^2(\zeta-\beta)^3 + \gamma^2\zeta + \delta \tag{F-7}$$

we retain the functional form of a cubic polynomial, but with coefficients that depend on the parameters  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$ . The derivative

$$T'(\zeta) = 3\alpha^2(\zeta - \beta)^2 + \gamma^2$$

is clearly everywhere nonnegative, enforcing the condition that the polynomial  $T(\zeta)$  be everywhere increasing (except that it will have zero slope at  $\zeta = \beta$  if  $\gamma = 0$ ). But the parameters  $\alpha$ ,  $\beta$ , and  $\gamma$  enter the expression for  $T(\zeta)$  in a nonlinear manner, complicating the regression procedure. We express the nonlinear regression as

$$\sum_{i=1}^{N} [t_i - T(\zeta_i; \alpha, \beta, \gamma, \delta)]^2 = \text{minimum}.$$
 (F-8)

We have solved this nonlinear least-squares regression problem for  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  with the FORTRAN subroutine LMDER1, which implements the Levenberg-Marquardt algorithm (Moré et al. 1980). This procedure has been successful with all of the FMPC particle-size data.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page F-3

### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

Once  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  are known for a given distribution, we may relate the coefficients  $c_0, \ldots, c_3$  of Eq. F-4 to these parameters as follows:

$c_0 = \delta - \alpha^2 \beta^3$	4	(F-9)
$c_1 = 3\alpha^2\beta^2 + \gamma^2$	· · · · ·	(F–10)
$c_2 = -3\alpha^2\beta$	· · · · ·	(F–11)
$c_3 = \alpha^2$ .	•	(F-12)

It is  $c_0, \ldots, c_3$  as given in Eqs. F-9 through F-12 that we report in the tables accompanying Figs. F-1 through F-15.

Summary statistics on each fitted distribution are obtained by numerical methods. The median (which may be read from the 50th percentile of the graph) is calculated from iterated interval bisections, and the mean and standard deviation are calculated from numerical algorithms for the integrals

$$\mu = \int_{x_{min}}^{x_{max}} x \, d\Phi(x) \tag{F-13}$$

$$\sigma = \left[ \int_{x_{min}}^{x_{max}} (x - \mu)^2 \, d\Phi(x) \right]^{\frac{1}{2}} \tag{F-14}$$

2

1.100

where the numbers  $x_{\min}$  and  $x_{\max}$  replace the infinite limits of integration for practical computation (the values 0 and 100 were appropriate for the data treated here).

Interest in whether a distribution has multiple modes may exist, and it is not difficult to answer the question numerically for the distribution  $\Phi(x)$ . We used a partition of the interval  $[x_{\min}, x_{\max}]$  and checked the derivative  $\phi(x) = \Phi'(x)$  for changes from increasing to decreasing or from decreasing to increasing from one subinterval to the next. Using subinterval length 0.01, all distributions were analyzed and the diameter corresponding to each extremum was recorded. The existence of three extrema (maximum, minimum, maximum) implies a bimodal distribution.

It is important to realize that parameter estimates (median, mean, standard deviation) based on distributions fitted by this regression technique may be expected to differ from their counterparts presented in the NKES report (Reed 1985). The methodology of the NKES report is based on the assumption of lognormality, which our results indicate is seldom justified in the case of these data. In the case of the median of a distribution, our estimate is based on the diameter at which the fitted curve, plotted on log-probability paper, crosses the 50th percentile. The linear fit (lognormal assumption) in general does not intersect the 50th percentile line at the same diameter as does the cubic fit. The geometric standard deviation (GSD) has meaning only in the context of the lognormal distribution and thus is generally not applicable to the distributions based on the cubic regression (but this formulation does include the lognormal distribution as a special case, namely for  $\alpha = 0$ ). Dispersion information such as the first and third quartiles can be read directly from the plots of these fitted distributions. In using a single number, such as a standard deviation or an interquartile range  $(Q_3 - Q_1)$ , as a measure of dispersion for these distributions, one must keep in mind the lack of symmetry of the distributions when one tries to interpret such a parameter.

Page F-4

### Appendix F Fitting Particle Size Distributions for FMPC Dust Collectors

Page F-5

CAVEATS: Some cautions need to be observed in dealing with the particle-size data from the NKES 1985 study and the fitted distributions described in the present report. The first is that each fitted distribution is based on just eight points of an observed cumulative distribution function (i.e., cumulative mass fraction). Second, we observe that extrapolation is at best a questionable exercise, and the use of the fitted distributions outside the diameter regions spanned by the data must be undertaken only with this realization in mind. The polynomial transformation introduced into the regression is, of course, arbitrary, but no more so than other functional forms that are commonly applied to empirical data analysis. We consider that such extrapolations will be necessary in the course of the dose reconstructions, and it is our judgment that the errors introduced will be less serious than those which would result from the use of artificially truncated distributions. The fitted distributions must be regarded in the same way that any model which makes predictions beyond available data is regarded. At a more fundamental level, the question of the extent to which one may generalize the observed and fitted distributions - based only on processes sampled in 1985 to the longer history of the FMPC must be considered. If satisfactory answers to this question cannot be found, relevant components of uncertainty in the predicted doses must be estimated from the 1985 data.

### RESULTS

• • •

This appendix shows input and output information for the particle-size distribution at the inlet duct and the emission stack for each of the fifteen dust collectors as presented by Boback et al. (1987) but corrected, in two cases (the inlet ducts for G5-254 and G5-256), from the original data sheets. For each distribution in Figs. F-1 through F-15, the accompanying data table gives the identification of the plant and dust collector, the calculated coefficients (i.e., the linear representation, corresponding to Eq. F-4) of the polynomial  $T(\zeta)$ , the predicted and observed cumulative probabilities (cumulative mass fractions) corresponding to the diameters of the input distribution, the summary statistics of the fitted distribution, and the number and locations (i.e., diameters) of extrema of the density function (i.e., the derivative of  $\Phi(x)$ ). Each plot shows the fitted distribution in relation to the points of the empirical distribution, plotted with reference to log-probability axes. The extent of departure of the plot from linearity is indicative of the extent of departure of the distribution from lognormality. The number of modes is not obvious from these plots; in particular, these examples demonstrate that a curvilinear distribution on log-probability paper does not necessarily correspond to a bimodal distribution. All but perhaps two of the distributions considered here show some curvilinear trend (usually sigmoid). For these two inlet ducts (G4-5 and G4-7), the coefficients of the  $\zeta^2$  and  $\zeta^3$  terms of the cubic are small (decisively so in the former case), so that  $\Phi(x)$  approximates a lognormal distribution.

### CONCLUSIONS

In this appendix, we have demonstrated a cubic transformation method, based on nonlinear least-squares polynomial regression, for fitting a CDF to the particle-size distributions measured at the FMPC in 1985. The method is useful as an instrument for interpolation, extrapolation, and smoothing of the distributions. The resulting numeric data and plots are shown in Figs. F-1 through F-15.
쒼

Ó

102.1

#### REFERENCES

- Abramowitz, M.; Stegun, I.A. Handbook of mathematical functions. New York; Dover Publications, Inc.; 1965.
- Boback, M.W.; Dugan, T.A.; Fleming, D.A.; Grant, R.B.; Keys, R.W. History of FMPC radionuclide discharges. Westinghouse Materials Company of Ohio; FMPC-2082; 1987.
- DellaValle, J.M.; Orr, C., Jr.; Blocker, H.G. Fitting bimodal particle size distribution curves comparison of methods. Industrial and Engineering Chemistry 43(6): 1377–1380; 1951.

Moré, J.J.; Garbow, B.S.; Hillstrom, K.E. User guide for MINPACK-1. Argonne, Illinois; Argonne National Laboratory; ANL-80-74; 1980.

Reed, K.P. A study of the emissions of the process stacks at NLO: Plant #9, Plant #5-260, Plant #5-261. Unpublished report from Northern Kentucky Environmental Services (NKES) of a study commisioned by NLO; 1985. Appendix F Fitting Particle Size Distributions for FMPC Dust Collectors





0.67

0.45

PLANT 4 DUST COLLECTOR G4-2: INLET DUCT

Diameter 0.01

0.05

6.43

Coefficients	of polynomia coeff[i]	J
ō	-2.49664	•
1	0.667467	
2	0.21843	•
3	0.0238272	•
Equivalent	Predicted	Observed
Diameter	Probability	Probability
11 .	0.754384	0.693
6.5	0.372323	0.466
4.2	0.154222	0.202
2.9	0.0655723	0.06
1.8	0.0214851	0.012
0.92	0.00537394	0.004
0.58	0.00256086	0.003
0.37	0.0014998	0.002
Median diamet	cer based on	regression: 7.79
Mean of fitte Standard devi	ad distributi lation of fit	on: 8.47 ted distribution: 4.41

Number of extrema detected = 3 Type of extreme

max

min

max

PLANT 4 DUST COLLECTOR G4-2: EMISSION STACK

i 0 1 2 3	coeff[1] -1.77972 0.364822 -0.0553174 0.106503		
Equivalent Diameter	Predicted Probability	Observed Probability	
12	0.662541	0.649	
7.8	0.366683	0.39	
5.1	0.191719	0.199	
3.4	0.11106	0.104	
2.2	0.0702061	0.064	
1.15	0.0418582	0.043	

0.026097 0.0153661

Coefficients of polynomial

Median diameter based on regression: 9.63

Mean of fitted distribution: 10 Standard deviation of fitted distribution: 5.49

0.03

Number of	extrema detected = 3
Diameter	Type of extreme
0.35	max
1.49	min
8.9	max

Radiological Assessments Corporation "Setting the standard in environmental health"

Page F-7

..... 2

4.7



ç.

. .

10000

1. N. N. N.

ĩ

ŝ,

ľ,

Figure F-2. Particle equivalent diameter distributions for inlet duct and emission stack G4-5.

37 (J.

1.1

6.1

14. <u>1</u>1 i.

Coefficients 1 0 1 2 3	of polynomia coeff[1] -1.65107 0.99859 -1.96857E 5.28563E-		•	Coefficients i 0 1 2 3	of polynomiz coeff[1] -1.26806 0.640205 0.0034074 0.0122341	19
Equivalent Diameter	Predicted Probability	Observed. Probability ·	· .	- Equivalent Diameter	Predicted Probability	Observed Probability
11	0.771393 -	0.722		12	0.702479	0.7
6.9 St	0.609388	0.646		7.1	0.536659	0.546
4.5	0.440731	0.551		4.9	0.423513 ·	0.418
3.1 .'	0.301091	0.29 i		3.3	0.316314	0.313
1.9	0.156218	0.115		2.1	0.215875	0.22
1	0.049362	0.037 🔅		1.1	0.113715	0.109
D.51	0.0100771	0.018		0.65	0.0612699	0.065
0.4	0.0051428	0.004		0.43 (30.8	0.0348924	0.034
Median diame	ter based on	regression: 5.2	22	Median diame	ter based on	regression: 6.32

Standard deviation of fitted	distribution: 9.86	Standard deviation of fitted dis	tri
Number of extrema detected = Diameter Type of extreme 1.92 max	ν του Ευροποίο 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Number of extrema detected = 1 Diameter Type of extreme 0.57 max	•

-

Page F-9

# Appendix F Fitting Particle Size Distributions for FMPC Dust Collectors



Figure F-3. Particle equivalent diameter distributions for inlet duct and emission stack G4-7.

PLANT 4 DUST COLLECTOR G4-7: INLET DUCT Coefficients of polynomial coeff[i] 1 0 -0.775328 1 1.19451 -0.0523289 2 3 0.00076522 Courses land Dradietad 01---

Diameter	Probability	Probability	
9	0.945727	0.94	
5.9	0.88185	0.868	
3.9	0.774987	0.809	
2.6	0.62511	0.696	
1.7	0.437974	0.393	
0.91	0.18715	0.151	
0.5 <sup>.</sup>	0.0516888	0.052	
0.32	0.0137109	0.016	

PLANT 4 DUST COLLECTOR G4-7: EMISSION STACK Coefficients of polynomial i coeff[i]

0 1 2 3	-1.42257 0.933117 -0.272263 0.0658473	1
Equivalent Diameter	Predicted Probability	Observed Probability
20	0.757941	0.754
12.5	0.601927	0.616
8.8	0.498533	0.493
5.9	0.399024	0.393
3.2	0.273605	0.27
1.7	0.16005	0.17
1.1	0.0907661	0.086 .

0.273605 0.16005 0.0907661 0.0364854

Median di	iameter based on	regression: 1.95	Median
Mean of 1	itted distribut	ion: 3.12	Mean of

Mean of fi Standard deviation of fitted distribution: 4.05

Number of extrema detected = 1 Diameter Type of extreme 0.9 mar

#### diameter based on regression: 8.85

fitted distribution: 13.3 Standard deviation of fitted distribution: 13.5

0.037

Number of extrema detected = 1 Diameter Type of extreme 0.86 mar

Radiological Assessments Corporation "Setting the standard in environmental health"

Ô

. Line

Page F-10

\$

÷ 1

aller -

Zj 7.

1999 - A.S.

あたたてい

.

ŝ



O PLANT 4 DUST COLLECTOR G4-12: INLET DUCT PLANT 4 DUST COLLECTOR G4-12: EMISSION STACK

Figure F-4. Particle equivalent diameter distributions for inlet duct and emission stack G4-12.

PLANT 4 DUST COLLECTOR G4-12: INLET DUCT

coeff[i]

-2.34342 0.324196

0.088823

Predicted Probability

0.614991

0.247777

0.0930367

0.0400207

0.0190911

0.00930586

0.00613794

0.00400619

Mean of fitted distribution: 10

Median diameter based on regression: 9.71

0.097744

Observed

0.612 0.253

0.093

0.04

0.018

0.01

0.006

0.004

Probability

Coefficients of polynomial

1

0

1

2

3

11

6.9

4.5

1.9

0.97

0.59 0.39

3

Equivalent

Diameter

PLANT 4 DUST COLLECTOR G4-12: EMISSION STACK

Coefficients	of	polynomial coeff[i]
ō		-2.13727
1		0.342225
2		0.139168
3	<i>`</i>	0.078725

Equivalent Diameter	Predicted - Probability	Observed Probabilit		
11.2	0.729691	0.713		
7.1	0.367326	0.404		
4.9	0.177248	0.185		
3.2	0.0767844	0.065		
2.1	0.0379824	0.035		
1.1	0.0177192	0.02		
0.6	0.0111195	0.012		
0.42	0.00863733	0.008		

Median diameter based on regression: 8.48

Mean of fitted distribution: 8.86 Standard deviation of fitted distribution: 4.38 Standard deviation of fitted distribution: 4.27

з

Number of	extrema detected	 3	N: 2 2 3
Diameter	Type of extreme	٠,	212 23
0.24	· mar		19 JO
0.85	min		
9.08	Eax C		*

Number of	extrema detected =
Diameter	Type of extreme
0.15	max
0.69	min
7.73	max

Appendix F Fitting Particle Size Distributions for FMPC Dust Collectors



O PLANT 4 DUST COLLECTOR G4-14; INLET DUCT PLANT 4 DUST COLLECTOR G4-14; EMISSION STACK

Figure F-5. Particle equivalent diameter distributions for inlet duct and emission stack G4-14.

PLANT 4 DUST COLLECTOR G4-14: INLET DUCT

Coefficients	of polynomial
i	coeff[i]
0	-3.00214
1	0.475575
2	0.0837776
3	0.0656336

ð

.....

Equivalent Diameter	Predicted Probability	Observed Probability
11.5	0.350237	0.37
7.2	0.108991	0.109
4.9	0.0382558	0.022
3.3	0.0137899	0.016
2.2	0.00549654	0.012
1.1	0.00155823	0.001
0.66	0.000711381	0.0005
0 44	0 000373606	0.0005

Median diameter based on regression: 13.7

Mean of fitted distribution: 14.4 Standard deviation of fitted distribution: 6.17

Number of	extrema detected	-	1
Diameter	Type of extreme		
12.47	max :.		

PLANT 4 DUST COLLECTOR G4-14: EMISSION STACK

Coefficients	of p	olynomial
i	č	:oeff[i]
0		1.61264
1	(	.403673
2	0	0.0318019
3	0	0.0504584

Equivalent Diameter	Predicted Probability	Observed Probability	
16	0.795739	0.79	
9.9	0.535023	0.55	
6.8	0.356978	0.357	
4.6	0.228673	·0.233	
2.9	0.138763	0.125	
1.45	0.0727413	0.075	
0.9	0.0489744	0.055	
0.67	0.0381604	0.035	

Median diameter based on regression: 9.26

Mean of fitted distribution: 10.5 Standard deviation of fitted distribution: 7.35

Number of	extrema detected = :
Diameter	Type of extreme
0.21	max .
1.34	min
6.74	mar



1 · · · ...

O PLANT 5 DUST COLLECTOR G5-249: INLET DUCT PLANT 5 DUST COLLECTOR G5-249: EMISSION STACK

10

2

3

.

Figure F-6. Particle equivalent diameter distributions for inlet duct and emission stack G5-249.

**1**.....

· • •

. . . .

PLANT 5 DUST COLLECTOR G5-249: INLET DUCT

PLANT 5 DUST COLLECTOR C5-249: EMISSION STACK

coeff[1]

-0.784878 0.0638725

-0.00260951

0.0871555

·- · · ;

2000

Maria da

с У

į

\_'

è:

Ę,

Į,

coefficients of polynomial	
i coeff[i]	
0 -2.15589	
1 0.369058	
2 0.0669841	
3 0.0729165	
•	

Equivalent Diameter	Predicted Probability	Observed Probability	
12	0.615471	0.596	
7 .	0.258874	0.298	
4.8	0.129085	0.132	
3.2	0.0640987	0.054	
2	0.0326201	0.029	
ī	0.0155463	0.018	
0.61	0.00988324	0.011	
0.42	0.00669466	0.006	

Median diameter based on regression: 10.3

Equivalent Predicted Observed Diameter -Probability Probability 0.758 12 0.756477 7.8 0.536138 0.534 0.38 5.2 0.383574 0.295 3.4 0.290856 0.240925 0.24 2.1 0.22 1.01 0.206152 0.2 0.65 0.187458 0.19 0.44 14

Coefficients of polynomial

Median diameter based on regression: 7.19

Mean of fitted distribution: 10.9 Standard deviation of fitted distribution: 5.59

Mean of fitted distribution: 7.83 Standard deviation of fitted distribution: 6.32

Number of	extrema detected	<b>-</b> 3	1 ° 1 . 7 3	Number of	extrema detected	- 3
Diameter	Type of extreme			Diameter	Type of extreme	
0.23	mar	·		0.13	Bar -	`
0.88	min	•		1.14	min	
9.2	mar	- D		7	max -	
•		1				

Appendix F Fitting Particle Size Distributions for FMPC Dust Collectors Page F-13



Figure F-7. Particle equivalent diameter distributions for inlet duct and emission stack G5-250.

PLANT 5 DUST COLLECTOR G5-250: INLET DUCT

-

.

2

PLANT 5 DUST COLLECTOR G5-250: EMISSION STACK

Coefficient	s of polynomia	ป	Coefficient	s of polynomia	al .
i	coeff[1]		, <b>i</b>	coeff[i]	
0	-2.86696	•	0	-1.47564	
1	0.178617	. •	1	0.419789	
2	0.17733	•	2	0.0436889	<b>)</b>
3	0.0586841	•	3	0.040651	L
Equivalent	· Predicted	Observed	Equivalent	Predicted	Observed
Diameter	Probability	Probability .	Diameter	Probability	Probability
13	0.400562	0.373	· 11 ··	0.634072	0.625
7.9	0.110836	0.134	6.6	0.399468	0.421
5.2	0.0338114	0.038	4.5	0.271894	0.264
3.6	0.0130788	0.012	2.9	0.17616	0.185
2.3	0.00521454	0.004	1.9	0.119507	0.106
1.2	0.00234079	0.002	0.95	0.0671878	0.067
0.7	0.00180256	0.002	0.59	0.0454234	0.052
0.47	0.00171669	0.002	0.38	0.0302079	0.028
Median diam	eter based on	regression: 14.5	Median diam	eter based on	regression:
Mean of fit Standard de	ted distributi viation of fit	on: 15.1 ted distribution: 6.	Hean of fit 19 Standard de	ted distributi viation of fit	lon: 9.9 ted distribu
Number of e Diameter	xtrema detecte Type of extrem	d = 3	Number of e Diameter	itrema detecte Type of extrem	ed = 3 1e
~ ~ ~	max		0.16	max	
0.06			1 47	min	
0.06	min		1		

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties



O PLANT 5 DUST COLLECTOR G5-251: INLET DUCT PLANT 5 DUST COLLECTOR G5-251: EMISSION STACK

1 2 3

12

4.75

3.25

0.63

0.42

2.1 1.05

7

Equivalent

Diameter

Figure F-8. Particle equivalent diameter distributions for inlet duct and emission stack G5-251.

- PLANT 5 DUST COLLECTOR G5-251: INLET DUCT

0.846798

0.98466

Coefficients of polynomial i coeff[i]

Ö

1

0.48

PLANT 5 DUST COLLECTOR G5-251: EMISSION STACK

Observed

Ó.85

0.302

0.231

0.186

0.127

0.076

0.053

0.4

Probability

Coefficients of	polynomial
<b>i</b> '	coeff[i]
0 1	-1.12925
1	0.297224
2	-0.231645
3	0.181877

Predicted

0.833889

0.464985

0.294427

0.211011

0.168036

0.132366

0.046464

0.0911078

Probability

3	0.154204		
Equivalent Diameter	Predicted Probability	Observed Probability	
12	0.982074	0.981	
7.1	0.957499	0.962	
4.8	0.941501	0.941	
3.2	0.9271	0.925	
2.1	0.907061	0.902	
1.1	0.825245	0.823	
0.62	0.589967	0.623	

0.402236

Median diameter based on regression: 0.544

Median diameter based on regression: 7.42

Mean of fitted distribution: 1.28 Standard deviation of fitted distribution: 2.65

0.38

Mean of fitted distribution: 7.45 Standard deviation of fitted distribution: 4.62 3

Number of	extrema detected	-	1		
Diameter	Type of extreme				
0.39	max		-`	1.	•

Number of	extrema detected	-
Diameter	Type of extreme	
D.38	max	-
1.78	min	
7.68	Ear	

147127

9. C. V. C. S.

ŝ

Ş

Appendix F Fitting Particle Size Distributions for FMPC Dust Collectors



O PLANT 5 DUST COLLECTOR G5-253: INLET DUCT
 PLANT 5 DUST COLLECTOR G5-253: EMISSION STACK

Figure F-9. Particle equivalent diameter distributions for inlet duct and emission stack G5-253.

PLANT 5 DUST COLLECTOR G5-253: INLET DUCT

 Coefficients of polynomial

 i
 coeff[i]

 0
 -1.58257

 1
 0.504374

 2
 -0.218532

 3
 0.143409

27

ç

÷

S.,

Equivalent Diameter	Predicted Probability	Observed Probability		
11	0.635932	0.672		
7 <sup>.</sup>	0.354982	0.275		
4.8	0.218993	0.227		
3.2	0.143237	0.181		
2	0.0984905	0.097		
1	0.0567598	0.054		
0.62	0.0294271	0.025		
0 42	0 0113575	0.013		

Median diameter based on regression: 9.05

Mean of fitted distribution: 9.35 Standard deviation of fitted distribution: 5.42

Number of extrema detected = 3 Diameter Type of extreme 0.51 max 2.09 min 8.71 max PLANT 5 DUST COLLECTOR G5-253: EMISSION STACK

Coefficients of	polynomial
1	COBII[1]
0	0.395111
1	1.5468
2	-0.991084
3	0.27408

Equivalent Diameter	Predicted Probability	Observed Probability
12	0.98995	0.987
7	0.952713	0.967
4.8	0.925164	0.941
3.3	0.90244	0.878
2	0.860458	0.817
1	0.65362	0.648
0.63	0.288363	0:396
0.42	0.0306367	0.021

Median diameter based on regression: 0.801

Mean of fitted distribution: 1.55 Standard deviation of fitted distribution: 2.27

Number of extrema detected = 1 Diameter Type of extreme 0.59 max

Radiological Assessments Corporation "Setting the standard in environmental health"

Page F-15

Page F-16

· · · ·

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties



O PLANT 5 DUST COLLECTOR G5-254: INLET DUCT PLANT 5 DUST COLLECTOR G5-254: EMISSION STACK

Figure F-10. Particle equivalent diameter distributions for inlet duct and emission stack G5-254.

PLANT 5 DUST COLLECTOR G5-254: INLET DUCT

PLANT 5 DUST COLLECTOR G5-254: EMISSION STACK

Coefficients i 0 1 2 3	of polynomia coeff[i] -1.74205 1.051 -0.326252 0.117889	1		Coefficient: i 0 1 2 3	s of polynomiz coeff[1] -1.27232 0.699124 -0.167917 0.120992	μ ,
Equivalent Diameter	Predicted Probability	Observed Probability		Equivalent Diameter	Predicted Probability	Observed Probability
10 6.1 4.1 2.8 1.7 0.89 0.55 0.37	0.650774 0.416333 0.281811 0.190214 0.104086 0.0308016 0.00599949 0.000629015	0.649 0.432 0.277 0.172 0.098 0.06 0.002 0.001	-	11 6.8 4.5 3 1.9 0.98 0.59 0.4	0.865807 0.619082 0.425057 0.292363 0.194682 0.099131 0.0440296 0.0158973	0.858 0.651 0.416 0.283 0.187 0.103 0.047 0.015

 Hedian diameter based on regression: 7.4
 Median diameter based on regression: 5.36

 Mean of fitted distribution: 8.51
 Mean of fitted distribution: 6.04

 Standard deviation of fitted distribution: 6.04
 Standard deviation of fitted distribution: 4.31

 Number of extrema detected = 1
 Number of extrema detected = 3

 Diameter Type of extreme
 Diameter Type of extreme

Diameter	Type of extreme		Diameter	Type of extreme
1.13	_ max		0.57	max
			2.8	min ·
		,	4.03	max

RAN ARAL

7

N 1.

1

Appendix F Fitting Particle Size Distributions for FMPC Dust Collectors





Figure F-11. Particle equivalent diameter distributions for inlet duct and emission stack G5-256.

PLANT 5 DUST COLLECTOR G5-256: INLET DUCT

 Coefficients of polynomial

 i
 coeff[i]

 0
 -2.23783

 1
 0.321723

 2
 0.224742

 3
 0.0523317

....

Ĵ

.....

Equivalent Diameter	Predicted Probability	Observed Probability
11	0.707948	0.69
7.1	0.363288	0.39
4.8	0.163988	0.17
3.2	0.0698094	0.07
2.1	0.0318662	0.03
1	0.012616	0.01
0.63	0.00954764	0.01
0 47	0 00861032	0.01 ·

Median diameter based on regression: 8.53

Mean of fitted distribution: 8.99 Standard deviation of fitted distribution: 4.36

Number of	extrema detected = 3
Diameter	Type of extreme
0.03	max
0.24	min
7.6	max

PLANT 5 DUST COLLECTOR G5-256: EMISSION STACK

Coefficients of	polynomial
<b>i</b> .	coeff[i]
0	-0.913069
1	0.660854
2	-0.331578
3	0.156728

Equivalent Diameter	Predicted Probability	Observed Probability
11	0.822766	0.847
6.9	0.600922	0.519
4.2	0.426869	0.437
2.9	0.345991	0.382
1.8	0.271807	0.289
0.91	0.16392	0.163
0.59	0.0842422	0.065
0.38	0.0224867	0.027

Median diameter based on regression: 5.34

Mean of fitted distribution: 6.18 Standard deviation of fitted distribution: 5.02

Number of extrema detected = 3 Diameter Type of extreme 0.52 max 3.2 min 5.65 max

11 1.

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties





Figure F-12. Particle equivalent diameter distributions for inlet duct and emission stack G5-260. 

PLANT 5 DUST	COLLECTOR GS	-260: INLET DUCT	•	PLANT 5 DUST	COLLECTOR G5	-260: EMISSION	STACK
Coefficients i 0 1 2 3	of polynomia coeff[i] -1.92417 0.577013 0.176517 0.0179997	1	•	Coefficients i 0 1 2 3	of polynomia coeff[1] -0.132047 1.54057 -0.72514 0.149104	<b>1</b>	•
Equivalent Diameter	Predicted Probability	Observed Probability		Equivalent Diameter	Predicted Probability	Observed Probability	
11 6.6 4.4 2.9 1.9 0.95 0.58 0.38	0.76503 0.465827 0.266564 0.1383 0.0699279 0.0253921 0.0142981 0.00981042	0.758 0.469 0.27 0.15 0.072 0.02 0.013 0.012		14 8.9 6 4.1 2.6 1.3 0.8 0.55	0.947791 0.907918 0.876562 0.845388 0.790455 0.588979 0.303773 0.0894604	0.95 0.905 0.866 0.841 0.831 0.537 0.319 0.09	
Median diame	ter based on	regression: 7		Median diame	ter based on	regression: 1.	09

Mean of fitted distribution: 8.01 Standard deviation of fitted distribution: 5.19

Mean of fitted distribution: 2.94 Standard deviation of fitted distribution: 5.08 1.43. 2

1000 S

à.

Number of	extrema detected	<b>#</b> 3
Diameter	Type of extreme	
0.01	max	
0.04	min	
5.02	max	1

Number of extrema detected = 1 Diameter Type of extreme 0.68 max

# Appendix F Fitting Particle Size Distributions for FMPC Dust Collectors



Figure F-13. Particle equivalent diameter distributions for inlet duct and emission stack G5-261.

PLANT 5 DUST COLLECTOR G5-261: INLET DUCT

-2.29694

0.415779

0.161617

0.0266991

PLANT 5 DUST COLLECTOR G5-261: EMISSION STACK

Coefficients	of polynomial
i	coeff[i]
0	-1.68163
1.	0.491472
2.	0.0411743
3	0.0753348

Equivalent Diameter	Predicted . Probability	Observed Probability	
11	0.780035	0.785	
6.8	0.477049	0.445	
4.4	0.268268	0.325	
3.1	0.167583	0.13	
2	0.0974717	0.115	
1	0.0463207	0.04	
0.6	0.0266811	0.03	
0:4	0.0155676	0.015	

Median diameter based on regression: 7.07

Mean of fitted distribution: 7.67 ł Standard deviation of fitted distribution: 4.68

Number of	extrema detected = 3
Diameter	Type of extreme
0.31	max
1.01	min
5.91	max

Radiological Assessments Corporation "Setting the standard in environmental health"

Coefficients of polynomial i coeff[i] 0 1 2 3

Equivalent Diameter	Predicted Probability	Observed Probability	
12	0.557189	0.555	
7.2	0.260782	0.27	
5.1	0.141172	0.13	
3.5	0.0707907	0.075	
2.2	0.0317587	0.035	
1.2	0.0133596	0.01	
0.68	0.00745039	0.01	
0.46	0.00562473	0.005	

Median diameter based on regression: 11

Mean of fitted distribution: 12.2 Standard deviation of fitted distribution: 7.06

Number of	extrema detected = 3
Diameter	Type of extreme
0.01	max
0.22	min
8.71	max



# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

1

Ċ.

1. S. C. C.

and the second

ï .

Ì

ļ



Figure F-14. Particle equivalent diameter distributions for inlet duct and emission stack G43-27.

PLANT 8 DUST	COLLECTOR G4	13-27: INLET DUCT	. PLANT 8 DUS	T COLLECTOR G4	13-27: EMISSION STACK
Coefficients 1 0 1 2 3	s of polynomiz cosff[1] -1.69976 0.592724 0.0746656 0.0251448	a	Coefficient i 0 1 2 3	s of polynomia coeff[1] -2.28575 0.83555 -0.002803 0.0576776	ц 343 5
Equivalent Diameter	Predicted Probability	Observed Probability	Equivalent Diameter	Predicted Probability	Observed Probability
13 7.2 5.2 3.5 2.2 1.1 0.68 0.45	0.76916 0.481949 0.342029 0.21459 0.120262 0.0502364 0.0275121 0.0162484	0.764 0.512 0.318 0.215 0.12 0.051 0.028 0.016	13 7.8 5.1 3.5 2.2 1.2 0.7 0.48	0.791675 0.467583 0.247481 0.129238 0.0547524 0.0164563 0.00484433 0.00173144	0.8 0.45 0.234 0.134 0.066 0.015 0.004 0.002
Median diame Mean of fitt Standard dev	eter based on ed distributi	regression: 7.48 on: 9.11	Median diam Mean of fit Standard de	eter based on ted distributi	regression: 8.21 ion: 9.11 thed distribution: 5.36
Number of ex Diameter 1 4.06	trema detecte Type of extrem max	and = 1	Number of e Diameter 6.33	xtrema detecte Type of extrem max	ad = 1 be

2 Appendix F · •; Fitting Particle Size Distributions for FMPC Dust Collectors

5

....

. .

.

3



O PLANT 9 DUST COLLECTOR G9N1-1039: INLET DUCT PLANT 9 DUST COLLECTOR G9N1-1039: EMISSION STACK

Figure F-15. Particle equivalent diameter distributions for inlet duct and emission stack G9N1-1039.

PLANT 9 DUST COLLECTOR G9N1-1039: INLET DUCT PLANT 9 DUST COLLECTOR G9N1-1039: EMISSION STACK

	•				
Coefficients	s of polynomia	<u>д</u>	Coefficient	s of polynomia	1
i	coeff[i]	•	1	coeff[1]	
0	-1.64175		0	-0.200583	<b>,</b>
1	0.752471		1	0.696287	
2	-0.195005	5	2	-0.406941	
3	0.192257	• •	3	0.161856	
Equivalent	Predicted Probability	Observed Probability	Equivalent	Predicted Probability	Observed Probability
DIAMACAL	Probability	FIODEDIILLY			
10.5	0.939296	0.937	11 -	0.913231	0.907
6.5	0.634708	0.632	6.4	0.76579	0.794
4.3	0.358512	0.407	4.5	0.683265	0.681
2.9	0.203384	0.179	2.9	0.608271	0.588
1.8	0.109764	0.097	1.8	0.540209	0.52
0.92 ·	0.044008	0.051	0.95	0.406177	0.432
0.56	0.0145888	0.015	0.56	0.219861	0.222
0.38	0.00319984	0.003	0.39	0.0881633	0.085
Median diam	eter based on	regression: 5.42	Median diam	eter based on	regression: 1.42
Mean of fits Standard des	ted distributiviation of fit	ion: 5.6 ted distribution: 2.99	Mean of fit Standard de	ted distributi viation of fit	ion: 3.77 ted distribution: 4.41
Number of e	strema detecte	od = 3	Number of e	xtrema detecte	d = 1
Diameter	Type of extrem	10	Diameter	Type of extrem	16
0.72	max		0.44	max.	
1.45	min				
5.23	max				

# APPENDIX G

## ESTIMATES OF BIAS IN EFFLUENT SAMPLING FOR PARTICLES

### INTRODUCTION

1

1

This appendix treats three possible sources of bias in particle sampling results for dust collector exhaust stacks at the FMPC. These are (a) nonrepresentative sampling, due to use of a single sampling probe; (b) anisokinetic sampling, due to a mismatch between the fluid velocity in the probe and that in the stack; and (c) losses of particles, due to deposition or impaction on the wall of the sampling line between the probe inlet and the collection filter. These issues have not been addressed in previous analyses of the uranium release data.

The effect of using a single sampling probe in large ducts can only be estimated quantitatively. Calculation methods for estimating anisokinetic sampling bias and line losses are presented together with example calculations for uranium aerosols. The distributions used to characterize specific variables for Monte Carlo calculations of corrections for previous sampling conditions (Appendix E) are described. Results of some of the calculations and of a sensitivity analysis are presented.

#### NONREPRESENTATIVE SAMPLING

One design feature that was not consistent with standard guidance for sample collection from exhaust ducts was the use of a single sampling probe in larger ducts. The guide developed by the American National Standards Institute (ANSI, 1969) guide recommends multiple sample withdrawal points for ducts greater than 15 cm in diameter. The reason for multiple probes is to provide assurance that the samples will not be biased because of a nonuniform distribution of the contaminant in the stack. The sample extracted from the center of a dust collector exhaust stack would be representative if the particles were uniformly mixed in the exhaust or if the concentration on the centerline happened to be equal to the average concentration in the stack. When this is not the case, the sample is not representative of the material being discharged. The bias introduced may be positive or negative, depending upon the actual relationship between the centerline and average concentrations. Quantitative assessment of this question requires tracer measurements in the exhaust stacks. Such an effort is well beyond the scope of this work and is not feasible for many of the exhausts, so a qualitative assessment must be made.

Two features favor a well mixed exhaust stream at the point of sample extraction: the exhaust systems were generally simple and the sampling point was downstream of the discharge fan. Operation of the fan tends to mix exhausts that may be inhomogeneous at the inlet to the fan. Combinations of exhausts from several individual discharge fans are frequently not well mixed, so a complex exhaust duct arrangement would indicate greater potential for inhomogeneity. On the other hand, the exhaust stack diameters, some greater

Page G-2	The Fernald Dosimetry Reconstruction Project
·	Tasks 2 and 3, Source Terms and Uncertainties

than 1 m, increase concern about possible nonrepresentative sampling. Only one of the ducts sampled was less than 15 cm in diameter (RAC 1991).

It is assumed that the variation of the concentration distribution is greater for stacks with larger diameters. Thus, the chance that the concentration determined from a single sample of the exhaust stack will differ from the average concentration in the stack increases with stack size. Estimated ranges of possible bias (B) for six stack diameter categories are shown in Table G-1. These estimates are based on practical experience in measuring tracer concentration profiles in stacks and ducts. As noted above, the bias may have been in either direction. In the lower portion of the table are the stacks whose diameters (or effective diameters for the few rectangular stacks) lie within the ranges shown. The range of uncertainty at the top of the column is applied to all stacks listed in that column. Not shown in the table is stack G2-235, whose diameter was less than 15 cm. For that stack the fractional uncertainty for concentration inhomogeneity is estimated to be 8%.

#### ANISOKINETIC SAMPLING

Accurate sampling of the particulates in gaseous effluents often requires that the fluid velocity in the sampling probe  $(u, \text{ cm s}^{-1})$  be the same as the velocity of the stack gas at the point of sampling  $(v, \text{ cm s}^{-1})$ . When this condition is achieved, the sampling is termed "isokinetic." Deviations from this condition, called "anisokinetic sampling," can lead to bias in the sample. The bias may be high or low, depending upon whether the sampling flow rate yields a probe fluid velocity u < v or u > v. The method for estimating the bias is discussed below.

#### General Approach

1.1 .1

with 🚬 📜

The approach developed by Durham and Lundgren (1980) was used to assess the potential effects of deviations from isokinetic sampling conditions. The consequences of such deviations depend upon the ratio of the fluid velocities (u/v), the size and densities of the particles to be sampled, the diameter of the sampling probe, and, to a much lesser extent, the air temperature. Improper alignment of the sampling probe along the streamlines of flow in the stack can also lead to sampling biases. However, if the probe axis is within 15° of the proper position, the effects of misalignment are small, -5% (Durham and Lundgren 1980). In this assessment, it was assumed that alignment of the sampling probe was sufficiently accurate to make any bias from that source small compared with measurement uncertainties.

For a properly aligned sampling probe, the ratio (R) of the sampled concentration of particulates to the concentration actually present in the stack can be computed using the following equations.

- The set price let the

R = 1 + [(v)]	(u) - 1][1 - (1/k)]		. (G–1)
		•	

k = 1 + [2 + 0.62 u/v] Stk

(G-2)

٠.

e F

W240 - 244123

÷.

1

Appendix G Estimates of I	Bias in Effluent	Sampling for H	Particles		Page G-3
		<u></u>			
	Table G-1. E	stimated Bias	(B) Due to Non	representative	•.
San	pling of Uraniu	<u>im Concentration</u>	on in Dust Coll	ector Exhaust S	tacks
. •	Cat	egories of stack	diameters (D <sub>s</sub>	, cm)	•
$15 < D_s \le 30$	$30 < D_s \le 46$	$46 < D_s \le 61$	$61 < D_s \le 76$	$76 < D_s \leq 91$	$91 < D_s \le 122$
Estimat	ed bias (B) due	to nonrepresen	tative samplin	g in stack of dia	meter D <sub>s</sub>
±10%	±15%	±20%	±30%	±35%	±50%
	Dust collec	tor exhaust stac	ks grouped by	size category	
G2-1	G2-68	G2-63	G4-3	Mid ESP	G6-6057
G2-171	G2-172	G264	G4-7	G9N1-1039	North ESP
G2-174	G1–94	G267	G4-14	735-13-7050	South ESP
G2-6042	G1-754	G2-76	G5-A100	G5-259	G9E2-400
G4-1	G1-856	G2-77	G43-27	G5-261	
G4-4	G5-247	G1-252	G42-615		
G4–5	G5-248	3∸N	G42A-100		
G4-12	G6-86	3–S	108843		
G4–13	G6-88	G4-2	•		
G4–15	G4-2509	G4-8			
G4-7001	G4-2510	G5-249	•		
G55-E-100	G3A-2	G5-250	· .		
G8-7	G8-1	G5-251			
6018	G8N1-1000	G5-252			
6019	G43-29	G5-253	• .		
8002	G43-44C	G5-254		-	•
8021	8035	G5-256			
8024	8057	G5–258			
8083	G37-5011	G5-260			
2102		G5-A101			
G-1		G4-2507			
G-2	• •	G4-2508			
		· G8–2	•		
		G8-3		•	
		G8-4		•	
	•	. G20–20			
	·	G6–93A	· • •		
	<b>-</b> • ·	735-13-7041	, • • ,		•

.

where u and v are the velocities defined above and Stk is the Stokes number for the particles. It is given by

Stk = 
$$[\rho d^2 C_c v] / [18 \eta \delta]$$
 (G-3)

where  $\rho$  and d are the density (g cm<sup>-3</sup>) and physical diameter (cm) of the particle, respectively,  $C_c$  is the dimensionless Cunningham slip correction factor for the particle,  $\eta$ is the viscosity of the exhaust air (dyne s cm<sup>-2</sup>) and  $\delta$  is the diameter (cm) of the probe opening. The factor  $C_c$  can be calculated using the following empirical equation (Hinds 1982):

Page G-4

# The Fernald Dosimetry Reconstruction Project <u>Fasks 2 and 3, Source Terms and Uncertainties</u>

# $C_c = 1 + 2 [6.32 + 2.01 \exp(-0.1095 Pd 10^4)] / (Pd 10^4)$

where d is the particle diameter, as defined above, P is the absolute pressure (cm Hg), and the factor of  $10^4$  is just the conversion from cm to  $\mu$ m. Calculations show that  $C_c$  is quite close to unity for particles with diameters greater than  $1 \mu$ m.

**Results for Typical Conditions** 

The sequence of equations given above were used to compute the effects of deviations from isokinetic sampling conditions. The calculations did not address an exhaustive list of sampling conditions that were present in the many exhaust stacks. The actual conditions prevailing when deviations from isokinetic sampling occurred are not known. Based upon a review of effluent discharge points at the FMPC (RAC 1991), a representative set of conditions (listed below) was chosen for the calculations.

Air temperature: 20°C

Air pressure (P): 76 cm Hg

Air viscosity ( $\eta$ ): 1.81 x 10<sup>-4</sup> dyne s cm<sup>-2</sup>

Air density ( $\rho_a$ ): 1.2 x 10<sup>-2</sup> g cm<sup>-2</sup>

Stack gas velocity (v):  $1500 \text{ cm s}^{-1}$ 

Sampling probe diameter ( $\delta$ ): 0.62 cm

Calculations were performed for four chemical forms of uranium that were present in FMPC effluents:  $U_30_8$ ,  $UO_3$ ,  $UF_4$ , and  $UO_2$ . Results are presented for spherical particles of  $UF_4$  and  $UO_2$ , whose densities (4.7 and 10.9 g cm<sup>-3</sup>, respectively) bound the range for the chemical forms considered (Hodgman et al. 1959).

The results in Table G-2 show that deviations from isokinetic conditions have little effect upon sampling for small particles. For aerodynamic diameters that are less than 2  $\mu$ m, the bias introduced is 25% or less. As the particle diameter increases, the Stokes number increases, k becomes smaller, and the concentration ratio R approaches the limiting value of (v/u).

Increasing the density of the particles increases the aerodynamic diameter,  $[d \sqrt{\rho}]$ , and Stokes number. Table G-3, which contains results for  $UO_2$ , shows the more rapid approach to the limiting value of R as the physical diameter of the particles increases. Results for particles of  $U_3O_8$  and  $UO_2$  are qualitatively similar to those shown in Tables G-2 and G-3 but reflect the different densities of those materials. The concentration ratio for a specific aerodynamic diameter is the same, regardless of the chemical form of the particle.

Method Used to Estimate Corrections for Previous Sampling

As the tabulations show, anisokinetic sampling may lead to either an overestimate or an underestimate of the amount of material in the air being discharged. The discharge would be underestimated if the sampling flow rate exceeded the appropriate value for a par-

(G-4)

12

Appendix G

.

Estimates of Bias in Effluent Sampling for Particles

to Stack Concentration for Anicolainatia Sampling of LEP. Darticles							
Diameter (um) Concentration ratio (R) for specific ( $u/u$ )							, <del>_</del> ,
Physical	Aerodynamic	0.25	0.50	0.75	1.25	1.5	2.0
0.1	0.22	1.01	1.00	1.00	1.00	. 1.00	1.00
0.2	0.43	1.02	1.01	1.00	1.00	1.00	1.00
0.3	0.65	1.03	1.01	1.00	1.00	1.00	0.99
0.5	1.1	1.07	1.03	1.01	0.99	0.99	0.98
0.8	1.7	1.16	1.06	1.02	0.99	0.98	<b>0.96</b>
1	2.2	1.24	1.09	1.03	0.98	0.96	0.94
2.	4.3	1.74	1.26	1.09	0.94	0.90	0.84
3	6.5	2.25	1.43	1.15	0.90	0.84	0.74
5	11	2.98	1.67	1.23	0.86	0.76	0.63
8	.17	3.49	1.84	1.28	0.83	0.71	0.56
10	22	3.65	1.89	1.30	0.82	0.70	0.54
20	43	3.90	1.97	1.32	0.81	0.67	0.51

Dn

Table G-3. Calculated Ratios of Probe Concentration

	to Stack Concentration for Anisokinetic Sampling of UO <sub>2</sub> Particles							
Diameter (µm)		Concentration ratio (R) for specific $(u/v)$				)		
Physical	Aerodynamic	0.25	0.50	0.75	1.25	1.5	2.0	
0.1	0.33	1.02	1.01	1.00	1.00	1.00	1.00	
0.2	0.66	1.04	. 1.01	1.00	1.00	0.99	0.99	
0.3	0.99	1.07	1.03	1.01	0.99	0.99	0.98	
0.5	1.7	1.16	1.06	1.02	0.99	0.98	0.96	
0.8	2.6	1.36	1.13	1.04	0.97	0.95	0.92	
1	3.3	1.51	1.18	1.06	0.96	0.93	0.88	
2	6.6	2.29	1.45	1.15	0.90	0.83	0.73	
3	9.9	2.87	1.64	1.22	0.86	0.77	0.64	
5	16	3.45	1.83	1.28	0.83	0.71	0.56	
8	26	3.76	1.92	1.31	0.81	0.69	0.53	
10	33	3.84	1.95	1.32	0.81	0.68	0.52	
20	66	3.96	1.97	1.33	0.80	0.67	0.50	

ticular duct or if the flow rate in that duct was actually lower than that upon which the standard sampling rate was based. Overestimates may be due to a reduced sampling flow rate or an increase in the duct discharge rate (due, for example, to repair of the exhaust fan).

Estimates of releases from the dust collector exhausts at the FMPC relied on isokinetic sampling of the stacks. When the probe velocity and the stack fluid velocity are equal, there is a very simple relationship between the mass of material released from the stack and the mass of material collected on the filter. That relationship, which involves the flows through the sampling probe and the stack, was used to estimate releases from the dust collector exhausts. Because the flow through a tube is the product of the fluid velocity and the cross-sectional area, one way to express the relationship is as follows:

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

$$Q_r = [v_a / v] [A_s / A_p / M_f]$$
 (G-5)

where  $Q_r$  is the amount of material released (g),  $v_n$  is the average fluid velocity (cm s<sup>-1</sup>) in the stack, v is the fluid velocity (cm s<sup>-1</sup>) at the stack centerline (the point of sampling),  $A_s$ and  $A_p$  are the areas (cm<sup>2</sup>) of the stack and the probe, respectively, and  $M_f$  is the amount of material (g) found on the filter. Implicit in Equation (G-5) is the assumption that u = v, which reflects the fact that the effluent sampling systems were designed to operate isokinetically. An equivalent expression for  $Q_r$  is

 $Q_r = [F_s^* / F_p^*] M_f$  (G-6)

1. A. A. A.

State Astro

where  $F_s^*$  and  $F_p^*$  are the current "standard" flow rates in the stack and sampling probe, respectively. That is,  $F_p^*$  is the computed sampling flow rate that would provide isokinetic sampling for the stack whose measured flow rate was  $F_s^*$ . The value of  $F_p^*$  for a given stack was adjusted when a new value for  $F_s^*$  was obtained from pitot tube measurements in the stack.

At this time, previous deviations from isokinetic conditions can only be estimated based, upon knowledge of the systems and measured variability of operating flow rates. Flow rates were recorded at the beginning and ending of a sampling period (Boone 1956b), but those data are unavailable. The sampling flow rate was established by setting a flow control valve to achieve a desired rotameter setting at the start of sampling period. Vibration could cause the valve opening to increase or decrease during the period. The flow was checked again at the end of the period; however the procedure does not specify use of the flow rate data to make corrections in the standard release estimate. The pleated filters used for sample collection had a large surface area. This would reduce the chance of sampling flow reduction due to loading of the filter; however, there were times when filter loadings were substantial and flow reductions may have resulted.

To account for possible variations in parameters that would produce anisokinetic sampling conditions, distributions were developed to characterize each of the parameters. Given the chemical form and particle size distribution for the uranium effluent from a particular stack (Appendix E), an estimate of the density and a set of independently selected, representative particle diameters were obtained. This information, together with randomly selected, independent estimates of  $F_p^*$  and  $F_s$ , was used to estimate the effect of anisokinetic sampling by computing R, using Equation (G-1), for each representative particle size in the distribution. The distributions chosen for particular parameters are described in the subsections that follow. The bounds and shapes of the distributions are best estimates given the present knowledge.

Chemical Form. The chemical form(s) of uranium released from particular stacks in the various plants have been discussed in Appendix E. The particle density is dependent on the chemical form of the material being released. As noted above, the range of densities for the uranium compounds of greatest interest range from 4.7 to 10.9 g cm<sup>-3</sup>. The purity of the material will also affect its density; mixtures of MgF<sub>2</sub> and UF<sub>4</sub> will have densities lower than the value of 4.7 g cm<sup>-3</sup> for pure UF<sub>4</sub>. In the absence of definitive data on the chemical purities of the exhaust streams, a right triangular distribution with lower limit of 0.9  $\rho^*$ 

Page G-6

#### Appendix G

#### Estimates of Bias in Effluent Sampling for Particles

Particle Size Distribution. Most of the particle size data obtained in 1985 indicate median aerodynamic diameters in the range of 2 to 10  $\mu$ m, although the distributions are not necessarily lognormal (see Appendix F). It has been suggested, because there were no substantial changes in plant processes, that those data are representative of the historic size distributions of aerosols released from the stacks studied. Composites of distributions have been produced for UF<sub>4</sub> and U<sub>3</sub>O<sub>8</sub> and other available data have been utilized for some processes for which no measurements at the FMPC are available (Appendix E). Ten particular particle sizes are used to represent an effluent particle size distribution. The variability in measured size distributions of FMPC produced UF<sub>4</sub> and U<sub>3</sub>O<sub>8</sub> (Appendix E) suggest that it is appropriate to consider a range of values from 0.8  $d_{ri}$  to 1.2  $d_{ri}$ , where  $d_{ri}$ is one of the representative particle diameters used in calculations. A uniform distribution of diameters of that range was assumed.

Stack Flow Rate. During the time between evaluations of the stack flow rate, the actual value  $(F_s)$  might be higher or lower than the current standard  $(F_s^*)$ . Data from recent stack traverse data sheets were evaluated to determine the likely magnitude of such variability. There were many stacks whose normal flow rate had been measured two or more times between 1984 and 1989 (RAC 1991). Examination of these data led to the choice of a triangular distribution for  $F_s$  with bounds of  $0.5 F_s^*$  and  $1.5 F_s^*$  and a mode of  $F_s^*$ .

Sampler Flow Rate. Similarly, the actual flow through the sampling probe  $(F_p)$  could vary from the standard value  $(F_p^*)$  and could, at any time, be higher or lower than the standard value of  $F_p^*$ . However, the effect of filter loading would increase the probability that the sampling flow would be less than the desired value. In the absence of any definitive information to describe this variable, a triangular distribution with bounds of  $0.5 F_p^*$  and  $1.25 F_p^*$  and a mode of  $F_p^*$  was chosen.

#### LOSSES OF PARTICLES IN THE SAMPLING LINE

#### Introduction

There are indications that collection of particles in sampling systems was a problem at the FMPC. In the monthly reports of effluent releases, there are references to plugged sampling lines. These comments do not define the reason(s) for the plugging; some may have been due to unusual operating conditions. For example, a high moisture content in the sampled air could lead to condensation in cold weather or to particle agglomeration and greatly increase the rate of accumulation of material in the sampling line. There may have been other factors, such as high concentrations of reactive gases, that could create similar effects.

In the evaluation of the FMPC monitoring program by Oak Ridge Associated Universities (ORAU 1985), it was noted that "<u>All probes inspected were partially clogged</u>

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page G-7

12

Page G-8	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3 Source Terms and Uncertainties

with material . . . ." While the observed buildup may be due in part to impaction on the relatively blunt ends of the probes (the report noted that the probes were not knife-edged), some of it was surely due to deposition. In the fall of 1985, a complete inspection of all sampling systems was undertaken. The exhaust stack flow rates were measured and the sampling probes were removed for cleaning. Some of the probes were replaced (NLCO 1985–1986).

Another complete refurbishment of the sampling probes appears to have been completed in 1988-1989. Probes were disassembled, checked, repaired, and cleared of deposited material. There were numerous indications of internal contamination of the sampling probes, lines, and the cones above the filter holders. In some cases the probe decontamination task required hot soapy steam or hydrochloric acid and was accomplished in the decontamination facility (WMCO 1988-1989).

There are two primary mechanisms that can lead to losses of particles in the sampling line itself. These are deposition on the walls of the vertical and horizontal sections of the line and impaction of particles on the walls due to the presence of bends in the line. A competing process which may mitigate these effects is resuspension of material deposited on the walls of the sampling line. Treatments of the problem of sampling line losses generally do not account for resuspension. Fluid velocities in sampling lines are often below those at which significant reentrainment of deposited material has been shown to occur (Corn 1965; Sehmel 1970).

1

5.5 × 1.7

04022

.

In the next section, the sampling system is described. In sections that follow, the methodology that was developed to analyze deposition and impaction losses of particles from the sampled air stream between the stack and the filter is presented. Each of those sections contains results of some generic calculations and discussion of them. Distributions that reflect the variability of the important parameters are presented.

#### **FMPC** Particle Sampling System

Detailed descriptions of individual dust collector exhaust sampling systems are not available. Many of the process exhaust systems have been modified or removed and the sampling systems have been removed as well. Other systems are presently inaccessible. The sampling lines employed for exhaust stacks were relatively simple (Ross and Boback 1971). Figure G-1 is illustrative of a typical sampling arrangement for a vertical stack. The probe, constructed of copper tubing, faced into the exhaust air stream. Outside the stack, the small diameter copper sampling line was enclosed in a protective and supportive pipe. There were two rounded 90° bends in the sampling line between the probe and the collection filter.

Measurements of the lengths of sampling lines remaining in Plants 4 and 5 in June 1991 showed that for most systems the horizontal section was 10-12 cm long. However, three systems had horizontal sections with lengths of about 30 cm because there were obstacles near the exhaust duct and a shorter line was not feasible. Outside the duct, the vertical line sections were about 14 cm long at which point the line enters an 8-cm tall conic expansion leading to the filter holder. The base of the conic section is about 8 cm in diameter and attaches to the filter holder. The pleated collection filters were about 10 cm in diameter.



Figure G-1. Schematic diagram of dust collector stack sampling system. The diagram does not show the support piping that was located outside the stack or the rain caps that were atop dust collector stacks.

These dimensions are in general agreement with a drawing prepared at the time the first samplers were being installed (Boone 1956a). That drawing shows that the vertical portion of the line inside the duct was 10 cm in length and that the sampling line internal diameter was small, 0.62 cm. The sample extraction point was the center of the exhaust duct, so the horizontal length of tubing inside the duct varied as a function of the size of the duct being sampled.

### Estimates of Particle Deposition

The topic addressed first in this section is the nature of the flow in the sampling system. The typical linear velocity ( $v = 1500 \text{ cm s}^{-1}$ ), sampling probe opening ( $\delta = 0.62 \text{ cm}$ ), air density ( $\rho_a = 1.2 \times 10^{-3} \text{ g cm}^{-3}$ ), and air viscosity ( $\eta = 1.81 \times 10^{-4}$  dyne s cm<sup>-2</sup>) used in the previous section were also employed here. For these parameter values, the Reynolds number (Re) for the sampling line would be:

Re = 
$$(v \ \delta \rho_a) / \eta = -6200$$
 (G-7)

Flow in such a line would be turbulent. Transport of particles to the wall by turbulent diffusion would be much more important than transport by Brownian diffusion.

Page G-10		The Fernald Dosi	metry Recons	truction Project
•		Tasks 2 and 3, Source	Terms and	Uncertainties
	· · · ·			

Gravitational settling would also be of limited importance because of the brief transport time through the horizontal section of the line.

Vincent (1989) has summarized results from a number of studies of deposition in lines under turbulent conditions. He defines the "penetration" to be the ratio of the particle concentration at the outlet of the line to that present at the line inlet. This ratio has also been called the sampling line "transmission factor" for the particles and that terminology will be employed here. This presentation follows the treatment given by Vincent; however, there are other expositions of some of the same ideas, including Schwendiman and Postma (1961). the ANSI guide (ANSI 1969), and other references cited below.

The relevant equation for the transmission factor that reflects losses due to deposition  $(TF_D)$  is:

 $TF_D = \exp[-4(w/v)(L/\delta)]$  (G-8)

where w is the deposition velocity (cm s<sup>-1</sup>) appropriate for the specific particles in the sampling line, L is the length (cm) of the sampling line, and v and  $\delta$  have been previously defined.

Using a figure from Liu and Agarwal (1974), Vincent illustrates that satisfactory agreement among three theoretical approaches and experimental data can be shown by plotting the normalized deposition velocity  $(w^*)$  against a normalized relaxation time  $(\tau^*)$  that reflects particle size. The dimensionless normalized parameters are:

1. Sec. 1.

Art. Oak. Sugar

 $w^* = w / [(f/2)^{0.5} v]$  (G-9)

and

٩.

$$[\tau \rho_{\alpha}(f/2)v^{2}]/\eta$$
 (G-10)

where  $\tau$  is the relaxation time and f is the Fanning friction factor. The relaxation time is defined by

$$\tau = [\rho d^2 C_c] / [18\eta] \tag{G-11}$$

For Reynolds numbers less than  $10^5$ , Perry et al. (1984) give the following expression for the friction factor:

主要で		:
$f = 0.0791  \mathrm{Re}^{-0.25}$		(G-12)
	r -	

A good approximation to the best theoretical relationships between  $w^*$  and  $\tau^*$  can be obtained using power functions. For these calculations, two power functions were used. For values of  $\tau^*$  between 0.1 and 10:

 $w^* = (5.40 \times 10^{-4}) \tau^{*(1.974)}$ 

(G-13)

.....

Estimates of Bias in Effluent Sampling for Particles

For values of  $\tau^*$  between 10 and 300:

$$w^* = (2.45 \ge 10^{-2}) \tau^{*(0.3178)}$$

The normalized deposition velocity is approximately constant (0.15) for values of  $\tau^*$  that are greater than 300. Use of these functional relationships allowed a closer correspondence to the experimental data when estimating  $w^*$  and then w for particles of various uranium compounds.

The deposition velocities derived from these relationships were used to compute transmission factors for a 1-m sampling line having an inside diameter of 0.62 cm, with a fluid velocity of 1500 cm s<sup>-1</sup>. Results of the calculations are shown in Table G-4 as a function of the physical diameter of the particles. The calculated losses due to deposition of particles begin to be substantial for physical diameters of  $2 \mu m$  or greater.

The estimated deposition losses calculated as described above are higher than those given in the ANSI Guide (ANSI 1969). Back calculation of deposition velocities from the results presented in Table B3 of (ANSI 1969) indicates that substantially lower values of w were used in those calculations. The deposition velocities used in the ANSI guide appear to be based on a correlation developed and later published by Schmel (1970). The correlation relates the normalized deposition velocity to particle density, the ratio of the particle diameter to the tube diameter, and the Reynolds number. The dependence on Re is much stronger than in the correlation described above.

Physical Calculated transmission factors for a 1 m line					
diameter (µm)	UF <sub>4</sub> particles	UO <sub>3</sub> particles	U <sub>3</sub> O <sub>8</sub> particles	UO <sub>2</sub> particles	
0.1	1.0	1.0	1.0 -	1.0	
0.2	1.0	1.0	1.0	1.0	
0.3	1.0	. 1.0	1.0	1.0	
0.5	1.0	0.99	0.99	0.99	
0.8	0.99	0.97	0.96	0.94	
1	0.97	0.93	0.92	0.86	
2	0.68	0.40	0.31	0.13	
3	0.16	0.087	0.079	0.063	
5	0.054	0.023	0.020	0.014	
8	0.020	0.011	0.009	0.006	
10	0.011	0.006	0.005	0.003	
20	0.002	0.002	0.002	0.002	

Table G-4. Estimated Transmission Factors for

Schmel's experimental results for deposition velocity are among the smaller values that have been measured (Gieseke et al. 1980) and are uniformly lower than predicted values from Friedlander and Johnstone (1957). The Friedlander and Johnstone theoretical values and the predictions of Beal (1970) and Liu and Ilori (1974) are reasonably

Radiological Assessments Corporation "Setting the standard in environmental health"

Page G-11

(G-14)

ę,

100 A

representative of the set of rather variable data (Gieseke et al. 1980, Vincent 1989). Theoretical estimates developed by Davies (1965) follow the same general trend of increasing  $w^*$  with  $\tau^*$ , but the specific values of  $w^*$  are much lower than experimental results and the predictions of the three other theoretical analyses.

At least some of the variability in the data is due to differences in measurement goals. Some measurements were made to determine the flux of particles to the surface and efforts were made to assure that particles transported to the wall of the line did not reenter the air stream. Other measurements made with liquid drop aerosols would similarly be free of the effects of particle bounce at impact or subsequent resuspension. The former appears to be the most important mechanism for flows with Reynolds numbers considered in this context. Resuspension of previous deposits apparently requires Re  $- 5 \times 10^4$  or greater (Corn 1965; Sehmel 1970).

To address the fact that not all particles striking the wall of the sampling line will stick to it, an attachment fraction for deposition  $(a_d)$  is introduced. For the purpose of estimating line losses, an effective deposition velocity is defined as the product  $[a_d w]$  and is used in Eq. (G-8). Marshall et al. (1982) compared experimental measurements against predicted sampling line losses for particle diameters of 5-20 µm and found that the latter values consistently exceeded those that were measured. Beal (1978) also compared computed deposition velocities with measured ones to assess the probability that a particle would stay on the wall. However, these comparisons may only illustrate bias in the calculational models.

Direct evidence for incomplete attachment of particles on tubing walls is provided by a figure presented by Sehmel (1967). It shows mean deposition velocities to tacky surfaces for particles with aerodynamic diameters between 2 and 30  $\mu$ m to be factors of 5 to 20 higher than those to untreated surfaces. The data were for Re = 36,000 in a large diameter line, which initially clouded their utility for the small diameter and lower Reynolds numbers characteristic of sampling lines at the FMPC. However, the analysis by Beal (1978) of data generated by Sehmel (1966, 1968) suggests a method that can be used. He found the dimensionless stopping distance (S<sup>+</sup>) to be a useful parameter for developing correlations.

For particles in the probe and sampling line, the stopping distance (S, cm s<sup>-1</sup>) is defined as

$$S = 0.05 \, u \, d \, \rho \, (f/2)^{0.5} \, / \eta + 0.5 \, d \tag{G-15}$$

in which the parameters all have the meanings that were defined above. The dimensionless stopping distance  $(S^+)$ 

$$S^{+} = S u (f/2)^{0.5} \rho_a / \eta$$
 (G-16)

is used to relate the attachment fraction to the particle size and flow parameters.

Direct comparisons between measurements of deposition onto tacky tubing walls and deposition onto untreated walls form the basis for the estimation of the attachment fraction. In this analysis the tacky surface is regarded as a perfect sink; that is, it is assumed that the applied film holds all the particles that reach the wall of the line. Estimates of the attachment fraction and dimensionless stopping distance for the measurement conditions

# Appendix G

. .

. .

1

# Estimates of Bias in Effluent Sampling for Particles

were computed from Schmel's data. There is substantial variability in these estimates, which are plotted in Figure G-2. Also shown in the figure are the central estimates of the attachment fraction, described by the following functions

$$a_d = c \text{ for } S^+ \le 1.5$$
  
 $a_d = (0.1/S^+)^e \text{ for } S^+ > 1.5$  (G-17)

Central estimates of c and e are 0.20 and 0.59, respectively. The experimental deposition measurements upon which these estimates are based were made using vertical tubes. In our analysis of sampling line losses, Eq. (G-17) was used for both horizontal and vertical tube sections. In the Monte Carlo calculations (discussed below), estimates of  $a_d$  are made by sampling distributions of these two parameters. Figure G-2 shows the ranges of values of  $a_d$  computed for three values of  $S^+$ .



Figure G-2. Dependence of the attachment fraction upon the dimensionless stopping distance. Points are observed values from experimental comparisons of tacky and untreated surfaces. The thin lines show the functional form of the relationship given by Eq. (G-17). The vertical lines show the ranges of computed attachment fractions considering the uncertainties in c and e.

#### **Estimates of Particle Impaction in Bends**

Also contributing to the loss of material between the point of sample extraction and the collection filter would have been impaction of large particles in the two 90° bends in the sampling line. Vincent (1989) presents an analysis that indicates that the probability of particle impaction on the wall of the line  $(\varepsilon_i)$  is a complicated function of the Stokes number, but independent of the radius of curvature of the bend in the line. Other

The Fernald Dosimetry Reconstruction Project 'Tasks 2 and 3, Source Terms and Uncertainties

investigators have developed relationships in which the impaction probability is a linear or slightly curvilinear function of the Stokes number (Yeh 1976, Crane and Evans 1977). Cheng and Wang (1981) consider the radius of curvature of the bend  $(R_b)$  using Dean's number (De), which is defined by

$$De = Re / (2R_b / \delta)$$
 (G-18)

where, as before, Re is the Reynolds number for the flow in the sampling line and  $\delta$  is the internal diameter of the line. In this formulation, higher flow rates and tighter bends lead to greater impaction probabilities. For a particular value of De, the impaction probability is a function of the Stokes number and thus reflects both the physical diameter and the density of the particles. For Reynolds numbers in the range 100–1000, the shape of the impaction probability curve is sigmoid. For higher Reynolds numbers it approaches the curvilinear form for idealized flow (Cheng and Wang 1981). The curve for idealized flow was defined for 90° bends of differing radii of curvature by Cheng and Wang (1975).

Experimental confirmation of their approach has been reported for the conditions De = 400 and Re = 1000 (Pui et al. 1987). However, the experimental data for De = 35 and Re = 100 do not agree with the theoretical values of Cheng and Wang. For fully turbulent flow, the theory also failed to match the measurement results (Pui et al. 1987).

The latter case is of great interest for the current problem. Measurements were made with lines having internal diameters of 0.50 and 0.85 cm at Re of 6,000 and 10,000. No dependence on Re or d can be seen in the results. The data fit the function

 $\varepsilon_i = 1-10^{-0.963}\,\mathrm{Stk}$ 

very closely at nearly all values of Stk studied, from 0.03 to 1.35.

A set of estimates of the impaction probabilities is presented in Table G-5 for selected Stokes numbers. The functional relationship given above can be used to obtain impaction probabilities for other values of Stk in the experimental range. The transmission factor that reflects losses due to impaction of particles is designated  $TF_I$ . For a sampling line having n 90° bends

 $TF_I = [1 - \varepsilon_i]^n$ 

(G–20)

(G-19)

101.8	Single 90° Ben	a as a Function of St	okes Number
Stokes number (Stk)	Impaction probability (e_i)	90.2 % Stokes Source number (Stk)	Impaction probability $(\varepsilon_i)$
0.03	0.064	0.7	0.79
0.05	0.10	0.8	0.83
0.1	0.20	0.9	0.86
0.2	0.36	1.0 Tables 1.0	0.89
0.3	0.49	199 242 1924 1.1 . S	0.91
0.4	0.59	1.2	0.93
0.5	0.67	ATT 1.3	0.94
0.6	0.74	1.35	0.95

#### Table G-5. Estimated Impaction Probability for a Single 90° Bend as a Function of Stokes Numbe

Page G-14

G-18)

1212

対応的

k

「おいい

# Appendix G

Estimates of Bias in Effluent Sampling for Particles

The results in Table G-5 are for n = 1. Table G-6 contains estimated transmission factors for particles of various uranium compounds for passage through two 90° bends. These estimates are based on the data of Pui et al. (1987). The calculations indicate that losses due to impaction begin to be substantial for particle diameters of 2 µm and increase sharply with increasing particle size. The effect of particle density can be seen by reading across a row for particle diameters greater than 0.3 µm.

Physical	Estin	mated Transmissio	n Through Two 90	° Bends
diameter (µm)	UF <sub>4</sub> particles	UO3 <sup>†</sup> particles	U <sub>3</sub> O <sub>8</sub> particles	UO <sub>2</sub> particles
0.1	1.0	0.99	0.99	0.99
0.2	0.99	0.98	0.98	0.97
0.3	0.98	0.97	• 0.96	0.95
0.5	0.95	0.92	0.91	0.89
0.8	0.89	0.83	0.81	0.76
1	0.84	0.76	0.73	0.66
2	0.51	0.36	0.31	0.21
3	0.23	0.10	0.075	0.033
5	0.019	0.002	0.001	< 0.001
8	< 0.001	< 0.001	< 0.001	< 0.001
10	< 0.001	< 0.001	< 0.001	< 0.001

## Table G-6. Estimated Transmission of Particles of Pure Uranium Compounds Through Two 90° Bends

The impaction probabilities and transmission estimates in Tables G-5 and G-6 are based upon measurements of uranine traced liquid aerosols. The deposition in the bend was physically removed and analyzed. Solid particles of uranium compounds will not attach to the tubing walls as effectively as the oleic acid aerosol used in the experiments. An effective impaction parameter was defined as the product  $[a_i \varepsilon_i]$  and used in Eq. (G-20) to estimate impaction losses. Because measurements that could be used to derive attachment fractions specific for impaction are unavailable, relationships comparable to those in Eq. (G-17) were used to define  $a_i$ 

$$a_i = c$$
 for  $S^+ \le 1.5$   
 $a_i = (0.1/S^+)^e$  for  $S^+ > 1.5$  (G-21)

The nominal values of c and e are 0.20 and 0.59. Parameter distributions that were sampled as part of the calculation of  $a_i$  are discussed below.

### **Estimates of Overall Transmission Factors**

ç.,

 $\mathcal{O}_{\mathcal{O}}$ 

Overall particle transmission will reflect losses due to both deposition and impaction. For a given size and density, the overall transmission factor for a particle  $(TF_P)$  is the product

$$TF_P = TF_D \times TF_I$$

Radiological Assessments Corporation "Setting the standard in environmental health"

(G-22)

Page G-15

where  $TF_D$  and  $TF_I$  are the transmission factors for deposition and impaction, respectively.

It was noted earlier that the measured deposition velocities for particles in sampling lines exhibit variability, both within and among sets of experimental results. There is a smaller uncertainty associated with the measured impaction probabilities. In both cases, the possibility that retention on the wall of particles that are transported to it may be different for uranium aerosols produced by plant processes than for those generated for laboratory experiments is a concern.

To address the uncertainties associated with deposition and impaction of the uranium aerosols in FMPC sampling lines, distributions of important parameters were developed for use in the Monte Carlo calculation procedure for the particle transmission factors. The 24. C. K.

1.13

WINN WINN

3

.

1.

1. i.i.

important parameters and the chosen distributions are discussed below.

Particle Density. The density of the released particles is primarily determined by the chemical form of the uranium and the degree of purity of the discharged material. The same right triangular distribution with bounds of 0.9  $\rho^*$  and  $\rho^*$  defined previously was used for the particle transmission calculations.

Particle Size Distribution. As noted earlier, the particle size distributions are treated in calculations using a representative particle diameter  $(d_{ri})$  for each tenth of the particles in the distribution. As for the evaluation of previous deviations from isokinetic sampling conditions, a uniform distribution between 0.8  $d_{ri}$  and 1.2  $d_{ri}$  was used for each of the representative diameters to reflect the uncertainty in the particle size distribution.

Fluid Velocity in Sampling Line. Once the diameter of the sampling line is fixed (and no evidence has been found that the early sampling lines were constructed of anything but the small diameter copper tubing previously described) the fluid velocity depends only on the sampler flow rate. The distribution given previously, namely triangular with a mode of  $F_p^*$  and bounds of 0.5  $F_p^*$  and 1.25  $F_p^*$ , was also used to compute u for the particle transmission calculations.

Sampling Line Configuration. The basic physical layout of the sampling lines appears to have been highly uniform. As noted the line diameter and material do not appear to have changed and all lines that have been inspected or seen in photographs had two 90° bends. For the particle impaction calculations, n was always equal to two.

The lengths of the sampling lines varied. However, for a particular exhaust duct the only uncertainty was associated with the length of the horizontal section outside the stack. The inner and outer vertical segments were taken to be 10 and 22 cm in length, respectively, and the length of the horizontal section inside the duct was half the duct diameter. These dimensions are based on physical observation of the sampling systems and the drawing (Boone 1956a) that describes them. The length of the exterior horizontal section was represented by a right triangular distribution with a minimum value and mode of 10 cm and a maximum value of 30 cm. The total length of each stack sampling line was computed using the known dimensions and the randomly selected sample of the one variable segment length.

# Appendix G Estimates of Bias in Effluent Sampling for Particles

Effective Deposition Velocity. The aforementioned variations in particle density, diameter, and velocity were used in the calculation of the normalized relaxation time  $\tau^*$  and the dimensionless stopping distance  $S^*$ . The relationships between  $\tau^*$  and  $w^*$  and between w and  $w^*$  are given in Eqs. (G-13, -14) and in Eq. (G-9), respectively. The attachment fraction was estimated using Eq. (G-20). For  $S^+ \leq 1.5$ , the value of  $a_d = c$  was randomly selected from a triangular distribution with bounds of 0.03 and 0.38 and a mode of 0.20. For larger values of  $S^+$ , the distribution of the exponent (e), whose nominal value is 0.59, was taken to be uniform with bounds of 0.32 and 0.86. This procedure yields a distribution of values of  $a_d$  that is comparable to estimates derived from experimental measurements. Then the effective deposition velocity,  $[a_d w]$ , was used in place of w in Eq. (G-8).

Effective Impaction Efficiency. The particle density, diameter, and velocity derived from the distributions described above were used in the calculation of the Stokes number. The value of Stk is the fundamental determinant of the impaction efficiency  $\varepsilon_i$ . The attachment parameter for impaction  $(a_i)$  was computed and the quantity  $[a_i \ \varepsilon_i]$  was used in place of  $\varepsilon_i$  in Eq. (G-17) to compute  $TF_I$ . Estimates of  $a_i$  were made using Eq. (G-21). The distribution of c was assumed to be triangular with a mode of 0.20 and bounds of 0.03 and 0.38. A uniform distribution was sampled for values of  $\varepsilon_i$  its bounds were 0.32 and 0.86.

# OVERALL SAMPLING BIAS

े

For a particular sampling system, the estimate of overall sampling bias was the product of three factors: B, R, and  $TF_P$ . The appropriate operating conditions and inlet particle size distribution, either measured or inferred, for that line were used in a single Monte Carlo calculation to make estimates of the overall sampling bias and its uncertainty. Estimates of the bias (B) due to nonrepresentative sampling were taken from Table G-1. It was assumed that a symmetric uniform distribution applied and that B was equally likely to overestimate or underestimate the true concentration. The bias due to anisokinetic sampling (R), computed using Eq. (G-1), could also be either positive or negative depending upon the randomly selected values of duct and probe air velocities. The calculations just described led ultimately to a value of  $TF_P$  computed using Eq. (G-22). In the Monte Carlo procedure, the overall bias,  $BR TF_P$ , was calculated repeatedly to obtain a distribution of estimates.

Examples of the results of calculations of overall bias are shown below for selected exhaust ducts. Figure G-3 shows the distribution of estimates for the G4-3 exhaust in Plant 4. The distribution is approximately lognormal with a median value of 0.92 and a geometric standard deviation (GSD) of about 1.5. The 5th and 95th percentile values are 0.49 and 1.6, respectively. These results indicate that there is less than a 5% chance that releases from this stack were underestimated by more than a factor of two and an equal probability that they were overestimated by more than a factor of 1.6.



Figure G-3. Distribution of estimates of overall bias for the sampler serving the G4-3 exhaust stack in Plant 4.

An analysis was performed to determine the sensitivity of the estimates of bias to the parameters used in the calculation. Four parameters ranked much higher than any of the others: v, B, u, and e. The relatively large uncertainties in these variables were discussed above. For G4-3, the estimated range for B is  $\pm 30\%$ . There is, unfortunately, no simple way to reduce these uncertainties, which primarily relate to unknown conditions of past operations.

Figure G-4 shows the distribution of estimates of overall bias for the G4-2509 exhaust in Plant 7. The distribution is approximately lognormal with a median of 0.88 and a GSD of about 1.4. The 90% confidence interval ranges from 0.52 to 1.4. The sensitivity analysis revealed the importance of the same four parameters, but in different order: u, v, e, and B. For G4-2509, the estimated range for B is smaller, ±15%.

Figure G-5 shows the distribution of estimates of overall bias for the G5-260 exhaust in Plant 5. This distribution is also approximately lognormal with a median of 0.85 and a GSD of about 1.5. The 90% confidence interval lies between 0.52 and 1.4. The sensitivity analysis revealed the importance of the same four parameters, but in a third sequence: e, u, v, and B. For G5-260, the estimated range for B is  $\pm 20\%$ .

### CONCLUSIONS

Three possible sources of bias in dust collector effluent sampling have been investigated. They are nonrepresentative sampling, anisokinetic sampling conditions, and losses of particles from the sampled air stream due to deposition and impaction. All could affect the reported releases from the dust collector exhaust stacks at the FMPC. Nonrepresentative sampling and anisokinetic sampling could produce either a high or low bias in the reported results, depending upon inhomogeneities in the concentration and

Ś.





a constant

80





Figure G-5. Distribution of estimates of overall bias for the sampler serving the G5-260 exhaust stack in Plant 5.

Page G-19

possible changes in flow rates in the duct and sampling line. The effect of losses due to deposition and impaction is one-sided, always leading to an underestimation of the amounts released.

The overall bias reflects all three factors and is dependent upon a number of variables. Distributions of the parameters required for bias estimation were developed. These distributions are used in Monte Carlo calculations of the sampling biases for FMPC sampling systems. The confidence bounds for these estimates of overall bias indicate that releases may have been underestimated by as much as a factor of two or overestimated by as much as a factor of 1.6. The results of these calculations are employed in Appendix E.

#### REFERENCES

ANSI (American National Standards Institute). Guide to sampling airborne radioactive materials in nuclear facilities. New York: American National Standards Institute, Inc.; 1969.

Beal, S. K. Correlations for the sticking probability and erosion of particles. J. Aerosol Sci. 9: 455-461; 1978.

Boone, F. W. Drawing of stack sampler (unnumbered). Fernald, OH: National Lead Company of Ohio; 3 August 1956 (1956a).

Boone, F. W. Stack sampling procedure. Fernald, OH: National Lead Company of Ohio; 5 September 1956 (1956b).

Cheng, Y-S; Wang, C-S. Inertial deposition of particles in a bend. J. Aerosol Sci. 6: 139-145; 1975.

Cheng, Y-S; Wang, C-S. Motion of particles in bends in circular pipes. Atmos. Environ. 15: 301-306; 1981.

Corn, M.; Stein, F. Re-entrainment of particles from a plane surface. AIHA Journal. 26: 325–336; 1965.

Crane, R. I.; Evans, R. L. Inertial deposition of particles in a bent pipe. J. Aerosol Sci. 8: 161–170; 1977.

Davies, C. N. The rate of deposition of aerosol particles from turbulent flow through ducts. Ann. Occup. Hyg. 8: 239-245; 1965.

Well marsh .

•• •<u>•</u>\* • •

-1020-04

10 A 10 A

Beal, S. K. Deposition of particles in turbulent flow on pipe or channel walls. Nucl. Sci. Engng. 40: 1-11; 1970.
Appendix G

8

() •

5

Page G-21

#### Estimates of Bias in Effluent Sampling for Particles

- Durham, M. D.; Lundgren, D. A. Evaluation of aerosol aspiration efficiency as a function of Stokes number, velocity ratio, and nozzle angle. J. Aerosol Sci. 11: 179-188; 1980.
- Friedlander, S. K.; Johnstone, H. F. Deposition of suspended particles from turbulent gas streams. Ind. Eng. Chem. 49: 1151-1156; 1957.
- Gieseke, J. A.; Lee, K. W.; Goldenberg, M. A. Measurement of aerosol deposition rates in turbulent flows. Washington, DC: U. S. Nuclear Regulatory Commission; Document NUREG/CR-1264; January 1980.
- Hinds, W. C. Aerosol technology, properties, behavior, and measurement of airborne particles. New York: John Wiley & Sons; 1982.
- Hodgman, C. D.; Weast, R. C.: Selby, S. M. Handbook of chemistry and physics. Fortieth Edition. Cleveland, OH: Chemical Rubber Publishing Co.; 1959.
- Liu, B. Y. H.; Agarwal, J. K. Experimental observation of aerosol deposition in turbulent flow. J. Aerosol Sci. 5: 145-155; 1974.
- Liu, B. Y. H.; Ilori, T. A.. Aerosol deposition in turbulent pipe flow. Environ. Sci. Technol. 8: 351-355; 1974.
- Marshall, M.; Stevens, D. C.; Birch, R. Sampling airborne particulate effluents in the nuclear industry. In Proceedings of the third international symposium: radiological protection — advances in theory and practice. Reading, UK: Society for Radiological Protection; 1982.
- NLCO (National Lead Company of Ohio). Stack traverse report; 3-page form NLO-H&S-2583. Cincinnati, OH: National Lead Company of Ohio; Task completion dates in 1985 and 1986.
- ORAU (Oak Ridge Associated Universities). Environmental program review of the Feed Materials Production Center, Fernald, Ohio. Final Report. October 1985.
- Pui, D. Y. H.; Romay-Novas, F.; Liu, B. Y. H. Experimental study of particle deposition in bends of circular cross-section. Aerosol Sci. Tech. 7: 301-315; 1987.
- Perry, R. H.; Green, D. W.; Maloney, J. O. (eds.) Perry's chemical engineers' handbook. Sixth edition. New York: McGraw Hill Book Company; 1984.
- RAC (Radiological Assessments Corporation). The Fernald dosimetry reconstruction project, task 1: identification of release points. Neeses, SC: Radiological Assessments Corporation; January 1991.

Š

Livite de

2

L. M. J

F

\*\*\*\*

ざんべい

No. of Street, or other

÷

- Ross, K. N.; Boback, M. W. The control and sampling of airborne contaminants from uranium production. Cincinnati, OH: National Lead Company of Ohio; Document NLCO-1087; 15 November 1971. 7 4.3 Com
- Schwendiman, L. C.; Postma, A. K. Turbulent deposition in sampling lines. In: Proceedings of the Seventh AEC Air Cleaning Conference. Oak Ridge, TN: Division of Technical Information, U. S. Atomic Energy Commission; Document TID-7627; 1961.

Schmel, G. A. Particle deposition and re-entrainment in long vertical conduits. Richland, WA: Battelle-Northwest Laboratories; Report BNWL-235-3; 1966.

Schmel, G. A. Validity of air samples as affected by anisokinetic sampling and deposition within sampling line. In: Proceedings of an IAEA symposium on assessment of airborne radioactivity. Vienna: International Atomic Energy Agency; 1967.

Schmel, G. A. Aerosol deposition from turbulent air streams in vertical conduits. Richland, WA: Battelle-Northwest Laboratories; Report BNWL-578; 1968.

Schmel, G. A. Particle sampling bias introduced by anisokinetic sampling and deposition within the sampling line. AIHA Journal. 31: 758–771; 1970.

Vincent, J. H. Aerosol sampling, science and practice. Chichester: John Wiley & Sons; 1989.

WMCO (Westinghouse Materials Company of Ohio). Stack sampler assembly inspection check lists. Cincinnati, OH: Westinghouse Materials Company of Ohio; Task completion dates in 1988 and 1989. 

Yeh, H. C. Comments on the paper: inertial deposition of particles in a bend by Y-S Cheng · · · · · · · · · and C-S Wang. J. Aerosol Sci. 7: 275-276; 1976.

the second s

15 365 8 1 1 F 4 7 1 F

75-44 - 27 7 **6**5 3 4 11

· · .

۰.

S 11. 1 · · · ; :

and approved the second provide

a the state of the second s 

Presidente and a state of some constant

at a star in

1. Sec. 1. Sec

. . . . .

1 Aug 1 .

#### APPENDIX H

#### **DISCHARGES FROM PLANT 2/3 DENITRATION OPERATIONS**

#### INTRODUCTION

 $45^{\circ}$ 

After 1956, exhausts from the denitration operations in Plant 2/3 were treated by a wet scrubber prior to discharge. The releases of uranium from the scrubber exhausts were not sampled, even periodically, until recently. In June 1988, an investigation of environmental radioactivity measurements led to the conclusion that releases from Plant 2/3 processing activities were the source of the observed higher offsite air concentrations (Investigation Board 1988). In sections that follow the scrubber exhaust system is described and the previous estimates of releases are discussed. Results of a review of the denitration operations are then presented. The approach to estimation of releases from the denitration operations is described and the results of its implementation are presented. Because information is lacking on early operations with dust collectors, releases from those years are estimated using the same model used for years when the scrubbers were in operation.

#### SYSTEM DESCRIPTION

Two processes are of primary interest in describing the Plant 2/3 denitration scrubber system. The first of these is the denitration process itself. As the name implies nitrates were removed from the uranyl nitrate hexahydrate (UNH) to produce uranium trioxide ( $UO_3$ , also called orange oxide). Fumes of oxides of nitrogen that were produced during denitration were routed to the scrubber system. Absorption of these gases in aqueous solution produced nitric acid that was recycled to the digestion area of the plant. The second process was the vacuum transfer of the orange oxide from the denitration pots to a storage hopper. This process was called "gulping" the orange oxide. That term, derived from the fact that the snakelike tool appeared to swallow the  $UO_3$ , is employed in subsequent discussion.

There were two parallel lines of denitration pots, located along the north and south sides of the building. Each of the pot lines had a storage hopper, a product mill, and a product packaging station. The suction of the vacuum system pulled the product out of the pot and carried it through two sequential cyclone separators that removed most of the product from the stream. The exhaust of the second cyclone, which contained the UO<sub>3</sub> that had not been removed by the separators, was routed to the scrubber. Uranium captured by the scrubber was routed to the digestion area when the scrub liquor collection tank was pumped to the digestion area (Cahalane 1957, Hicks 1957, Semones and Sverdrup 1988).

> Radiological Assessments Corporation "Setting the standard in environmental health"

1

age H–2	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3, Source Terms and Uncertainties

Wet scrubbers are a class of devices that have long been used to remove particles or mists from air streams. Detailed technical descriptions of scrubbers can be found in the literature (Perry, Green and Maloney 1984; ECT 1978). The scrubbers for the  $UO_3$  vacuum transfer or gulping process employed a nitric acid solution. First contact of the scrub solution with the airstream occurs in the throat of the venturi scrubber under highly turbulent conditions. The liquid droplets remove particles from the airstream by impingement. After the impingement section, the air stream containing liquid droplets and the remaining free particles enters the separator section. This is typically a chamber containing baffles or other surfaces upon which the large droplets are deposited by impaction. The air leaving the separator contains small droplets of scrub liquor and the free particles. In the Plant 2/3 scrubber system, there was a wire mesh demister in the stack that was used to remove more droplets and particles from the exhaust air. Limited data on both the particle fraction and the entrained liquor fraction of the release are available. The nature of the releases from the Plant 2/3 scrubber system is discussed in more detail in a later section.

. .

.

N. S. S. S.

20000

1

j.

**1** 

#### PREVIOUS RELEASE ESTIMATES

P

Estimates of historic releases from the Plant 2/3 denitration system scrubbers were added to the list of FMPC source terms in 1989 (Clark et al. 1989). Those estimates rely on the analysis of Semones and Sverdrup (1988) who investigated the scrubber emission source. Their report includes results of the only known effluent sampling results for the Plant 2/3 scrubber system exhausts. The experimental measurements of releases of uranium during scrubber operation were related to the scrub liquor uranium concentration during the test operations. Release estimates were obtained for mist entrainment when  $UO_3$  was not being transferred and for particulate losses during gulping. The estimated release factor was used to make estimates of the releases from the scrubber systems over the years of operation of the system.

In addition to the release factor developed from the effluent testing effort, other parameters were required to estimate releases. A nominal processing cycle was developed; the time required for pot gulping was taken to be one hour. The number of pots gulped in a year was estimated using the annual production of  $UO_3$  and a pot capacity of 843 kg of uranium. The frequency of pumping of the scrub liquor to the digestion area affects the average concentration of uranium in the scrub liquor and the discharge of uranium entrained in mist during scrubber operations. A mean concentration of 41 g U L<sup>-1</sup> of scrub liquor, partly based on measurements between 1985 and 1988, was used in calculations of releases for earlier years.

An operational history for the denitration process was estimated. For the years 1953– 1964, it was assumed that the process operated during 3 shifts per day, 50 weeks per year. The scrubber was assumed to operate during 90% of the available hours during 1960, the year of maximum  $UO_3$  production. Scrubber operation was prorated according to the total annual  $UO_3$  production for other years.

These assumptions led to estimates of Plant 2/3 scrubber releases that were presented by Clark et al. (1989). Over the entire period of operation, inclusion of the Plant 2/3 scrubber

Appendix H Discharges from Plant 2/3 Denitration Operations

source term estimates raised the earlier total uranium release estimate by about 28% (Clark et al. 1989).

#### URANIUM TRIOXIDE PRODUCTION

. . .

.

5.2.5

÷.

Uranium trioxide production data have been summarized on a fiscal year basis in Appendix C. Short term production data were generally not available, except for the very detailed data in Shift Foreman's logs that were found for some years (see below). Average values for calendar years were estimated approximately using the tabulation in Appendix C. Figure H-1 shows the average annual uranium trioxide production amounts for each year of operation. The plot shows that production in metric tons of uranium (MTU) varied markedly from year to year. The years of maximum production were 1959-1961, when about 12,000 MTU of  $UO_3$  was produced. The period of greatest activity was soon followed by a shutdown, which began in July 1962 and continued for two years. Two other secondary production peaks occurred in later years.



Figure H-1. Production of uranium trioxide (UO<sub>3</sub>) in Plant 2/3.

#### **REVIEW OF DENITRATION OPERATIONS**

Because the analysis of Semones and Sverdrup (1988) indicated that the Plant 2/3 scrubber releases accounted for about 30 percent of the total releases to the atmosphere from the FMPC, a review of the basis for those estimates was undertaken. The review of denitration operations and the release estimates was conducted in several steps. Each part

3

1. N. N. N.

. .

1. A 194

(1275))

-

of the review focused upon a particular set of the relevant technical reports or historic records that had been found. The following subsections treat particular aspects of the denitration process and the releases that resulted from its operation. Some large collections of original records were found that greatly assisted the investigation.

Review of Logbooks from 1969, 1970, and 1973

The initial review of records focused on logbooks from the denitration area of Plant 2/3 that covered operations during the years 1969, 1970, and 1973. This review indicated that actual plant operating data differed from parameter values that had been assumed in the analysis of Semones and Sverdrup (1988).

Plant logbook data for 5 May through 26 September 1973 showed that the denitration process operated nearly continuously (NLCO 1973). This contrasted with the operating schedule of five days per week that had been assumed by Semones and Sverdrup (1988) for the years from FY 1965 through FY 1982.

Production data were available on a shift by shift basis in the logbook, which permitted evaluation of a question about the relative releases at different times of the day. During the night (12-8), day (8-4), and afternoon (4-12) shifts, the plant denitrated 898, 816, and 799 pots of UNH, respectively. The amounts of  $UO_3$  packaged were 989, 917, and 996 MTU for the three shifts, respectively. The processing and packaging rates did not vary greatly during this time period. The production data indicate that nocturnal releases from the Plant 2/3 scrubbers would not have exceeded those during the day shift by more than about 10%.

During May-September 1973, 2513 pots of UNH were denitrated and 2902 MTU were packaged as  $UO_3$  (NLCO 1973). The gross average amount of product per pot was 1.15 MTU, as opposed to the assumed quantity of 843 kg U. Calculation of the amount of product per pot on a daily basis and averaging of the daily values yielded an estimate ( $\pm$  sample standard deviation) of 1.17  $\pm$  0.15 MTU packaged per pot denitrated.

The time required to transfer the  $UO_3$  in a pot using the gulping system is another variable employed in the analysis of releases. Two sets of plant logbook entries yielded information about this parameter. During May-August 1969, 2% enriched UNH was being denitrated to  $UO_3$  and packaged in Plant 2/3. From data for 27 production batches, the mean time ( $\pm$  standard deviation) to transfer a pot of UO<sub>3</sub> was 81  $\pm$  22 minutes (NLCO 1969). In 1970, 34 batches of enriched UNH were denitrated during a 2-month period. Transfer times were recorded for transfers of 28 pots of UO<sub>3</sub> (NLCO 1970). The mean UO<sub>3</sub> transfer time for a pot of product was  $93 \pm 18$  minutes. Both sets of observations led to transfer times longer than the 60-minute duration assumed in Semones and Sverdrup (1988). It is possible that the transfer times were longer because of extra care taken with the more valuable enriched uranium. Overall production was low during the periods cited and that may have been an influence as well. The recorded heating times for 19 batches of UNH lead to an average of  $9.3 \pm 0.4$  hours, compared to the "standard" estimate of 6.0 hours given by Semones and Sverdrup (1988). This suggests a more leisurely pace of operations during the enriched uranium operations. Transfer times were not recorded during the period of higher production in 1973 cited above.

Review of logbook data showed that production of uranium trioxide was not constant throughout the year. For example, between 9 September 1970 and 5 January 1971, there was no denitration of UNH (NLCO 1970). In FY 1973, 25% of the total production occurred in two months (NLCO 1973). These data indicated that if detailed time resolution is needed for dose estimates the generally available annual production rates could be misleading. Annual production data do not indicate periods of variable production or of plant outages.

As a result of the initial review, it was determined that further investigation was needed to determine appropriate parameters for the calculations of release rates from the Plant 2/3 scrubbers. This entailed review of additional detailed data on denitration operations in Plant 2/3.

#### Review of Operational Data for 1960-1962

. . .

: N. 1

Historic records on the denitration of UNH in Plant 2/3 during 1960-1962 were located in storage. The Shift Foremen's Logs that were kept during those years (NLCO 1960-1962) contained information on the number of pots charged with UNH, the number of processed pots of UO<sub>3</sub> that were gulped, and the number of drums or hoppers of milled product that were packaged during each shift. The log sheets also contained some information on the amount of scrub liquor pumped to the digestion area and on the normality of the liquid transferred. Although data on the uranium concentration in the scrub liquor at the time of transfer had been found in the logbooks for later years, little information on that parameter was found on the log sheets for 1960-1962. Although sample log sheets were used to record information on uranium concentrations in scrub liquor, no substantial collection of these forms has been located. It is known that many original analytical laboratory data sheets, another possible source of such data, have been incinerated.

Data from the Shift Foremen's Logs were compiled and analyzed. Daily production and packaging rates have been computed from the values recorded for each shift. The number of pots gulped and the reported production of orange oxide were used to estimate the quantity packaged per pot gulped. For the three years 1960, 1961, and 1962, the average production amounts per pot were 1.11, 1.06, and 1.14 MTU. These values are somewhat lower than the value (1.17 MTU) found for 1973.

The day to day variability in the amount of material transported by the gulping system was also examined. Plant  $2/3 \text{ UO}_3$  production was full time five days a week but much lower on the weekends. There was generally more production on Saturday than on Sunday and there were outages for holidays. These data differ from those found for later years (see above).

Radiological Assessments Corporation "Setting the standard in environmental health" 11

3

3

ż

Page H–6	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3 Source Terms and Uncertainties

The daily shift log sheets (NLCO 1960-1962) also provided some information on the amount of time the scrubber systems operated. In some cases there were notations in the log that the scrubbers were shut down or started up during a particular shift. During shifts when there were no  $UO_3$  gulping activities recorded in the log, the scrubbers may have been off; however, without a notation on the log sheet it is uncertain. The fraction of the time that the other scrubbers may have been shutdown, termed the maximum scrubber outage fraction, was computed on a monthly basis using the denitration log sheet data. This fraction generally increased with time while the production rate declined. It was estimated that the actual outage time was about 75% of the maximum value derived from the logsheets. Using this assumption, the average scrubber outage fraction for the 3-year period was 0.10, which is consistent with operator estimates for periods of high production (Semones and Sverdrup 1988).

.

Π.

Ş

ひまん

.

The relationship between the production rate and the scrubber outage fraction was evaluated for production rates between 13 and 37 MTU d<sup>-1</sup> during the 30 months of operation in 1960–1962. In Figure H-2, the estimated scrubber outage fraction  $(f_o)$  is plotted as a function of the average daily production. The best fit line through the data points (lower line in figure) has an intercept of 0.287 ± 0.035 and a slope of -0.00586 ± 0.00123 (d MTU<sup>-1</sup>). The correlation is not extremely strong (r<sup>2</sup> = 0.45).



Figure H-2. Observed dependence of the scrubber outage fraction  $(f_o)$  on the average amount of UO<sub>3</sub> gulped (P', MTU d<sup>-1</sup>). The points are monthly average values from 1960–1962, with the best-fit line shown. The equation of the line is  $f_o = 0.29 - 0.0059 P'$ .

The scrubbers did not operate during periods when the plant was shut down ( $f_o = 1$ ). Estimation of the outage fraction for production rates between zero and those shown in Figure H-2 is discussed in a later section.

#### Appendix H

Discharges from Plant 2/3 Denitration Operations

#### Review of Operational Data for 1956-1959 and 1967

Nearly complete sets of Operator's Shift Logs for the years 1959 (NLCO 1959) and 1967 (NLCO 1967) were found in the archives. These were reviewed to ascertain if additional information on the duration of the gulping process for a pot of orange oxide. Data for 1959 were of particular interest because only natural uranium was processed during that year. Two pot lines and the associated scrubbers were operating in both years. The times at which gulping and charging were completed were recorded, but, unfortunately, times for the start of gulping were not. The logsheets do support heating times that are longer than the value of 6 hours that had been previously assumed by Semones and Sverdrup (1988).

Partial records from the denitration area of Plant 2/3 were found for the years 1956, 1957, and 1958. These logsheets contained information on the numbers of pots gulped and hoppers of product filled, but no information on the times required to perform operations. Notations on the logsheets indicated that denitration times were sometimes lengthened by lowering the heat input to the pots.

The logs indicated the collection of samples, but no analytical results were included. Some data on the concentrations of uranium in the UNH charge to the pots. However, like the heating time, these data are not critical to the calculations of releases from the Plant 2/3 scrubbers.

#### **Review of Effluent Measurements**

No evidence of early measurements of the discharge of uranium from the Plant 2/3 scrubber exhausts has been found. Although numerous measurements of scrubber efficiency were made in Plant 8 during the 1960s and again in the 1980s (see Appendix I) it appears that no comparable measurements were made in Plant 2/3. At this time, the only known effluent monitoring results available for the Plant 2/3 scrubber exhausts are those that were made in 1988 (Semones and Sverdrup 1988).

Two operational conditions were studied by Semones and Sverdrup (1988). The first was operation of the scrubber system alone without operation of the  $UO_3$  gulping system. Because the scrubber system was also used to remove oxides of nitrogen and convert them to nitric acid that was recycled, the system operated while the UNH was being heated to produce  $UO_3$ . Uranium was present in the scrub liquor at these times and could be discharged to the environment as the result of entrainment of mist from the scrubber with the exhaust airstream. The second condition studied was operation of the  $UO_3$  vacuum transfer system in concert with the scrubber system. During gulping operations, penetration of  $UO_3$  particles through the scrubber would also contribute to the quantity released. The total release would then be the sum of the two components. Only a limited number of tests were conducted to measure the reentrainment and particle penetration releases in Plant 2/3. Results of these few measurements are discussed below.

The results of two measurements during scrubber operations alone are shown in the upper part of Table H-1. Three measurements were made of the discharge rate when the scrubbers were operating alone, but isokinetic sampling conditions were not achieved

Page H–8	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3, Source Terms and Uncertainties

during the first run. The estimated release rate for that test, which was anomalously low, was not included in average release rate used by Semones and Sverdrup (1988) and is not considered here either. The normalized entrainment release rate  $[Q_e, (kg U h^{-1}) per (kg U L^{-1})]$  was obtained by dividing the uranium release rate by the uranium concentration in the scrub liquor. The average of the two estimates of  $Q_e$  (± the standard deviation) of the two estimates is  $3.40 \pm 0.38$  (kg U h<sup>-1</sup>) per (kg U L<sup>-1</sup>).

Also shown in Table H-1 are the results of measurements of the uranium release rate when both the gulping system and the scrubber system were operating. Again, one of the three measurements was deemed invalid by Semones and Sverdrup (1988) and two results are available. The net normalized releases from UO<sub>3</sub> gulping (last column) are the differences between the gross values and the average normalized release rate for operation of the scrubber alone. The products of these normalized release rates and the corresponding scrub liquor concentrations yield two estimates of the net particle release due to operation of the UO<sub>3</sub> gulping system ( $Q_g$ , kg U h<sup>-1</sup>). These estimates are shown in the lower portion of the first column. The mean (± standard deviation) of the two estimates of  $Q_g$  is 0.130±0.026 kg U h<sup>-1</sup>.

101 S

Operating	Release rate (kg U h <sup>-1</sup> )	Scrub liquor concentration (g U L <sup>-1</sup> )	Normalized r (kg U h <sup>-1</sup> ) per	elease rate (kg U L <sup>-1</sup> )
Scrubber only	0.150	48.0	3.13	· · · · · ·
, · · · · · ·	0.176	48.0	3.67	
		Average	3.40	
	••••••		~	Net due
UU <sub>3</sub> gulping with		· · · · · · · · · · · · · · · · · · ·	Gross	to gulping
scrubber	0.245	38.8	6.31	2.91
	0.209	<b>18.1</b>	11.55	8.15
UO <sub>3</sub> Gulping		2077 (1944) (194	•	· · · · · · · · · · · · · · · · · · ·
Net Values	0.113	the state of the second second	and the second	
· . ·	0.148	en esta en en en en en en		
Average	0.130	and the second second second		
	·	la dia 1912. Polo		Tri, C., i

				•	
r-hi-	TI 1 Decentes	- 6 M	1	****	Discharges
rable	n-i. Results		LOLUDE -	Uranium	Discharges
			a		
5 a. 1	£	TTI'+ O#		L	-
	- mnm the	PISTE 2/3	Schun	ner Syster	n

Measurement uncertainties were not presented in the original report (Semones and Sverdrup 1988). If the 1- $\sigma$  uncertainties associated with the release rate and scrub liquor concentration measurements were about 10% of the values, then the propagated uncertainties in the normalized release from entrainment of scrub liquor and the release rate from gulping alone would be comparable to the variability of the two estimates of each of those quantities.

#### Appendix H Discharges from Plant 2/3 Denitration Operations

#### Review of Scrub Liquor Concentration Data

<u>of data is shown in parentheses.</u>

1

.,

Although the concentration of uranium in scrub liquor was measured routinely, most of the records of this information appear to have been lost. Records of scrub liquor concentration measurements were found for parts of five years of operation: 1970, 1982, 1983, 1985, and 1987. Data from the periods of highest production would obviously be preferred, but no records for those periods have been located. Table H-2 summarizes the scrub liquor concentration data, which are included in the annex to this appendix.

	Individu	ual Measure	ments of Scr	ub Liquor C	oncentratior	$g U L^{-1}$
_	1970	1982	1983	1985	1987	Composite
Mean	34	52	134	47	63	68
Median .	. 35	43	139	45	59	57
Range	15-47	<1–134	34-242	28-72	4-124	<1–242
	(12) <sup>a</sup>	(66) <sup>a</sup>	(34) <sup>a</sup>	(32) <sup>a</sup>	(89)ª	(221) <sup>a</sup>
_	Se	et of Average	s of Scrub Li	quor Concen	tration (g U	L <sup>-1</sup> )
		37 (33) <sup>a</sup>	134 (34) <sup>a</sup>	47 (32) <sup>a</sup>	53 (30) <sup>a</sup>	
		66 (33)ª			75 (30) <sup>a</sup>	•
					59 (29) <sup>a</sup>	•

Based upon the measurements that were found, the average concentration of uranium in scrub liquor was estimated to be 0.068 kg U L<sup>-1</sup>. The median of the 221 values was 0.057 kg U L<sup>-1</sup>. As the table shows, there was substantial variation of values within each of the years. This is to be expected because of the nature of the process. Some of the concentrations were very low, <5 kg U L<sup>-1</sup>, indicating that the tank was completely drained at some times.

The desired distribution of long term average concentrations is not available. To approximate that distribution, sets of concentration measurements, shown in the lower part of Table H-2, were assembled. There were 34 and 32 measurements in 1983 and 1985, respectively. The sequential measurements in 1982 and 1987 were divided into groups of comparable size (29-33 measurements) and averaged. The seven average values were used to estimate the distribution of the average scrub liquor concentration, shown in Figure H-3. Because there were only 12 measurements in 1970, that average was not used in constructing this distribution. We believe that the breadth of the distribution is sufficient to reflect the uncertainty in our knowledge of the average scrub liquor concentration and is satisfactory for estimating annual releases from the Plant 2/3 scrubbers. Sampling from this distribution yields a mean concentration of 0.067 kg U L<sup>-1</sup>, comparable to the true mean, and a median value of 0.057 kg U L<sup>-1</sup>, the same as the median measured concentration.

Radiological Assessments Corporation "Setting the standard in environmental health"

#### Page H-9

#### Page H-10 The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties



Figure H-3. Approximated distribution of average scrub liquor concentrations (g U  $L^{-1}$ ). The distribution reflects the set of average concentrations given in the lower part of Table H-2.

#### S. S. S. A. ESTIMATES OF RELEASES

The methods used to estimate releases from the scrubbers are described below. The distributions used to characterize individual parameters are presented and discussed in the second subsection. The last subsection contains the release estimates for the Plant 2/3 scrubbers.

**Calculational Methods** 

. The release of uranium from the Plant 2/3 scrubbers is composed of releases due to scrub liquor entrainment and those due to particles of  $UO_3$  in the airstream that pass through the scrubber. Releases due to entrainment of scrub liquor  $(Q_s, \text{kg U})$  were computed using Eq. (H-1). 5 /

# $\frac{\partial Q_s}{\partial t_s} = n (1 - f_o) N_h C_s Q_{e_{1/2}} (21) \frac{\partial Q_s}{\partial t_s}$

(H–1)

in which:

a statue har eas n is the number of scrubbers operating

 $f_o$  is the scrubber outage fraction, which depends upon the production rate

 $N_h$  is the number of hours in the period

 $C_s$  is the average concentration of uranium in the scrub liquor

 $Q_e$  is the entrainment release per unit scrub liquor concentration (kg U h<sup>-1</sup>) per  $kgUL^{-1}$ ).

#### Appendix H Discharges from Plant 2/3 Denitration Operations

3-

.

-

For the years after 1977 when the plant was operating, there was normally one scrubber running; thus, n = 1 for those years. For other years of operation, the calculations use n = 2.

Before calculating the scrubber outage fraction, the average gulping rate is computed. Let P be the amount of UO<sub>3</sub> that was produced and transferred using the gulping system during the year. The units of P are metric tons of uranium (MTU). Then the average gulping rate, P' (MTU d<sup>-1</sup>), is equal to P divided by 365, the number of days in the year.

The equation used to compute the outage fraction depends upon the magnitude of P'. For values of  $P' \ge 15$  MTU d<sup>-1</sup>:

$$f_0 = a_1 - m_1 P' \tag{H-2}$$

Page H-11

From the best fit line in Fig. H-2, values of the parameters  $a_1$  and  $m_1$  are 0.29 and 0.0059, respectively. Distributions for these parameters are described below. It was assumed that for lower production rates, the outage fraction could be approximated using a straight line. Thus, for values of  $P' \le 15 \text{ MTU d}^{-1}$ :

 $f_0 = a_2 - m_2 P'$  (H-3)

was used with  $a_2 = 1$  (no scrubber operation when the plant was shut down) and  $m_2 = 0.053$ . Distributions for these parameters are described below. For P' = 15 MTU d<sup>-1</sup>, the two equations yield the same value, 0.20, within the uncertainty caused by rounding.

Figure H-4 illustrates the range of application of these two equations. Eq. (H-2), which is based upon the data plotted in Figure H-2, is used to estimate  $f_o$  for the higher average production rates. The assumed linear decline in  $f_o$  as P' increases from zero to 15 MTU d<sup>-1</sup> is shown by the dashed line.

Because the calculations are performed on an annual basis, the number of hours in the period  $(N_h)$  is 8760. The average scrub liquor concentration  $(C_s)$  and the entrainment release factor  $(Q_e)$  used in Eq. (H-1) are obtained by sampling from their distributions, which are described below.

The release due to particle escape during gulping operations  $(Q_g, \text{kg U})$  depended upon the duration of those operations and on the release factor that reflects particle penetration only  $(Q_g, \text{kg U h}^{-1})$ . That release was estimated using Eq. (H-4).

$$Q_{\gamma} = N_p T_g Q_g \tag{H-4}$$

in which  $N_p$  is the number of pots of UO<sub>3</sub> that were gulped during the period and  $T_g$  is the time (h) required to transfer all the UO<sub>3</sub> from a pot to the storage hopper.

The number of pots gulped is computed from the production, P (MTU) and the parameter k, which is the amount of uranium trioxide per pot. The relationship is  $N_p = P/k$ . The gulping time and the release fraction during gulping were obtained from their distributions, discussed below.

Page H-12

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

1.10.5

î4

×



Figure H-4. Approximated distribution of average scrub liquor concentrations (g U  $L^{-1}$ ). The distribution reflects the set of average concentrations given in the lower part of Table H-2.

The total uranium release  $(Q_e + Q_{\gamma})$  for each year of denitration operations was estimated by performing Monte Carlo calculations using Crystal Ball<sup>®</sup> (DI 1991). The program sampled each of the parameter distributions and repeatedly performed the calculations just described to produce a set of estimates of the release during each year. Totals for each decade were computed as part of the same set of calculations. The distributions of parameters used in the calculations are described below.

**Parameter Distributions** 

The distributions that were used for parameters in the calculations described above are presented below in the order of appearance of the parameters in the discussion. As noted, specific integer values are used for the number of scrubbers in operation, the number of hours in the year, and the outage fraction when there was no production.

Scrubber Outage Fraction Calculations. For the relatively high production and gulping rates,  $P' \ge 15$  MTU d<sup>-1</sup>, the calculation of  $f_0$  using Eq. (H-2) requires two parameters,  $a_1$  and  $m_1$ . The intercept for the best fit line  $(a_1)$  was represented by a triangular distribution with a mode of 0.29 and bounds of 0.22 and 0.36. The slope of the best-fit line  $(m_1)$  was also represented by a triangular distribution; the mode was 0.0059 (d MTU<sup>-1</sup>) and the bounds were 0.0084 and 0.0033 (d MTU<sup>-1</sup>).

For gulping rates lower than 15 MTU d<sup>-1</sup>, Eq. (H-3) requires a different intercept and slope,  $a_2$  and  $m_2$ , respectively. The value of  $a_2$  was taken to be one; that is, when there was no production the scrubbers did not operate. The slope of the estimation line ( $m_2$ ) was

#### Appendix H

.

;;;;

#### Discharges from Plant 2/3 Denitration Operations

represented by a triangular distribution with a mode of 0.053 (d MTU<sup>-1</sup>), between bounds of • 0.045 and 0.061 (d MTU<sup>-1</sup>). This distribution produces an uncertainty range for a gulping rate of 15 MTU d<sup>-1</sup>, that is very close to that obtained using the best fit line for the same gulping rate.

Average Scrub Liquor Concentration. The annual average concentration of uranium in scrub liquor was approximated by the distribution of short term average measurements shown in Figure H-4. Sampling from this distribution yields a mean concentration of  $0.067 \text{ kg U L}^{-1}$  and a median value of  $0.057 \text{ kg U L}^{-1}$ , both of which are comparable to the corresponding parameters for the set of available concentration measurements.

Entrainment Release Factor. There were only two measurements of the entrainment release factor. The distribution for  $Q_e$  was assumed to be uniform with a mean equal to the average of the two results in Table H-1. The mean value was 3.4 (kg U h<sup>-1</sup>) per (kg U L<sup>-1</sup>). A standard deviation of 0.6 (kg U h<sup>-1</sup>) per (kg U L<sup>-1</sup>), which is 50% greater than that computed from the two results, was used in the calculations to reflect the limited amount of information about this release fraction.

Amount of  $UO_3$  in a Pot. The distribution of k, the amount of  $UO_3$  per pot, was taken to be uniform in shape with boundaries of 1.06 and 1.17 MTU per pot. The bounds of the distribution were determined by the maximum and minimum of the four estimates of the ratio derived from Plant 2/3 logsheets and logbooks. The mean of the four values was 1.12 MTU per pot, which is consistent with the distribution selected.

Gulping Time. In the review of denitration production data, about fifty recorded values of the gulping time per pot were recorded. The mode was in the interval 70-80 minutes. The minimum time was 50 minutes. The maximum time was 130 minutes; however times in excess of 100 minutes are inconsistent with most  $UO_3$  production rates. For these calculations  $T_g$  was described by a triangular distribution with a mode of 75 minutes and a range of 50 to 100 minutes. Because the data upon which the distribution is based were recorded during processing of enriched uranium, it is possible that they may overestimate  $T_g$  appropriate to other periods. However, the distribution is based upon the best available information.

Gulping Release Factor. Only two measurements of the release rate during  $UO_3$  gulping have been made (Table H-1). The resulting estimates of the mean and standard deviation of the underlying distribution of release rates are uncertain. A uniform distribution was chosen to represent the release factor. The mean of the distribution was taken to be the mean of the two measured values, 0.13 kg U h<sup>-1</sup> (Table H-1). The standard deviation was taken to be 0.04 kg U h<sup>-1</sup>. which is 50% greater than the value computed from the two estimates, to reflect our lack of knowledge of the actual distribution.

₽,

E State

11. AN

in Annual

Sec. Sec.

Į,

#### Results of Plant 2/3 Scrubber Release Calculations

Estimates of Plant 2/3 scrubber releases obtained from the Monte Carlo calculations described above are presented in Table H-3. These estimates have been rounded to two significant figures. The best estimate for each year is given in column two of the table and is the median of the distribution of estimates for that year. Calculated releases for the first years of operation with dust collectors, prior to scrubber installation, have the added uncertainty that the present calculations are only surrogates. The highest releases are estimated to have occurred during the 5-year period between 1957 and 1961. Annual releases were nearly as high again in 1974–1976.

The median lies in the center of the distribution; half of the estimates were higher than the median and half were lower. The 5th, 25th, 75th, and 95th percentile values for each distribution are also given in Table H-3. These values, which have also been rounded to two significant figures, show the spread of the distributions and the range of release estimates for each year. There is a 50 percent chance that the release lies between the 25th and 75th percentile values and only a 10 percent chance that it lies outside the range defined by the 5th and 95th percentile values.

Cumulative probability distributions of release estimates for three years are presented as examples in Figure H-5. The vertical dotted line marks the 50th percentile or median values that are the best estimated given in Table H-3. The central parts of the three distributions are approximately straight lines. If the distributions of releases were lognormal, the plots of cumulative probability would be true straight lines. The tails of the distributions deviate more from the central slope of the lines, indicating deviations of the distributions from lognormality. The slopes of all three lines are comparable, which implies that the uncertainties are about the same for these years, and this is true for other years as well.

The median release estimates for each year between 1952 and 1988 are plotted in Figure H-6. As noted, the largest releases are estimated to have occurred during the late 1950s and early 1960s, with another period of substantial releases in the mid-1970s. The plot of annual release estimates is similar to that for annual production amounts (Fig. H-1).

Table H-4 contains summary release estimates by decade and for the entire period from 1952 to 1988. The estimates for each decade, also rounded to two significant figures, were obtained by summation as part of the Monte Carlo calculations of the annual releases. The distribution of estimates for the period 1952–1988 is also the result of Monte Carlo calculations using the distributions of releases for each of the four decades. These estimates do not correspond to simple arithmetic sums of medians or particular percentile values. The shapes of the distributions of the sums for each decade and (especially) for the whole period approach the normal distribution. The table shows that releases during the first three decades were comparable. Releases for -1978 and later years were relatively small and the total for the 1980s is much smaller than for the other decades.

1.1

## Appendix H Discharges from Plant 2/3 Denitration Operations

I

z

•••

	Table H-	-3. Annual Relea	se Estimates for 1	Plant 2/3 Scrubbe	2 <b>rs</b>
	Best estimate	Other percen	ntiles in distributi	<u>on of release esti</u>	mates (kg U)
Year	(kg U)	5th percentile	25th percentile	75th percentile	95th percentile
1953	200	. 120	160	270	460
1954	1,200	750	990	1,600	2,800
1955	2,700	1,700	2,200	3,700	6,000
1956	3,700	2,300	3,000	5,000	8,100
1957	4,200	2,600	3,500	5,500	8,800
1958	4,600	2,800	3,800	5,800	9,400
1959	4,800	3,000	3,900	6,100	9,700
1960	4,800	3,000	3,900	6,100	9,600
1961	4,300	. 2,600	3,500	5,600	9,100
1962	1,800	1,100	1,500	2,300	3,900
1963	<b>0</b> ª .	а.	a · _	а	. <b>a</b>
1964	170	100	140	230	390
1965	590	370	480	800	1,300
1966	1,000	610	800	1,300	2,300
1967	1,600	960	1,300	2,100	3,600
1968	1,700	1000	1,300	2,200	3,800
1969	930	<b>550</b> -	730	1,200	2,000
1970	540	320	420	710	1,200
1971	1,100	670	890	1,500	2,600
1972	2,000	1,200	1,600	2,600	4,400
1973	3,300	2,000	2,700	4,400	7,400
1974	3,900	2,400	3,200	5,100	8,300
1975	4,200	2,600	3,400	5,500	, 8,700
1976	3,700	2,300	2,900	<b>4,900</b>	<b>8,000</b>
1977	1100	6 <b>20</b>	830	1,400	2,300
1978–9	$0^{\mathbf{a}}$	a	a	а	a
1980	10	· 6	8	13	<b>20</b>
1981	51	30	41	. 65	100
1982	81	51	<b>66</b>	100	160
1983	160	. 98	130	200	310
1984	470	280	380 ,	620	1,100
1985	43	26	35	55	85
1986	17	10	14	22	33
1987	.60	. 38	<b>49</b>	. 75	120
1988	29	.18	24	37	58

There was no production of uranium trioxide during these years.

Radiological Assessments Corporation "Setting the standard in environmental health"

.

2

÷.

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

51

÷

Ē.

...

あったち

1. N. P.

ŧ.

\$









the fr

Appendix H	Page H-17
Discharges from Plant 2/3 Denitration Operations	5

	Best estimate of release	Other percen	tiles in distributi	ons of release est	imates (kg U)
Period	(kg U)	5th percentile	25th percentile	75th percentile	95th percentile
1950s	24,000	18,000	21,000	26,000	32,000
1960s	19,000	14,000	17,000	21,000	25,000
1970s	22,000	17,000	20,000	25,000	29,000
1980s	980	730	850	1,100	1,600
1952-					
1988	66,000	56,000	62,000	71,000	78,000 ·

#### ALTERNATIVE CALCULATION OF THE OUTAGE FRACTION

برج.

:

Alternative outage fraction calculations were performed to evaluate the effect of changing the range of applicability of Eq. (H-2). As shown in Figure H-4, for the results reported above, it was applied for P' > 15 MTU d<sup>-1</sup>.

• To test the effect of extrapolating the best-fit line to lower values of P', alternative calculations were performed. For these calculations, it was assumed that Eq. (H-2) applied for P' > 8 MTU d<sup>-1</sup>. The alternative calculations did not require changes in the distributions of parameters  $a_1$ ,  $m_1$ , or  $a_2$  however, it was necessary to revise the slope ( $m_2$ ) in Eq. (H-3) to fit its new domain of 0 < P' < 8 MTU d<sup>-1</sup>. A triangular distribution, with a mode of 0.095 d MTU<sup>-1</sup> and bounds of 0.083 and 0.11 d MTU<sup>-1</sup>, was used for the parameter  $m_2$  in the alternative calculations.

In general, the alternative approach produced somewhat higher release rates because some of the estimated outage fractions were lower and the corresponding entrainment release estimates (Eq. (H-1)) were higher. The greatest change of a median estimate for a decade was from 19,000 to 24,000 kg U for the 1960s. This was due primarily to differences in the estimates for 1962, 1967, and 1968. For those years, the production rates were near 8 MTU d<sup>-1</sup> and the differences in computed values of  $f_o$  were largest. All of the alternative median estimates lie within the bounds of the distributions of the original estimates presented in Tables H-3 and H-4.

#### PHYSICAL CHARACTERISTICS OF THE RELEASED URANIUM

There are two principal components to the release of material from the Plant 2/3 scrubbers to the atmosphere. The first is the particles of  $UO_3$  that penetrate the system. The calculations of scrubber releases described above indicate that this component accounts for about one-fourth of the total U release from the scrubbers. In years of low production, it is

Page H–18	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3. Source Terms and Uncertainties

estimated that the fraction was as low as 0.2. For years of high production, the corresponding fraction of the U release is estimated to be 0.3.

There are no reported measurements of the particle size distribution of the effluents from the Plant 2/3 scrubbers. The geometric mean physical diameter of the  $UO_3$  aggregates transferred in the Plant 2/3 gulping operation was reported to be 22  $\mu$ m (Semones and Sverdrup 1989). The particle size of material entering the scrubber would be small relative to the  $UO_3$  product because of passage through the two cyclone separators upstream of the scrubber system. To estimate penetration of particles through the two cyclones that were upstream of the scrubber, it was assumed that the geometric standard deviation of the product particle size distribution was 3. Using data on cyclone performance from Lund (1971), it was estimated that the two cyclones should have removed about 90% of particles having a diameter of 5  $\mu$ m and greater percentages of larger particle size fractions. Based upon the efficiencies reported for particle removal by venturi scrubbers (Lund 1971), about 90% of the UO<sub>3</sub> particles that passed through the scrubbers would have physical diameters less than 2  $\mu$ m. The diameter of more than 99% of the particles is estimated to be less than 5  $\mu$ m. The median diameter was estimated, by extrapolating the slope of the censored distribution, to be about 0.5  $\mu$ m.

¥22

14.55

かいたいと

A 61.1.1.1.1.1.

٤

í.

The wire screen mist eliminator used in the Plant 2/3 scrubber stacks was estimated to have a peak efficiency of 99% at an exhaust velocity of 3-4 m s<sup>-1</sup>. Thus nearly all of the small droplets of uranyl nitrate exiting the scrubber would be expected to impact the screen in the mist eliminator. However, the operating velocities were 6-12 m s<sup>-1</sup>, which would have increased reentrainment of liquid from the mist eliminator and reduced the overall efficiency. It was estimated that an overall efficiency of about 60% was appropriate for the operating conditions that prevailed (Semones and Sverdrup 1988). Nearly all of the release observed when only the scrubber was operating (see Table H-1) would have been due to reentrainment of liquid that had been trapped in the mist eliminator. The release calculations indicate that about three-fourths of the total U release was by this mechanism. The range of that fraction is estimated to be from 0.7 to 0.8 for years of high and low production, respectively.

Reentrained mist droplets are reported to be generally greater than 100  $\mu$ m in diameter (Black and Strauss 1981). Droplets from the Plant 2/3 scrubber system exhaust contained uranyl nitrate in nitric acid solution. They would have shrunk during downwind plume travel as a result of evaporation from their surfaces. Complete loss of liquid would leave solid uranyl nitrate hexahydrate (UNH) crystals in the plume. Calculations indicate that even the larger reentrained droplets would have dried by the time the plume had traveled a few hundred meters. The rapid crystallization of UNH from the liquid would result in a polycrystalline mass that could break apart during plume travel.

Calculations were made to estimate the size of solid particles that could be produced from the reentrained mist. It was assumed that the reentrained droplets had diameters that ranged from 80 to 180  $\mu$ m. Table H-2 shows that uranium concentration in the scrub liquor that are known have a median value of 57 g L<sup>-1</sup>. The geometric standard deviation of the distribution of those measurements is about 1.8. The uranium concentration range within two GSDs of the median is 17-180 g L<sup>-1</sup>. Using a density of 2.8 g cm<sup>-3</sup> for UNH, that range of concentrations, and the stated range of droplet diameters, the diameters of solid UNH

#### Appendix H

#### Discharges from Plant 2/3 Denitration Operations

ź

13

spherical particles that could be produced was estimated to vary between 29 and 53  $\mu$ m, with a central value of 41  $\mu$ m.

#### CONCLUSIONS

. .

÷.

.

Releases from the scrubbers serving the Plant 2/3  $UO_3$  gulping system were recognized only recently and were not sampled prior to 1988. Limited measurement data from that time formed the basis of models of effluent release processes. Plant 2/3 Foreman's log sheets and logbooks were found that contained information on parameters important for the calculation of releases due to the gulping operation. Data on scrub liquor uranium concentrations, required to estimate part of the releases, were also recovered for portions of five years of operation.

Independent estimates of releases from the Plant 2/3 scrubber system were performed using models of scrubber penetration by particles and mist reentrainment. Monte Carlo calculations produced distributions of release estimates for each year, each decade, and for the entire period, 1952–1988. Median estimates of releases during three of the four decades of operation were comparable, about 20,000 kg U, while the value for the 1980s was much lower. The median release estimate for the entire period of operation was 66,000 kg U. This estimate was bounded by 5th and 95th percentile values of 56,000 and 78,000 kg U, respectively.

About 25% of the release is estimated to have been small (< 5- $\mu$ m) particles of UO<sub>3</sub> that penetrated through the scrubber. The larger fraction (~ 75%) would have been UNH particles produced by evaporation of entrained droplets of scrub liquor. The approximate size range for these particles is estimated to be between 29 and 53  $\mu$ m. The physical stability of these large particles during transport in the atmosphere is not known.

#### REFERENCES

- Boback, M. W.; Dugan, T. A.; Fleming, D. A.; Grant, R. B.; Keys, R. W. History of FMPC radionuclide discharges. Cincinnati, OH: Westinghouse Materials Company of Ohio; Document FMPC-2082 (Revision to FMPC-2058); May 1987.
- Black, G. M.; Strauss, W., eds. Air pollution control, part IV. New York: John Wiley & Sons, Inc.; 1981.
- Cahalane, R. W. Process description denitration area. Cincinnati, OH: National Lead Company of Ohio; Specification No. 3A-103; FMPC Manufacturing Standards; 20 February 1957.
- Clark, T. E.; Elikan, L.; Hill, C. A.; Speicher, B. L. Addendum to FMPC-2082, history of FMPC radionuclide discharges; revised estimates of uranium and thorium air emissions from 1951-1987. Cincinnati, OH: Westinghouse Materials Company of Ohio; March 1989.

1

12

開い記

に行うた

7

Ì.

- DI (Decisioneering, Inc.). Crystal Ball<sup>®</sup>, a forecasting and risk management program for the Macintosh, version 2.0. Boulder, CO: Decisioneering, Inc.; 1991.
- ECT. Encyclopedia of chemical technology. 3rd ed. New York: John Wiley & Sons, Inc.; 1978.

Hicks, W. R. Process description — the fume scrubbing system in the denitration area. Cincinnati, OH: National Lead Company of Ohio; Specification No. 3A-203; FMPC Manufacturing Standards; 20 February 1957.

the first of the second second second second

Sec. Const.

Investigation Board. Investigation report on Plant 2/3 gulping emission at the Feed Materials Production Center, June 1988. Oak Ridge, TN: U. S. Department of Energy; Document DOE-ORO-897; November 1988.

Lund, H. F. Industrial pollution control handbook. New York: McGraw Hill, Inc. 1971.

- NLCO (National Lead Company of Ohio). Ore refinery Plant 3, shift foremen's log. Cincinnati, OH: National Lead Company of Ohio; 1956-1959.
- NLCO (National Lead Company of Ohio). Ore refinery denitration area, shift foremen's log. Cincinnati, OH: National Lead Company of Ohio; 1960-1962.
- NLCO (National Lead Company of Ohio). Ore refinery denitration area, shift foremen's log. Cincinnati, OH: National Lead Company of Ohio; 1967.
- NLCO (National Lead Company of Ohio). Operator's logbook 2691, UO<sub>3</sub> production (2%). Cincinnati, OH: National Lead Company of Ohio; 1969.
- NLCO (National Lead Company of Ohio). Operator's logbook 2694. Cincinnati, OH:. National Lead Company of Ohio; 1970.
- NLCO (National Lead Company of Ohio). Operator's logbook 2344 denitration. Cincinnati, OH: National Lead Company of Ohio; 1973.

Perry, R. H., Green, D. W.; Maloney, J. O., eds. Perry's chemical engineers' handbook. 6th ed. New York: McGraw Hill Book Company; 1984.

Semones, T. R. and Sverdrup, E. F. Uranium emissions from gulping of uranium trioxide. Cincinnati, OH: Westinghouse Materials Company of Ohio; Document FMPC/Sub-019; December 1988. ö

#### ANNEX TO APPENDIX H -- SCRUB LIQUOR DATA TABULATION

Table H1-1 contains the data on uranium concentrations in Plant 2/3 scrub liquor that were found in laboratory data records for 1982. Sampling times were not generally given so the sequence of multiple samples on the same day is not known and should not be presumed from the ordering of the data in the table.

Table H1-2 contains the data on uranium concentrations in Plant 2/3 scrub liquor that were found in laboratory data records for 1983 and 1985. Sampling times were generally not given so the sequence of multiple samples on the same day is not known and should not be presumed from the ordering of the data in the table.

Table H1-3 contains most of the data on uranium concentrations in Plant 2/3 scrub liquor that were found in laboratory data records for 1987. Sampling times were generally not given so the sequence of multiple samples on the same day is not known and should not be presumed from the ordering of the data in the table. The remainder of the data from 1987 and a smaller number of values form 1970 are contained in Table H1-4.

	1	The Ferna	ald Dosir	netry R	econstr	uction Projec	:t
	Tasks	2 and 3,	Source	Terms	and U	<u>ncertaintie</u>	S
 	- <b>v</b> - v	1 . 7	• •	•••		- :	

÷.

1.1.1

19 19 A

1400 A

241X11X14

•.

Page H-22

1982	Concentration	1982	Concentration
Date	(g U L <sup>-1</sup> )	Date	(g U L <sup>-1</sup> )
19 June	64.9	22 September	76.8
19 June	<b>50.3</b>	23 September	_<1
21 June	46.1	23 September	87.7
22 June	31.9	23 September	99.3
22 June	26.6	24 September	· <1
23 June	29.2	24 September	106
23 June	26.6	24 September	111
23 June	24.1	24 September	<1
24 June	31.3	25 September	107
24 June	36.8	25 September	82.1
25 June	34.7	25 September	<1
25 June	39.3	18 October	. 8
25 June	30	19 October	26.3
26 June	<b>32.1</b> ·	20 October	58.3
26 June	35	21 October	93.3
26 June	35.1	22 October	125
28 June	23.7	26 October	105
28 June	29.2	27 October	134
29 June	21.6	28 October	46.8
29 June	35.4	29 October	78.9
29 June	37.1	1 November	34.1
30 June	24.3	2 November	66.2
30 June	23.5	4 November	71.2
2 July	21.8	5 November	78.1
2 July	16.9	8 November	79.3
6 July	25.4	9 November	71
6 July	26.2	10 November	106
7 July	28.7	10 November	49.1
September	59.7	11 November	46.5
September	99.2	12 November	54.6
September	104	15 November	67.4
September	73.4	16 November	77.7
September	<1	`	•
September	51.1	,	

. ...

## Appendix H Discharges from Plant 2/3 Denitration Operations

ŕ

1983	Concentration	1985	Concentration
Date	(g U L-1)	Date	(g U L <sup>-1</sup> )
1 March	33.8	27 February	31.3
15 March	58.4	27 February	<b>33.3</b> ·
16 March	67.1	27 February	53.2
17 March	78.4	27 February	41.6
18 March	58.4	28 February	32.6
18 March	81.5	28 February	28.1
21 March	85	28 February	34.4
22 March	90.8	1 March	30.5
23 March	130	1 March	40.4
24 March	157	4 March	44.9
25 March	178	4 March	59.5
28 March	242	4 March	46.8
28 March	178	5 March	63.1
29 March	194	5 March	72.4
29 March	· 204	6 March	44.9
31 March	129	6 March	_ 45.3
11 April	158	7 March	50.4
14 April	184 .	7 March	60.3
15 April	177	7 March	44.9
4 May	<b>110</b> (c) (c)	8 March	53.2
4 May	114	11 March	65.2
5 May	150	11 March	36.5
6 May	188	12 March	45.3
9 May	188	12 March	50.5
10 May	197	13 March	43.5
11 May	132	14 March	40.3
12 May	149	15 March	37.3
13 May	192	18 March	49.8
1 June	203	19 March	59.9
3 June	145	20 March	55.1
3 June	133	21 March	52.5
3 June	86.7	22 March	47
6 June	47.8		
7 June	52.2	•	

Table H1-2. Concentrations of Uranium in Plant 2/3 Scrub Liquor in 1982 and 1985

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

112 CA . 2000

14 A 16

LOW Y

533249

1987	Concentration	1987	Concentration
Date	(g U L <sup>-1</sup> )	Date	(g U L <sup>-1</sup> )
5 May	39	22 May	91.8
7 May	29.3	28 May	90
7 May	22.1	28 May	93.9
11 May	76.3	29 May	88.5
11 May .	74.1	29 May	89.8
12 May	124	29 May	96.9
13 May	33.9	1 June	89
13 May	36.1	1 June	98.1
13 May	37.8	- 1 June	88.1
13 May	41	2 June	114
13 May	40	2 June	115
13 May	14.9	2 June	114
14 May	25.4	2 June	114
14 May	27.9	2 June	117
15 May	40.3	3 June	117
15 May	39.1	6 July	· 81.2
15 May	38.4	6 July	<b>2</b> 5 <sup>'</sup>
15-May	114	6 July	25.6
15 May	44.4	.7 July	38,8
18 May	43.1	7 July	30.5
18 May	42.3	7 July	38.4
19 May	50.1	8 July	56.8
19 May	58.7	8 July	41
19 May	42	8 July	43.3
20 May	•56.4	9 July	60.8
20 May	59.2	9 July	51.2
20 May	49.5	9 July	55.3
21 May	. 81.3	10 July	71.4
22 May	102	10 July	68
22 May	109	10 July	- 81.2

· · ·

Page H-24

### Appendix H Discharges from Plant 2/3 Denitration Operations

1987	Concentration	1970	Concentration
Date	(g U L <sup>-1</sup> )	Date	(g U L <sup>-1</sup> )
.1 July	67.6	11 August	15
11 July	63.8	13 August	18
l I July	74.8	14 August	24
l 1 July	3.8	16 August	29
2 July	60.6	17 August	35
July	60.5	30 August	34
July	67.6	31 August	42
3 July	65.2	2 September	45
3 July	57.6	3 September	43
4 July	. 71	5 September	47
4 July	66.6	6 September	35
5 July	72.8	9 September	37
5 July	.62.4		
July	59.2		
July	51:4		
July	46		
July	54.4		
July	74		
ugust	29.3		·
ugust	31		
ugust	48	•	
ugust	32		
August	52		
ugust	74.4		
August	68.6		
August	98.4		
August	39		
August	97		
lugust	62.4	•	.*

#### APPENDIX I

#### RELEASES FROM PLANT 8 SCRUBBER SYSTEMS

#### INTRODUCTION .

.

•

<u>ي</u>

Several of the high temperature and other exhausts from Plant 8 were discharged through scrubber systems. In these systems the exhaust air is cleansed, or scrubbed, by contact with droplets of liquid. This liquid, called the scrub liquor, scavenges reactive gases and particles that are in the airstream. Table I-1 contains a listing of the Plant 8 scrubbers and the process equipment serviced by each of them. The first six scrubbers listed handled hot exhaust gases from the kiln and furnaces. Scrubbers from this group were among the most important sources of uranium releases to the atmosphere from Plant 8 and are the subject of this appendix.

Table I-1. Exhaust Air Scrubbing Systems for Plant 8					
Scrubber	Equipment		Equipment		
designation	number	Scrubber type	served		
Rotary kiln	735-43-9F	Ejector-venturi	Rotary kiln		
Oxidation #1	D43-205	Ejector-venturi	Oxidation furnace #1		
Caustic	F43-6	Ejector-venturi altered	Primary calciner;		
(primary calciner)		by NLO	box, muffle, and		
		-	Graphite furnaces		
UAP furnace	735-43-1F	NLO special design	UAP furnace		
		ejector-venturi			
Oxidation #2	D-8N1-1000 or	Turbulaire-Doyle	Oxidation furnace #2		
(NPR)	735-43-8031	-			
Green salt reverter		Ejector-venturi	Green salt reverter		
		•	furnace		
Old digester	735-43-16B	Ejector-venturi	Leach tank		
New digester	FG-101	Eiector-venturi	Digester		
ADU	W8-42	Packed tower	ADU system digester		
Leach tank	W8-36	Packed tower	Leach tank		

The last four scrubbers in the table treated ventilation air collected above digestion and other process tanks. Packed towers, with counter-current flow of exhaust gases and scrub liquids, are particularly useful for removal of gases from the exhaust stream. Fumes collected above the digesters and leach tanks could be effectively removed by such systems. Packed tower scrubbers can be plugged by dust and are not suitable for exhausts containing high concentrations of particulate material (Danielson 1973, CIV 1980). The much smaller releases from these scrubbers are considered in Appendix K.

*₹1* 

E.

10 M M

.

4

0.13.14

#### DESCRIPTIONS OF PLANT 8 SCRUBBER SYSTEMS

Early FMPC Manufacturing Standards, which contained process and equipment descriptions and drawings, show that furnace discharges were generally routed through a cyclone or knockout drum to remove large particles from the exhaust gas before it entered the scrubber. One system not having this design feature was the Box Furnace, which was serviced by the large caustic scrubber. The scrubbers were installed for two purposes: to neutralize acidic off-gases from the furnaces and to scrub out any entrained solids for recovery of uranium. However, the first purpose, fume scrubbing, was mentioned most prominently in the early descriptions of system operation. Caustic soda solution, with an initial concentration of 10%, was used as the scrub liquor (Calhane 1958a, 1958b, 1962; Harvey, Heareth and Hicks 1958; Hicks 1958a, 1958b, 1958c, 1958d, 1958e, 1958f).

The operation of ejector-venturi scrubbers is described by Perry, Green, and Maloney (1984), who note that these devices are widely used as gas adsorbers. (In some earlier editions of Perry's Handbook, the device is referred to as a water-jet scrubber). The jet of scrub liquor from the spray nozzle provides a draft that draws the air to be cleaned into the scrubber. At the FMPC, the downward facing nozzle and exhaust gas-droplet contact section was described as the obnoxious vapor condenser (OVC). Impaction of droplets and pollutants in the exhaust air results in pollutant removal and collection in the scrub liquor, which entered at one end of the scrubber hotwell. Exhaust fans withdrew the scrubbed air at the opposite end of the hotwell. Although not shown in the generic drawing in Perry, Green, and Maloney (1984), barriers to carryover of scrub liquor droplets were components of most of the scrubber systems of interest.

Table I-2 contains reported feed rates for the furnaces in Plant 8. Three sources of information on furnace capacities have been found and are tabulated. The first is the set of FMPC Manufacturing Standards prepared in 1959 by the Quality Control Group (1959a, 1959b, 1959c, 1959d, 1959e, 1959f, 1959g). These contain rated uranium feed rates for seven pieces of equipment. The only capacity stated for the calciner was for total material, namely 21,600 kg d<sup>-1</sup>.

The second and third sets of capacity data are taken from the history of residue recovery operations in Plant 8 (Mead 1972) and from a report by Savage (1975) that specifies FMPC equipment capacities. These sets of estimates show variations in capacity depending upon feed type. While of historical interest and included in Mead (1972), no estimates for the graphite furnace or green salt reverter are given in the 1975 data set. The graphite furnace was shut down in 1960 and the reverter only operated between 1956 and 1958 (Mead 1972).

The largest difference among the estimates is the very large rated feed rate given for the UAP Furnace in the 1959 specification, which is about 2.5 times larger than the values given later. Levy's transmittal memo (1975) for the Savage report states that the capacities were based on "actual previous experience" and may better reflect the true capacity of the equipment. Problems with operation of the UAP furnace were attributed in part to overloading it (Noyes 1962). Noyes states that the original capacity of that furnace for ammonium diuranate (ADU) cake was '108 lb 'U h<sup>-1</sup> (1170 kg U d<sup>-1</sup>), but that the throughput in June 1962 was 380 lb U h<sup>-1</sup> (4100 kg U d<sup>-1</sup>).

#### Appendix I Releases from Plant 8 Scrubber Systems

Table I-2. Esti	mated Production	Capacities	for Equipment i	n Plant 8
Equipment description	Rated feed rate (kg U d <sup>-1</sup> ) <sup>a</sup>	Feed type <sup>b</sup>	Capacity (kg U d <sup>-1</sup> ) <sup>c</sup>	Capacity (kg U d <sup>-1</sup> ) <sup>d</sup>
Box furnace	380	B	270	270
Muffle furnace	330	A, B, C	320	320
Graphite furnace	370	A, B	360	e
Calciner (for ADU)	e	C	1620	1620
Rotex screen output	e	В	7660	7660
Hydromet. prep.	e	С	e	5400
UAP furnace	3600-4500	С	1620	1620
Rotary kiln	600	. <b>A</b>	1690	1690
-	е	В	3380	3380
	e	С	1180	1180
Oxidation furnaces	1150	Α	900	900
	e	В	1170	1180
Green salt reverter	630	D	720	e

<sup>a</sup> Rounded estimate from rated capacities (lb U d<sup>-1</sup>) in FMPC Manufacturing Standards (Quality Control Group 1959a-g); variation with feed type not specified.

<sup>b</sup> A: high grade metallic sludges; B: high grade residues and compounds; C: low grade residues and compounds and "unlimited;" D: scrap UF<sub>4</sub>.

<sup>c</sup> Rounded estimate based on equipment capacities (U tons d<sup>-1</sup>) in Mead (1972).

<sup>d</sup> Rounded estimate based on stated capacities (U tons d<sup>-1</sup>) in Savage (1975).

<sup>e</sup> No estimate provided.

1

2

Processing rates are included in reports of recent stack exhaust measurements (Rakiewicz, Jackson, and Phoenix 1988a–e). Extrapolated to a 24-hour schedule, these correspond to about 270 kg U d<sup>-1</sup> for the oxidation furnace, 650 kg U d<sup>-1</sup> for the box furnace, 9800 kg U d<sup>-1</sup> for the rotary kiln, and a maximum of 8900 kg U d<sup>-1</sup> for the calciner. The estimated throughput for the oxidation furnace is lower than the values in Table I–2, while the values for the box furnace and rotary kiln are two to three times the tabled values. The calciner throughput was increased consistently as the tests progressed. A report by Adams (1975) indicates an ore concentrate calcining rate of about 12,000 kg d<sup>-1</sup> for the rotary kiln.

The discharges from the scrubber system exhaust blowers were not sampled on a regular basis. Periodic measurements of discharge concentrations and of scrubber efficiencies were performed by the Industrial Hygiene and Radiation Department. A number of their measurements for the caustic, kiln, UAP, and NPR scrubbers were made during the early 1960s, a period of substantial concern about releases of uranium from these systems. These are discussed later in this appendix.

In the early 1980s, when Plant 8 production was lower, measurements were made to determine emission factors for the Plant 8 scrubber discharges (Ross 1982, 1983). Application of the factors was based on the duration of furnace charging operations (Bardo 1985, 1986). It was assumed that most of the releases occurred during charging. Several source emission tests using EPA Method 5 were conducted for scrubber exhausts just prior. to shutdown of the FMPC operations (Rakiewicz, Jackson, and Phoenix 1988a-e). These

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page I-3

Page I-4	The Fernald Dosimetry Reconstruction Project
·	Tasks 2 and 3, Source Terms and Uncertainties
	· · · · · · · · · · · · · · · · · · ·

recent measurements led to the development of new emission factors (Beirne 1988, Bonfer 1988, Hill 1989). Emission factor estimates are also discussed in a later section.

Various scrubber efficiency estimates have been used to estimate releases to the atmosphere from the Plant 8 scrubbers during the early years. The following sections discuss those estimates, plant operational information related to release estimates for these systems, the efficiency measurements, and calculation of release estimates for this report.

#### PREVIOUS RELEASE ESTIMATES

The calculation of most of the releases from the Plant 8 scrubbers has employed estimates of scrubber efficiency together with measurements of the amounts of uranium that were collected in the scrub liquor. Let  $M_s$  be the amount of uranium (kg) found in the scrub liquor at the end of a specified period and let  $\varepsilon$  be the efficiency of the scrubber during the period. If these two quantities are known, then the release from the scrubber to the atmosphere during the period (Q, kg) can be calculated from mass balance considerations. If I is the amount of airborne uranium (kg) that entered the scrubber, then

$$Q = I - M$$

For operation at a constant efficiency,  $M_s = \varepsilon I$ ; therefore,

$$Q - M_s \frac{(1-\varepsilon)}{\varepsilon}$$
(I-2)

ŢŦ

1.0%

1

.

Į,

Ŀ

(I - 1)

A similar expression can be derived in terms of the penetration, p, the fraction of the material entering the scrubber that passes through the system and is discharged in the exhaust  $(p = 1 - \varepsilon)$ . It has been pointed out (Randle 1971, Anonymous 1989) that this calculation, made with no knowledge of either I or Q, is susceptible to substantial undetected error if  $\varepsilon$  is much less than the presumed value. For small values of  $\varepsilon$ , the equation is also unreliable because  $(1 - \varepsilon)/\varepsilon$  increases without limit as  $\varepsilon$  approaches zero. This leads to large overestimates of Q; in reality, Q can not exceed I.

Many estimates of uranium releases from the Plant 8 scrubbers were based on an estimated scrubber efficiency of 83%. This value, which is the midpoint of the range of 70 to 95 percent efficiency specified by one of the manufacturers, was used by the FMPC for an extended period of time for all of the scrubbers (Vath 1964c, Randle 1971, Diehl 1980). Although it was recognized that the feed material and operational conditions had an effect on scrubber efficiency, those effects were not quantified and considered on a routine basis. In an initial investigation, Vath (1964a) considered the range of quoted efficiencies (70 to 95%) as well as the average value. His estimate for the average value was a monthly release of about 610 kg (1340 lb); his estimated range of monthly releases was about 160 to 1270 kg (about 340 to 2800 lb).

The results of special measurements were used in some contemporary estimates of releases. Measured efficiencies of 95, 69, and 79 percent for the rotary kiln, UAP, and caustic scrubbers, respectively, were used by Starkey (1961) to estimate a monthly release of about 460 kg (1005 lb) from the scrubbers to the atmosphere. Starkey (1964) estimated a total

#### Appendix I Releases from Plant 8 Scrubber Systems

monthly loss from Plant 8 of about 660 kg (1460 lb). A comparable monthly release estimate of 1500 lb (~ 680 kg) is quoted in a contemporary letter to the Atomic Energy Commission by Noyes (1964) related to material accountability difficulties in Plant 8. Vath (1964c) also developed a revised estimate of 680 kg per month in a subsequent memorandum related to uranium accountability. Hill (1989) reported that at the end of fiscal year (FY) 1964, an inventory difference of about 58,000 kg of uranium was attributed to scrubber losses during previous years of operation.

In the compendium of FMPC releases, document FMPC-2082 (Boback et al. 1987), the total Plant 8 scrubber releases in early periods of operation are given by fiscal year. During a subsequent review, the calculations for FMPC-2082 could not be located, but it was reported to the reviewer that the amount written off at the end of FY 1964 had been distributed over the fiscal years 1954-1964 (Hill 1989). The sum of the releases reported in Boback et al. (1987) for those fiscal years is about 20,000 kg.

The rounded values from a handwritten tabulation of inventory adjustments (Courtney 1964) are shown in Table I-3. The inventory adjustments were assigned to FY 1964, but it was recognized that the losses had occurred over a number of years of previous operations. The amount attributed to unmeasured scrubber and vent losses was about 37,000 kg, roughly 64% of the total write-off in that category reported by Hill (1989) and 181% of the total scrubber emissions presented in Boback et al. (1987). The totals given agree approximately with amounts determined from the formal inventory withdrawal records (Gessiness 1964, Noyes 1964). For natural uranium, the FY 1964 write-off was about 130,000 kg U; for enriched uranium about 32,000 kg were removed from the inventory. The enriched uranium losses were later distributed by Vath (1966) to the fiscal years 1961-1965. The fractions of the loss attributed to the four fiscal years were 0.142, 0.157, 0.190, and 0.511, respectively.

	Plant 8 inventory adjustment (kg) <sup>b</sup>		
Adjustment category	Natural U	Enriched U	
Liquid effluent	33,000	. 17,000	
Barren filter cake	23,000	4,000	
Burn pit losses	44,000	3,000	
Scrubber and		•	
vent losses	29,000	8,000	
All_categories	129,000	32,000	

Table I–3.	Compilati	on <sup>a</sup> of Inve	entory Adj	ustments	to Account fo	r
Unmeas	sured Loss	es During ]	Previous J	lears Prio	r to FY 1964	

<sup>a</sup> Courtney (1964).

....

2

<sup>b</sup> Values have been converted from original tabulations in pounds of uranium and rounded to the nearest thousand kilograms. Although original values were given to four or five significant figures, it is clear that the specific values and the distributions by category are not known with great precision. An evaluation during May 1964 showed the Plant 8 volume and uranium concentration measurements to be substantial underestimates, by factors of 4 and 11, respectively (Vath 1964a). Comparison sampling of dry discards showed better results; Plant 8 values were low by about 33% (Vath 1964b).

Page I--5

Page I–6	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3, Source Terms and Uncertainties

Hill (1989) reported an upper limit estimate of scrubber losses during the FY 1954-FY 1964 period. In this calculation it was assumed that the monthly release rate of 680 kg (1500 lb) occurred in FY 1964, the year of highest production. Hill references Vath (1964c) who suggested that release rate in 1964, based upon an average scrubber efficiency of 83%. The releases for other fiscal years were then computed using a scaling factor that was the ratio of the production in the particular year to the production in FY 1964.

10000

SAN 2020

President President

54.52 JE

The results of Hill's (1989) calculations and the estimates from FMPC-2082 (Boback et al. 1987) both track the Plant 8 production data (see Appendix C). The total scrubber release for FY 1954-1964 estimated by Hill (1989) is 57,712 kg, the exact amount reported to have been written off at the end of FY 1964 (Hill 1989). The estimates from FMPC-2082 are consistently a factor of 2.85 lower than the estimates of Hill (1989). That difference could correspond to selection of scrubber penetration 2.85 times smaller than the 17% assumed by Hill, or  $\sim 6\%$ . As discussed later, some measurements of penetration of uranium through the scrubbers have been that low. However, the data show that consistent performance at that level was not realized.

#### DATA DESCRIBING PLANT 8 OPERATIONS

#### Production Data

Plant 8 production data have been summarized on a fiscal year basis in Appendix C. Monthly production data were not generally available although they were found for most of the period 1956-1960 in plots in a history of FMPC uranium inventories (Anonymous, circa 1973-1976). When monthly data were available, calendar year average recovery rates could be computed exactly. For most years, average values for calendar years were estimated approximately using the tabulation in Appendix C. Figure I-1 shows the average monthly uranium recovery amounts estimated for each calendar year of operation. During 1953 operations were conducted only in November and December; average recovery for those months was 37 metric tons of uranium (MTU).

Uranium Collected in Scrub Liquor

The Plant 8 scrubbers were charged with a 10% sodium hydroxide (NaOH) solution. The NaOH concentration was gradually reduced during scrubber operation. When it reached 1%, or after 1-2 weeks of operation, the scrubber solution was changed. The reaction of the NaOH solution with the  $U_3O_8$  particles captured in the scrubbers is very complicated chemically. The reaction produces a complex mixture of sodium uranates with low solubility. An excellent study of phase relations in the sodium oxide-uranium trioxide-water system (Ricci and Loprest 1955) showed that sodium uranates exhibit wide ranges of solid solution and that the solubility of uranium trioxide in the ternary solution

1.1

is only about 10 mg L<sup>-1</sup>.

Appendix I Releases from Plant 8 Scrubber Systems

. .

Ş

14.

Ş



Figure I-1. Estimated average monthly production (uranium recovery) for operations in Plant 8.

The recirculating scrub liquor carried the sodium uranate and uranium oxide solids in suspension. The solids gradually settled out in the main scrub liquor storage tank and were periodically removed. Reprocessing of the insoluble solids or "scrubber cake" was performed at the FMPC to recover the uranium.

After it was recognized that significant amounts of uranium were being discharged to the environment from the Plant 8 scrubbers, the method described above was used to estimate uranium releases. That method depended on knowledge of the amounts of uranium that were collected in scrub liquor. Detailed data on scrub liquor content were compiled and used to estimating losses of uranium from scrubber discharges. Unfortunately, nearly all of the detailed data has been lost. Monthly data on the amounts of uranium collected in scrub liquor have only been located for twenty months between 1959 and 1964 (Beers 1961, Vath 1964c). Table I-4 contains most of the data on uranium in scrub liquor as well as individual monthly or average data on production in Plant 8 (Rathgens 1970, Rathgens et al. 1985). One additional isolated value for scrub liquor content is 2964 kg in February 1964.

The contributions of individual scrubbers to the total amounts of uranium in scrub liquor were recorded in detail at the time. The breakdowns for October 1959 (Marshall 1959) and February 1964 (Vath 1964c) are given in Table I-5. These data indicate that the scrubbers serving the calciner, rotary kiln, and UAP furnace were the most important for estimation of releases to the atmosphere at that time. These data are generally consistent with the equipment capacity data given in Table I-2, but it would have been desirable to have additional empirical breakdowns of the contributions to the total scrub liquor.

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page I-7

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

Page I-8	
----------	--

	~		Month	ly	Scrub lie	quor
<u>.</u>		1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	producti	ion	conter	nt
	Year	Month	(MTU	)	(kg U	()
	1959	October	249		2139	· · · · ·
•		November	236		4345	t -
		December	227		1588	
	1960	January	204		562	
• ''	•	February	· · · · · 249		4804	·· ·
	•	March	295		5466	
		April	299			
•		May	299.			;
		June	. 318	•	· · · · ·	
		July	259	•		
		August	304	•	•	
		September	240	۰.		
	. :	October	268		· · · · · ·	
	1. 1. 1.	November	227		• • *	•
•	; :,~	December	- <b>240</b>			
	1961	January	8			
	•	February	<b>a</b>	•	. ,	• -
		March	8			• • • • •
		April	8			
		May	8			
		June	The state of the s		2849	
	,	July	••• b		1624	
	: -	August	b		485	
- 6		September	b		3075	
•	. ·	October -	Dialitic Diality P		1066	~
•		November	· · b		12615	•
	•	December	b		6731	•
	1962	January	• b		2159	
		February	b	•	3561	
		March	b		889	· .
		April	De b	,	3443	
		May	61-31 b		2617	•
		June	1. b		• • •	•, •

<sup>b</sup> Average monthly production during the last half of F 1 1901 metric tons of uranium (MTU). <sup>b</sup> Average monthly production during FY 1962 was 242 MTU

-

,

. . .

на с на селоти На 1910 г. на селоти На 1910 г. на селоти

εđ :

> . <u>۰</u>۰:

現代に

2

Appendix I	1:	Page I-9
Releases from Plant 8 S	Scrubber Systems	

	Uranium (kg) collected in scrub liquor		
Scrubber for	October 1959	February 1964	
Calciner, muffle and box furnaces	1370	522	
Rotary kiln	569	1310	
UAP furnace	184	1124	
Digesters	1	9	
Oxidation furnaces	15		
All equipment	2139	2965	

1

• :

2

Table I-5. Contributions from Individual Scrubbers to Total Recovery of Uranium in Scrub Liquor

Additional information on collection of uranium in scrub liquor was obtained from the records of withdrawal of uranium from the FMPC inventory (McCreery and Gessiness 1959–1978). The monthly data collected on uranium retention in the scrubbers were summed to make an estimate of the losses via scrubber discharges during each fiscal year. Typically, estimates of anticipated losses were made at the beginning of a 6- or 12-month period and the projections were revised once or more as better information became available or changes in processing schedule were determined. Table I-6 contains information on withdrawals from inventory for enriched uranium between July 1964 and June 1973. Average production figures are available for these periods.

• •	Withdrawals (kg U) for scrubber losses		
Period	Enriched U	Natural U	Total
July 1964–June 1965	2735	3075	5810
July-December 1965	454	225	679
January–June 1966	21	225	246
July-December 1966	182	484 .	666
January–June 1967	641	. 483	1124
July-December 1967	714	362	1076
January–June 1968	1644	363	2007
July-December 1968	2717	. <b>a</b>	2717
January-June 1969	406	а	406
July-December 1969	592	37	629
January–June 1970	â	37	37
July 1970–June 1971	203	338	541
July 1971–June 1972	а	a	а
July 1972–June 1973	34	5	39
<sup>a</sup> No withdrawal for period.			· · · ·

Table I-6. Withdrawals of Uranium from Inventory to Account for Scrubber Losses From FY 1965 Through FY 1973
<u>م</u> (

ļ

The total amounts withdrawn from inventory had been estimated using measured amounts of uranium collected in scrub liquor and the assumed efficiency of 83% in Eq. (I-2). This procedure was used at the FMPC until 1982 (Diehl 1980, Bardo 1985). The reverse procedure was used to compute the amounts that were measured in scrub liquor using the withdrawal data from Table I-6. Those values were then used together with average uranium recovery tonnages for those periods to estimate the ratio of the quantities in scrub liquor to the uranium recovery.

Page I-10

The inventory withdrawal records reviewed (McCreery and Gessiness 1959-1978) did not explicitly identify any scrubber losses after June 1973. Uranium recovery activity in Plant 8 was lowest during the period 1973-1974 (see Figure I-1), which may account for decreased attention to that facility. Some other sources of information were located for the years 1975-1981. These are discussed below.

Although not reflected in uranium recovery data for the plant, approximately 92,000 kg of ore concentrates were calcined in the rotary kiln between 30 June and 11 July 1975. At the end of this processing campaign approximately 2300 kg U were unaccounted for (Adams 1975). About 1850 kg U were removed during a thorough cleaning of the scrubber as part of the search for missing uranium. Although the possibility of loss to the atmosphere was not addressed in the report, that release path was probably important.

The importance of the rotary kiln to Plant 8 processing was continued during the next several years. Handwritten data on collections of uranium in scrub liquor (Anonymous 1980) show it to be the principal source of that material, accounting for 80–100 percent of the total. The box furnace, with its own scrubber, and an oxidation furnace continued to operate throughout the 1970s. The muffle furnace operated periodically until early 1977, and does not appear to have been used regularly again until 1982. The kiln, box furnace, and oxidation furnace were operating when Ross (1979, 1980, 1982, 1983) began measurements of releases from the scrubber exhausts that formed the basis for the emission factors used in the 1980s.

Table I-7 summarizes information on the collection of uranium in scrub liquor and the corresponding estimates of the ratio of scrub liquor content to production. Because only average uranium recovery rates are known for many periods, most of the estimates of the ratio (R, kg U MTU<sup>-1</sup>) of scrub liquor collection to plant production were made for periods of six months or more. The exception is the value for the short period when ore concentrates were calcined in the kiln in 1975. The four estimates for periods between October 1959 and June 1965 lie near the center of the range of values from subsequent periods. The data in the table provide a basis for estimating quantities of uranium in scrub liquor for periods when such information is unavailable. Their application is discussed in the section describing calculations of releases.

Quantities of uranium in scrub liquor and data on scrubber performance can be used together to make estimates of releases from the scrubbers. Scrubber performance can be characterized by a collection efficiency or its complement, the amount of penetration through the scrubber. In the following section data on scrubber performance from two sources are discussed.

> e splacingel e. De ste Sectur

.

.

to Prod	luction (Uranium Re	covery) in Plan	
··· · ·	Quantity (kg U)	Plant 8	· .
	collected in	production	Ratio (R)
Period	scrub liquor	(MTU)	(kg U MTU <sup>-1</sup> )
Oct 1959–Mar 1960	18904	1460 ·	12.9
June-Nov 1961	21714	1485	14.6
Dec 1961–May 1962	19400	1452	13.4
July 1964–June 1965	28336	2134	13.3
July–Dec 1965	3315	838	3.95
Jan-June 1966	.1201	838	1.43
July-Dec 1966	3252	920	3.54
Jan-June 1967	<b>5488</b>	920	5.97
July-Dec 1967	5253	1111	4.73
Jan-June 1968	9799	1111	8.82
July–Dec 1968	13265	593	22.4
Jan-June 1969	1982	<b>593</b>	3.34
July–Dec 1969	3071	365	8.42
Jan-June 1970	181	365	0.50
July 1970–June 1971	2641 .	370	7.15
July 1972–June 1973	190	66	2.89
June-July 1975	1850	92	20.2
July 1975–Jan 1977	<b>727</b> ·	154	4.73
Feb 1977–Jan 1978	. 2112	246	8.57
Feb-Nov 1978	356	112	3.18

Table I-7. Estimates of the Ratio of Uranium Collection in Scrub Liquor to Production (Uranium Resource) in Plant 8

#### MEASUREMENTS OF SCRUBBER PERFORMANCE

During the years 1958-1965 simultaneous measurements of concentrations of U in the exhaust and intake air were obtained by members of the Industrial Hygiene and Radiation staff at the FMPC. Two sources of information about these measurements have been located. The first source of data is a set of analytical data sheets from the Health and Safety Division's radiochemical laboratory (NLCO 1958-1965). Laboratory data sheets, which were used to record information about the samples and the analytical results, were found for fifty measurements of scrubber performance during the period. Records that contained enough information to estimate scrubber efficiencies were primarily for measurements made during 1961-1965. The second source of information was FMPC internal memoranda summarizing measurements of scrubber efficiency. Plant memoranda contained information about nineteen sets of scrubber performance measurements.

#### Performance Estimates Based on Data from Laboratory Analytical Sheets

The laboratory analytical sheets typically included descriptive information about the scrubber being measured and the intake and exhaust samples taken, and results of the

Page I-12	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3, Source Terms and Uncertainties

uranium analyses, in units of total uranium measured and concentration of uranium in the air (NLCO 1958–1965). Estimates of scrubber efficiency or penetration were not recorded on the data sheets, but these quantities can be computed using the recorded information.

Three categories of estimates of scrubber performance were established. The first category consists of estimates based upon measurements of concentrations of uranium in the inlet and outlet streams and of the corresponding flow rates. Then the inlet and outlet mass loadings can be computed. If  $F_i$  and  $F_o$  are the inlet and outlet flow rates (m<sup>3</sup> s<sup>-1</sup>), carrying uranium concentrations (g m<sup>-3</sup>) of  $C_i$  and  $C_o$ , respectively, then the corresponding mass loadings ( $M_i$  and  $M_o$ , g s<sup>-1</sup>) are

$$M_i = F_i C_i$$
 and  $M_o = F_o C_o$  (I-3)

and the penetration is computed using

$$p = M_o/M_i \tag{I-4}$$

and the efficiency is  $\varepsilon = 1 - p$ . Performance estimates of this type, based on the inlet and outlet mass loadings, are preferred and were used whenever possible.

If mass loadings could not be determined, estimates based upon uranium concentrations alone were used. If  $C_i$  (g m<sup>-3</sup>) is the concentration measured at the inlet and  $C_o$  (g m<sup>-3</sup>) is the outlet concentration, then the efficiency can be estimated using

$$p = C_o / C_i \tag{I-5}$$

This calculation assumes that the flow rate of air into the scrubber equals the flow rate exhausting the scrubber. There were two alternative concentration-based estimates. The best estimates of this type are those in which the concentrations were corrected to standard conditions of temperature and pressure (295 K and 1 atmosphere). Unfortunately, the data on temperatures and pressures that were available at the time were frequently not recorded on the analytical sheet. This fact required the definition of the third, and least preferred, type of estimate, one based on uncorrected concentration data.

Table I-8 contains estimates of apparent uranium penetration through the scrubbers based on results recorded on the analytical data sheets (Schmidt 1992). When the available data permitted more than one type of estimate, all of the estimates are shown. A blank in either of the last two columns indicates that it was not possible to make the corresponding type of estimate because of lack of information.

The term apparent penetration is used because carryover of uranium in drops of scrub liquor seems to have been an important process. When the inlet air concentration is relatively low but the scrub liquor is carrying high uranium concentrations, just prior to regeneration for example, carryover of droplets of the scrub liquor can lead to high outlet uranium concentrations and apparent penetrations that exceed 100 percent. The importance of carryover seems also to be supported by the finding, presented later, that the apparent penetrations were generally lower when the uranium concentrations in inlet air stream were high.

\* ---

1

1

.

Sec. 1.

\*\*\*\*\*

WALCO.

È.

٤.

: {•

.....

Tab Ph B	le I-8. Apparent Ura ant 8 Scrubbers Base ecorded on Analytic	nium Penetration T d on Measurement R al Data Sheets, 1961.	hrough esults -1965
	Apparent pene	tration (%) by estima	tion method
Date	Uncorrected	Corrected	Mass
sampled	concentration	concentration	loading
	Scrubbe	r for the primary cal	ciner
3-15-61	0.26	0.20	0.19
3-17-61	0.18		0.10
3-29-61	13		
3-30-61	20		
3-19-62	2.0	2.0	
3-20-62	1.5	•	1.5
3-22-62	5.7	4.0	4.2
3-22-62	6.0	5.8	5.3
6-3-65	76		100
6-4-65	9.9		14
	•	١	
	Scr	ubber for rotary kiln	·
3-20-61	8.0	· · · · ·	
3-21-61	100	•	
3-27-61	5.3		
3-28-61	1.1		
5-23-61	2.2		1.9
5-25-61	<b>6.9</b>	5.4	
5-26-61	<b>16</b>		
7-6-61	11,		· .
7-6-61	10		
11-3-61	1.2	0.74	0.83
12-5-61	2.2	1.8	2.7
7-30-62	22	•	
8-1-62	2.1		
8-2-62	7.6		
8-3-62	• 11		
	Scru	bber for NPR furnac	6
3-21-63	86	59	. 82
3-27-63	100	70	110
3-28-63	260	190	240
11-7-63	11	7.2	13
11-8-63	32	20	38
11-13-63	28	19	34
		-	

Radiological Assessments Corporation "Setting the standard in environmental health"

٠.

:

# Page I-14

10.000

		Apparent penetrati	on (%) by estima	tion method
	Date	Uncorrected THE	Corrected	Mass ·
· _•	sampled	concentration a co	ncentration	loading
		Scrubber	for UAP furnac	e
	3-24-61	160		
•	3-24-61	33	•	17 · · · ·
	9-18-62	<b>33</b>	21	29
	9-20-62	54		· ·
•	7-9-63	11	6.9	• * •
·	7-10-63	<b>29</b>	19	· . *
	7-11-63	<b>26</b>	<b>2</b> 6	• 1 0
	8-29-63	13	8.7	15
-	8-29-63	7.8	5.2	8.8
	11-15-63	1.1		
•	11-19-63	0.38	0.23	· · · · ·
	12-18-63	28	18	<b>32</b>
	12-19-63	7.9	5.0	9.2
	12-20-63	70	45	<b>88</b> .
i c	8-10-65	<b>60</b>	45	• • • •
•	8-11-65	3.7	2.5	
	8-12-65	2.9	2.0	
• '	9-8-65	0.97	0.52	
••	•		•	
		Scrubber for	oxidation furnac	e #1
	0 11 61	100		

Table I-8 (Continued)

Droplet carryover is of course not the only reason for poor collection efficiencies by the scrubbers. It was noted previously that overloading of the UAP furnace was considered an important reason for the difficulties with its operation (Noyes 1962). Variability in scrubber performance was also a factor. Although penetration of uranium through the scrubbers for the primary calciner and for the rotary kiln was usually found to be relatively low, some very high apparent penetrations were also observed. Performance of the other scrubbers was even more variable.

#### Performance Estimates Reported in Plant Memoranda

There were several internal plant memoranda that contained information on the performance of the Plant 8 scrubbers. These were prepared to document measurements, support estimates of uranium losses, and to support proposals to upgrade the scrubber discharge treatment equipment. Table 1-9, which includes the calculation method and the reference for each estimate, summarizes these performance estimates. Most results were reported as scrubber efficiencies that were computed using the mass loading method. In one memorandum the method used was not stated. Four of the results had been based on concentrations measurements alone, but better estimates have been derived from the data (Schmidt 1992). Those and other estimates in Table I-9 have been presented in terms of uranium penetration through the scrubbers.

	Table I-9. Es	timates of Uranium	Penetration	
T	rough Plant 8 S	crubbers Based on Fl	MPC Memoranda	
1	Date	Calculation	Penetration <sup>a</sup>	
Scrubber for	sampled	· basis	(percent)	Reference
Rotary kiln	Ъ	Mass loading <sup>b</sup>		Starkey (1961)
UAP furnace	Ъ	Mass loading <sup>b</sup>	31 <sup>b</sup>	Starkey (1961)
Primary calciner	. р	Mass loading <sup>b</sup>	21 <sup>b</sup>	Starkey (1961)
UAP furnace	3-24-61	Mass loading	33	Bipes (1963b)
UAP furnace	3-24-61	Mass loading	55	Bipes (1963b)
Rotary kiln	7-30-62	Mass loading <sup>c</sup>	20°	Bipes (1962)
Rotary kiln	8-1-62	Mass loading <sup>c</sup>	2,2°	Bipes (1962)
Rotary kiln	8-2-62	Mass loading <sup>c</sup>	6.7°	Bipes (1962)
Rotary kiln	8-3-62	Mass loading <sup>c</sup>	8.1°	Bipes (1962)
UAP furnace	9-18-62	. Mass loading	47	Bipes (1963b)
UAP furnace	9-20-62	Mass loading	· 79	Bipes (1963b)
UAP furnace	7-9-63	Mass loading	12	Bipes (1963b)
UAP furnace	7-10-63	Mass loading	29	Bipes (1963a,b)
UAP furnace	7-11-63	Mass loading	23 <sup>d</sup>	Bipes (1963a,b)
UAP furnace	8-29-63	Mass loading	· 8	Bipes (1963a,b)
UAP furnace	8-29-63	Mass loading	11 <sup>d</sup>	Bipes (1963a,b)
NPR furnace	11-7-63	Mass loading	12	Bipes (1963c)
NPR furnace	11-8-63	Mass loading	21	Bipes (1963c)
NPR furnace	11-13-63	Mass loading	30	Bipes (1963c)
UAP furnace	12-18-63	Mass loading	27	Bipes (1964)
UAP furnace	12-19-63	Mass loading	72	Bipes (1964)
UAP furnace	12-20-63	Mass loading	7.	Bipes (1964)
UAP furnace	Spring 1964 <sup>e</sup>	Not indicated	26-29°	Vath (1964b)

1 1 1 1 L

191.00

. . .

<sup>a</sup> The memos reported scrubber efficiencies in percent. The penetrations shown here were computed using  $p(\%) = 100\% - \varepsilon$  (%).

<sup>b</sup> The memo, dated 11 April 1961, states that the measurements had "recently been completed." This would indicate that they were performed in the previous month or two. Scrubber inlet loading data are given and it is presumed that they were used to estimate the efficiency. The memo also indicates that the values were averages; the number of samples was not given. The result for the calciner is also in a memo by Chenault (1961).

<sup>c</sup> The memo reported efficiencies based on concentrations. However, it also contained enough data to calculate penetration on the basis of inlet and outlet mass loadings (Schmidt 1992). The latter results are presented here.

<sup>d</sup> In Bipes (1963a), the efficiencies measured on 11 July and 29 August are stated to be 74% and 87%, respectively; no data are given. Examination of the data included in Bipes (1963b) indicates that the correct values for efficiency were 77% and 89%, respectively.

<sup>e</sup> The memo does not provide dates or the number of measurements.

The measurements for the UAP furnace scrubber that were performed in the summer of 1963 followed refurbishment of that scrubber. The feed to the furnace during the July measurements was at the normal rate of five drums per hour; however, at the end of August it was reduced to three drums per hour to test the effect of that action. There was a noticeable improvement in the scrubber's performance during operation at the reduced feed rate (Bipes 1963a). That reference does not include the result for 9 July, the first after the modifications were completed; the feed rate on that day is not known.

> Radiological Assessments Corporation "Setting the standard in environmental health"

:

st i i

.

÷.,

The measurements of scrubber efficiency for the rotary kiln scrubber were performed after the scrubber had been refurbished (June 1962) to reduce losses. Uranium fines were being processed during the measurements. The report of results (Bipes 1962) is detailed and contains information on inlet and exhaust flow and loading rates.

The reductions in efficiency observed during sequential measurements for the NPR Furnace scrubber in November 1963 were attributed to the buildup of solids in the scrubber. The first measurement was made after cleaning the scrubber cone; continued operation prior to the second and third measurements had resulted in an increasing buildup of material (Bipes 1963c).

### Summary

Both data sources were used to characterize uranium penetration through the Plant 8 scrubbers. Estimates based on mass loading were preferred over those based upon concentration data alone. When two estimates based on mass loading differed, the mean of the two values was used. Estimates based on corrected air concentration data were used whenever possible instead of those based upon concentrations that had not been converted to standard conditions. The following sections summarize the preferred estimate for each of the scrubber performance tests. These short-term test results are the only basis for estimating long-term average values needed for calculations of scrubber releases. In the summaries, mean values of apparent penetration (p) are given with  $(\pm)$  the standard deviation of the mean.

Ē.

1240-124

ŗ

:,

Uranium penetration through the primary calciner scrubber. The estimates for uranium penetration through the scrubber that served the primary calciner and other small furnaces were derived from information recorded on analytical data sheets. There were ten estimates in all; preferred values and the method used to derive them, from Schmidt (1992), are shown in Table I-10. Six of the ten estimates were based on mass loading calculations. One estimate was based on concentrations corrected to standard conditions. Typical scrubber inlet mass loadings were in the range of 30 to 110 kg d<sup>-1</sup>. One estimate of apparent penetration through the calciner scrubber was greater than 20%. It was obtained during testing of a new nozzle under conditions. For that reason it was not included in the calculation of the mean penetration of 6.7 percent or in the distribution of individual penetration estimates shown in Figure I-2.

Uranium penetration through the rotary kiln scrubber. Table I-11 contains the preferred values and the basis used to estimate uranium penetration through the scrubber serving the rotary kiln. Seven of the fifteen estimates were based on mass loading calculations and one was based on corrected concentration data. Nearly all of the estimates of penetration were less than 20%, but one indicated complete penetration. The mass loading during the measurement that yielded an apparent penetration of 100% is not known, although other measurements near the same time were performed at a loading of more than 20 kg d<sup>-1</sup>. The mean of all the measurements of penetration through the rotary kiln scrubber was 13 percent. The distribution of these short-term measurements is shown in Figure I-3.

and the second and the second s

· :

The second se

	Penetration	Through the l	Primary Calcine	er Scrubber	
Date	Methoda	p (%)	Date	Methoda	р (%)
3-15-61	ML	0.19	3-22-62	ML	4.2
3-17-61	ບ່	0.18	3-22-62	ML	5.3
3-29-61	U	13	6-3-65	ML	100 <sup>b</sup>
3-30-61	U	20	6-4-65	ML	14.
3-19-62	C	2.0			
3-20-62	ML	1.5	Mean <sup>c</sup>	(n = 9)	<u>6.7 ± 2.5</u>

<sup>a</sup> ML: mass loading; C: corrected concentration, U: uncorrected concentration. <sup>b</sup> Measured at very low loading; not included in average.

<sup>c</sup> Mean value ± the standard deviation of the mean; n: number of measurements.



Figure I-2. Distribution of results of short-term uranium penetration measurements for the calciner scrubber made during 1961-1965.

Date	Method <sup>a</sup>	p (%)	Date	Methoda	p (%)
3-20-61	U	8.0	7-6-61	U ,	10
3-21-61	<b>U</b> -	100	11-3-61	ML	0.83
3-27-61	U	5.3	12-5-61	ML	2.7
3-28-61	U	1.1	7-30-62	ML	20
5-23-61	ML	1.9	8-1-62	ML	2.2
5-25-61	· C	5.4	8-2-62	ML	6.7
5-26-61	U U	. 16	8-3-62	ML	8.1
7-6-61	U	· · · 11	Mean <sup>b</sup>	(n = 15)	13.3 ± 6.6

Table I-11. Summary of Short-Term Measurements of Uranium Penetration Through the Rotary Kiln Scrubber

<sup>a</sup> ML. mass loading; C: corrected concentration, U: uncorrected concentration. <sup>b</sup> Mean value ± the standard deviation of the mean; n: number of measurements.



Figure I-3. Distribution of results of short-term uranium penetration measurements for the rotary kiln scrubber made during 1961-1962.

Uranium penetration through the UAP furnace scrubber. There were eighteen shortterm measurements yielding estimates of uranium penetration through the scrubber that served the UAP furnace. Information about these measurements is given in Table I-12. Twelve of the estimates were based upon mass loading calculations and five were based on corrected concentration data. Mass loadings were typically less than 8 kg d<sup>-1</sup> although two measurements were made at 12 kg d<sup>-1</sup> and one was made at 20 kg d<sup>-1</sup>. The range of apparent penetrations was wide, ranging from 0.2 to 80 percent. Half of the estimates were between 20 and 80 percent. The mean value was 25 percent. The data indicate that the A SAME TO A SAME TO A SAME

.

Č.

performance for the UAP furnace scrubber was generally poorer than that of the scrubbers serving the primary calciner and rotary kiln.

	Penetrati	on Through the	e UAP Furnace S	Scrubber	
Date	Methoda	p (%)	Date	Methoda	p (%)
3-24-61	ML	55	11-19-63	C.	0.23
3-24-61	ML	33	12-18-63	ML	· 29
9-18-62	ML	38	12-1-63	ML	8.1
9-18-62	ML	<b>79</b> ·	12-20-63	ML	80
7-9-63	ML	12	8-10-65	С	45
7-10-63	ML	29	8-11-65	С	2.5
7-11-63	ML	<b>23</b> ·	8-12-65	C.	2.0
8-29-63	ML	. 13	9-8-65	С	0.52
8-29-63	ML	8.4			
11-15-63	U	1.1	Mean <sup>b</sup>	(n = 18)	$25.5 \pm 6.2$

Table I-12. Summary of Short-Term Measurements of Uranium Penetration Through the UAP Furnace Scrubber

<sup>a</sup> ML: mass loading; C: corrected concentration, U: uncorrected concentration. <sup>b</sup> Mean value ± the standard deviation of the mean; n: number of measurements.





Page I-19

Page I-20	The Fernald Dosimetry Reconstruction Project
	Tasks 2 and 3, Source Terms and Uncertainties

Uranium penetration through the oxidation furnace scrubbers. Most of the oxidation furnace scrubber measurements were made in the discharge from furnace #2, called the NPR furnace. Table I-13 contains information on uranium penetration through that scrubber. All of the estimates of apparent penetration were based on mass loading computations. Mass loadings for the NPR scrubber were generally low, averaging about 3 kg d<sup>-1</sup>. The smallest apparent penetration measured was 12%. Two of the six values exceeded 100%, indicating substantial carryover of uranium in scrub liquor droplets during the measurement. The single measurement for the other oxidation furnace, based upon uncorrected concentration data, indicated a penetration greater than 100%, again indicating substantial carryover of droplets during the measurement. Although the true penetration of uranium through these scrubbers can not be reliably determined from the data, it was clearly substantial, with an average estimated to lie between 50 and 60 percent.

Penetration Through Scrubbers for the NPR Furnace and Oxidation Furna				Furnace #	
Date	Methoda	p (%)	Date	Method <sup>a</sup>	р (%)
3-21-63	ML	82	11-8-63	ML	30
3-27-63	ML	> 100	11-13-63	ML	32
3-28-63	ML	> 100	8-11-61	U	> 100
11-7-63	ML	12		·	
			,		

<sup>a</sup> ML: mass loading, NPR Furnace; U: uncorrected concentration, Oxidation Furnace #1.

Entrainment of scrub liquor. As noted above and elsewhere in this section, entrainment or carryover of scrub liquor appears to have been an important factor that influenced overall performance of the scrubbers. This conclusion is based in part upon the observations of very high apparent penetrations, as in Table I-13, and upon comparison of measured performance with expected performance.

Removal efficiencies of venturi scrubbers for various inlet particle sizes given in Lund (1971) exceed 99% for particles with diameters greater than 5  $\mu$ m. Using a distribution of furnace off-gas particle sizes based upon plant documents, it was estimated that scrubber efficiencies should have been about 97% (Killough et al. 1993, App. D). The preceding tables show that most measured apparent penetrations were above 3%. This comparison also suggests that entrainment of droplets containing suspended uranium particles contributed substantially to the releases. Entrainment appears to be a more likely explanation than the alternative that the diameters of particles entering the scrubbers were very much smaller than is indicated in the limited available documentation.

#### DEPENDENCE OF PERFORMANCE ON SCRUBBER LOADING

Examination of the scrubber performance data suggested that uranium penetration through the scrubbers was dependent upon the concentration of uranium in the scrubber inlet duct (Schmidt 1992). Table I-14 contains all the penetration estimates obtained from mass loading calculations. For these tests the amounts of uranium entering the scrubber, referred to as the scrubber inlet loading, have been computed and are shown in the third

# Appendix I

. . .

<u>.</u>

~

# Releases from Plant 8 Scrubber Systems

column. The apparent penetrations are the best estimates from the data sheets and plant memos, evaluated as described previously.

For the calciner, inlet loadings  $(I, \text{kg d}^{-1})$  generally varied between about 30 and 110 kg d<sup>-1</sup>. The unusually low loadings in June 1965 were during a test of a new scrubber spray nozzle. Inlet loadings for the scrubber serving the rotary kiln were higher in 1961 than in tests conducted after scrubber refurbishment in 1962. The UAP furnace scrubber generally handled less than 10 kg d<sup>-1</sup>, although in three instances the loadings were higher than that. Loadings for the oxidation furnace scrubbers were even lower, about 3 kg d<sup>-1</sup>.

The relationship between  $\ln p$  and  $\ln C_i$  (the inlet concentration) seen by Schmidt (1992) suggested that there would be a similar relationship between  $\ln p$  and  $\ln I$  and that was observed: This implied that a potentially useful relationship between penetration and the rate of buildup of uranium in scrub liquor was also present. Values of this variable  $(M_s', \text{kg d}^{-1})$  were computed from the data in Table I-14 and are the basis for Figure I-5.



Figure I-5. Plot of the logarithm of the apparent penetration through scrubbers and the logarithm of the computed rate of uranium accumulation in scrub liquor.

These observations are consistent with the earlier observation that carryover of droplets of scrub liquor is an important factor. When the challenge aerosol concentrations are relatively low, the uranium carried in the droplets can be the controlling factor in determining the apparent penetration. This is perhaps best illustrated by the measurement made for the calciner when the inlet loading was only 0.2 kg d<sup>-1</sup>.

In Figure I-5 the logarithm of the apparent penetration of uranium through the scrubbers is plotted against the logarithm of the rate of accumulation of uranium in scrub liquor. This plot shows that  $\ln p$  generally decreases as  $\ln M_s$  increases; however, there is



•	The Fernald Dosimetry Reconstruction Project
Tasks	2 and 3, Source Terms and Uncertainties

Page I-22

substantial variability for all of the scrubbers. The limited data for the NPR furnace scrubber run counter to the general trend.

Fault	nt Samibhan	Apparent	
Dete		Apparent	· •
Date	inlet loading	uranium	· .
sampled 1	er (kg d <sup>-1</sup> )	penetration (%)	
Feb-Mar 1961 de	r 56	21	
3-15-61 .ne	r 110	0.19	
3-20-62	r i 110	<b>1.5</b>	,
3-22-62 Salcine:	r 29	<b>4.2</b> .	· <b>.</b>
3-22-62 Calcine	r 51	5.3	.:.
5-3-85 Calcine	r 0.2	100	
:65 Calcine	r .7.0	14	
Felo-Me 1 Rotary Ki	ln 23	5	
5- Rotary Ki	ln 4 26	1.9	
Rotary Ki	ln 62 .	0.83	
Rotary Ki	ln 102	2.7	
-62 Rotary Ki	ln . 4.4	20	•
1-62 Rotary Ki	ln 18	2.2	
-2-62 Rotary Ki	ln 4.3	6.7	
3-3-62 Rotary Ki	ln 📜 🖓 4.5	8.1	
	31		•
Feb-Mar 1961 UAP Furna	ace 7.3	31	
3-24-61 UAP Furns	ace 5.7	33	
3-24-61 UAP Furns	ace 1.2	55	•.
9-18-62 UAP Furns	ace 12	38	• •
9-20-62 UAP Furns	ace 5.1	79	
7-9-63 UAP Furns	ace 2.6	12	* .
7-10-63 UAP Furns	ace 3.0	2 <b>29</b> - Contract of the second	<u>::</u> !
7-11-63 UAP Furns	ace 2.4	.23	
8-29-63 UAP Furna	ace 6.7	- 13	
8-29-63 UAP Furns	ace 12	8.4	
12-18-63 UAP Furns	ace 4.1	. 29	
12-19-63 UAP Furna	ace 20	8.1	•••
12-20-63 UAP Furns	ace <sup>(1)</sup> 117 (2.9	80	
	$\mathbb{E}[G] \to \mathbb{E}[G] \to \mathbb{E}[G] \to \mathbb{E}[G]$	to a a constant of the	
3-21-63 NPR Furna	ice 46	82	•
3-27-63 NPR Furna	ice - 1992 - 6.1	. 110	
3-28-63 NPR Furna	ice	240	4.
11-7-63 NPR Furna	ice1.5	12	L.
11-8-63 NPR Furne	ice 0.9	30	
11-13-63 NPR Furna	.ce 2.4	32	

t e.d.:

When the penetration was apparently 100% or greater the rate of accumulation of uranium in scrub liquor is zero or negative; thus, those points cannot be shown on the figure. However, the correlation discussed below does include cases of complete penetration at low inlet mass loadings.

52

The equation of the line describing the correlation between the variables is:

$$\ln (p [\%]) = A - B \ln (M_s' [kg d^{-1}])$$
(I-6)

The two best-fit coefficients with their standard errors are  $A = 3.81 \pm 0.26$  and  $B = 0.71 \pm 0.10$ . The overall correlation coefficient (r) was 0.79. The relationship is applicable for scrubber uranium accumulation rates ranging from about 0.33 kg d<sup>-1</sup> (predicted value of p = 100%) to about 110 kg d<sup>-1</sup>. Evaluation of a data set that does not include the four results for the scrubber serving the NPR furnace improves the correlation slightly (r = 0.83) and changes the parameters of the line by about 10%. Correlations for individual scrubbers were also derived for possible use in making estimates of scrubber releases. The results of application of these correlations are discussed in a later section.

# OTHER FACTORS AFFECTING RELEASES FROM PLANT 8 SCRUBBERS

The ranges estimates from short-term measurements of uranium penetration, discussed above, illustrate the variability in performance. Examination of the apparent penetration of uranium through scrubbers as a function of time of measurement did not reveal any notable trends. There were numerous repairs of scrubber system components that were exposed to the corrosive alkaline scrub liquor, but the short-term performance data give no indication of significant improvement or degradation of performance of any of the scrubbers with time during the period 1961-1965.

The most important factor, besides performance variability, that affected scrubber releases seems to have been due to a change in the Plant 8 process. The "UAP furnace" was originally installed in mid-1955 to roast ammonium diuranate (ADU), not uranium ammonium phosphate (UAP). After the process was changed to produce UAP in 1958, problems with the off-gas system occurred. These included blow-back of furnace gases into the work area because of plugging of the off-gas system. Reducing the feed rate to the furnace reduced the problem but did not eliminate it (DeFazio 1966; Mead 1972).

At some point a scrubber bypass line was installed in the ventilation system. This would avoid the backflow of furnace exhaust while the blockage was being cleared and permit workers to continue to operate the furnace. The earliest documents found in FMPC records that cite release estimates from this source were from 1964. Release estimates of 25 lb U per 24 hours of furnace operation (DeFazio 1964) and 750 lb U per month (Starkey 1964) were given. The estimates are consistent for continuous operation of the UAP Furnace. Documentation of the basis for these release estimates has not been found in analytical data sheets. It appears that the emergency system could have been used fairly frequently, perhaps as much as 10% of the time. Such action would increase the average penetration from 25% to 33% and lead to correspondingly greater releases to the environment.

An early schematic drawing of the UAP furnace off-gas system shows no bypass and comparable diagrams for other scrubbers also show no direct pathways to the atmosphere (Calhane 1958b). A later schematic drawing (GFA 1966) contained in a Plant 8 ventilation survey also shows no bypass of the scrubber serving the UAP furnace. However, an undated drawing of the NPR furnace and associated systems in a procedure for calcining enriched uranium (Egart 1962-1963) shows emergency dampers that could release furnace

The Fernald Dosimetry Reconstruction Project
 Tasks 2 and 3, Source Terms and Uncertainties

....

7

For comparison, the data in Table I-14 were used to develop a set of release estimates for the earlier period when production was quite high. The results of those calculations are shown in Table I-16. The release rates measured during the 1961-1965 period were uniformly higher than those measured during years of low production. The mean release rate for the rotary kiln was about three times greater than that found during low production. The result for the NPR furnace was about eight times greater than a later value for another oxidation furnace. The mean calciner release rate was more than 100 times higher during the earlier, high production years.

the end of My the second	<u> </u>	Measured uraniur	n release (kg U d	l <sup>-1</sup> )
Year	<u>Rotary ki</u>	ln UAP furnace	NPR furnace	Primary
. 1961	1.2	<b>2.3</b> (1)	. <u>a</u>	· 12
and the second production and the	0.49	1.9	· ·	0.21
	<b>0.51</b>	0.66		
· .	2.8			;
1962	0.88	4.6	e	<b>1.6</b>
	0.40	4.0		1.2
	0.29	· • • • • • • • • • • • • • • • • • • •		2.7
Real Production of the	0.36			·
a second second second	. • .		· .	a start sea
1963		0.31	3.8	
		0.87	6.7	
		0.55	8.4	; •
		0.87	0.18	·
		1.0	0.27	
		1.2	0.77	•
		1.6		
	•	2.3		-
	·	1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1	·· , / : ·	
1965			· · · · ·	0.98

# CALCULATIONS OF RELEASES FROM THE PLANT 8 SCRUBBERS

Introduction

Page I-26

. . . and diamate bees 1. 10

The period of operation of the Plant 8 scrubbers was divided into two time periods and release estimates were computed differently for each period. The first period extended from plant startup through 1981. The second began in 1982 and ended in 1988. During the first period, release estimates were based upon estimated long-term average scrubber efficiencies; in the later years, the estimates depend upon release factors derived from

#### Appendix I

.

#### Releases from Plant 8 Scrubber Systems

measurements shown in Table I-15. The release factor approach is considered more reliable; however, sufficient data on plant operations are not available to apply that approach in earlier years.

The general approach employed is described briefly in the next section. Details of the calculations are discussed subsequently for each period.

#### General Calculational Technique

The calculations of releases from the Plant 8 scrubbers were performed using Crystal Ball<sup>®</sup>, a Monte Carlo spreadsheet program (DI 1991). The use of a Monte Carlo procedure explicitly recognizes that there is uncertainty due to variability and lack of knowledge of the individual parameters upon which the calculational result depends. This approach is greatly preferred over a calculation that is based upon point estimates of the various parameters and yields a single result that does not reflect the underlying uncertainties. The Monte Carlo calculation carries the underlying uncertainties in the parameters forward and displays its magnitude in the breadth of the distribution of results. The procedure employs distributions of model parameters and produces a distribution of results.

#### Calculations of Releases for 1953-1981

For the years 1953–1981, annual uranium releases from the Plant 8 scrubbers and the uncertainties associated with them were estimated by applying a simple model to each scrubber. The calculations employ plant-specific data that were presented above. The types of data used were:

- Plant 8 production (uranium recovery) data
- amounts of uranium found in scrub liquor
- the distribution of the amount of uranium in scrub liquor per unit production
- estimates of utilization and performance of the scrubbers serving the calciner, rotary kiln, UAP furnace, and the two oxidation furnaces

Releases from each scrubber were estimated using a variant of Eq. (I-2) that employs penetration rather than efficiency and rates rather than total amounts.

$$Q' = M'_s \frac{p}{(1-p)} \tag{I-7}$$

In this equation, Q' is the release rate and  $M_s'$  is the rate of accumulation of uranium in scrub liquor. Because average production information is being converted from fiscal to calendar years and because most information on accumulation of uranium in scrub liquor and its relationship to production is best defined for 6- to 12-month periods, six months was chosen as the basic time interval for these calculations. Some deviations from this schedule were necessary to accommodate calculations that considered the bypass of the

UAP scrubber and the availability of data on  $M_s$ . The sequence of calculations for each 6-month period is described below.

- The first step was to determine the rate of accumulation of uranium in scrub liquor during the period  $(M_s')$ . It could be known (Table I-7) or computed from the average production using the ratio R (kg U MTU<sup>-1</sup>). The value of R was selected from the distribution of values computed from plant data (shown below).
- The next step was to apportion the scrub liquor uranium content among four scrubbers: primary calciner, the rotary kiln, the UAP furnace, and the oxidation furnaces (grouped together for the calculations). Values of two of the apportionment fractions were determined by random selection from distributions described below. Two other fractions were obtained by calculation to assure that the sum of the four fractions chosen was one.
- The third step was to select an estimate of the long-term average uranium penetration through each of the four scrubbers. The distributions used to make these estimates, based upon measurements described previously, are discussed below.
- The fourth step was to compute the release estimate for each scrubber using Eq. (I-7) and to total those for the period. Estimates for calculational periods within a calendar year were then summed to obtain the total release for that year.
- In the last step, estimates of releases for each decade and, subsequently, for the entire period of operation were calculated using Monte Carlo procedures.

It was previously noted that Eq. (I-2) is unreliable for low scrubber efficiencies. The same applies to the analogous equation (I-7) for high scrubber penetrations. As papproaches one, the predicted release increases without limit. To avoid this difficulty, the maximum values of the long-term average scrubber penetration distributions were limited to values of 95% Even though short-term measurements indicated penetrations higher than 95%, such high values are highly unlikely to have persisted for a 6-month period. Scrubber release estimates were checked to assure that the highest predicted annual releases were credible; that is, that they did not exceed the quantity of material that could have entered the scrubber during the year.

In each of the steps requiring selection of a parameter value, that was accomplished using the Monte Carlo calculational procedure. Distributions of each of the parameters required for the calculations are presented next.

Scrub Liquor Accumulation Rate. For some periods, the scrub liquor accumulation rate was known (Table I-7). For those periods, values employed in the calculations were obtained by sampling a uniform distribution with bounds of  $0.9 M_s$  and  $1.1 M_s$ . If  $M_s$  was not known, it was computed using the ratio R.

the second second second

The Ratio R (kg U MTU<sup>-1</sup>). The ratio of the total amount of uranium collected in scrub liquor (kg U) per unit production (MTU) provides a link between furnace operations and plant production. Figure I-6 shows the composite distribution of the twenty estimates of the ratio R (kg U MTU<sup>-1</sup>) in Table I-7. The overall distribution covers a fairly broad range of values; the mean value was  $8.2 \text{ kg U MTU}^{-1}$ . The distribution in Figure I-6 was sampled

. رو بري

23

.....

to obtain estimates of R used, with production data, to compute an estimate of  $M_s$  for the period of interest.



Figure I-6. Distribution of ratios of scrub liquor accumulation to production for Plant 8.

Production Rates. Average production rates were derived from information previously tabulated by the FMPC on a fiscal year basis. Conversion from fiscal years to calendar years was performed in 6-month blocks until 1976. Thereafter, nine months of a fiscal year were in the following calendar year. The 6-month average production estimate was described by a uniform distribution that ranged from 0.9 to 1.1 times the tabulated average for the period. This spread corresponds approximately to the standard deviation of such mean values.

Scrub Liquor Apportionment. Apportionment of the uranium in scrub liquor to the different scrubbers was based on very limited data on individual scrub liquor collections and upon equipment capacities. Data on actual collection of uranium in scrub liquor (Table I-5) provides information on utilization of the furnaces at two times during the early years of operation. Capacity data were listed in Table I-2. The primary calciner and rotary kiln were physically larger and had greater capacities than the other furnaces employed in Plant 8. Stated furnace capacities greatly exceeded actual plant production, so they are only indicative. Average utilization fractions for the furnaces were estimated from information in Tables I-2 and I-5 and discussions with plant personnel.

For years prior to 1975, it was assumed that half of the scrub liquor uranium came from the primary calciner and that about 28% came from operation of the rotary kiln. Uniform distributions were assumed for both fractions, with ranges of 0.4-0.6 and 0.2-0.35, respectively. These fractions were selected independently. The sum of the four utilization fractions was constrained to be unity; thus, between 5 and 40 percent of the uranium

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page I-29

1

The Fernald Dosimetry Reconstruction Project
Tasks 2 and 3, Source Terms and Uncertainties

1

ŻΫ

. بر

Sec. No

л. Т. т. т.

1.1.1

ŝ.

remained to be assigned to the other furnaces. Fractions for the UAP furnace and oxidation furnaces were computed. The UAP furnace fraction was determined by multiplying the remainder by a parameter selected from a symmetrical triangular distribution with bounds of 0.55 and 0.85. The fraction for the oxidation furnaces was then calculated by difference. The resulting distributions for these two utilization fractions were symmetrical and triangular with ranges of 0.035-0.28 and 0.015-0.012, respectively.

Furnace utilization changed in the 1970s. In the last half of 1975, the special ore concentrate calcining in the rotary kiln was by far the largest amount of processing that was accomplished. In the first half of 1975, and in subsequent years through 1979, the rotary kiln fraction was taken to be an average of 0.9. This fraction was represented by a uniform distribution with values between 0.8 and 1.0. During this period, utilization fractions for the UAP furnace and oxidation furnaces were computed as described above. The resulting distributions of utilization factors were both symmetrical and triangular with ranges of 0-0.14 and 0-0.06 for the UAP furnace and oxidation furnaces, respectively.

For 1980 and 1981, data indicated that the box furnace, which used the same scrubber as the calciner, would account for 22% of the loading. For 1980, the fraction for the oxidation furnaces was determined by difference. All the scrub liquor uranium was distributed between these two scrubber categories. The distributions were both taken to be uniform, with ranges of 0.20-0.24 and 0.76-0.80, respectively. For 1981, the rotary kiln was estimated to account for 29% of the loading. Distributions of fractions for the box furnace and rotary kiln were sampled independently. Uniform distributions with ranges of 0.20-0.24 and 0.26-0.29, respectively, were used. The fraction for the oxidation furnaces was computed, with a resulting distribution that was uniform between 0.44 and 0.54.

Average Penetration Through the Scrubbers. Table I-17 contains information about the distributions used to estimate values of the long-term average scrubber penetrations used in the Monte Carlo calculations. The basis for these distributions was the short-term measurements summarized previously (Tables I-10 through I-13). For each distribution the lower bound and upper bound are listed; for the triangular distributions the mode is also given.

In the last two columns of the table are the computed mean values and standard deviations of the penetrations derived from these distributions. These resultant values are those that one obtains by sampling the specified distributions of penetration. The mean resultant penetrations correspond to the average penetrations measured during 1961-1965. The resultant standard deviations are all larger that the estimates from the measurements. This is considered appropriate when contemplating the uncertainties involved in estimating penetrations in other years and for a range of operating conditions that occurred before and after the period 1961-1965.

In the lower part of the table are descriptions of the distributions used to estimate average penetration through the UAP furnace scrubber during the period when the bypass line was installed. A bypass fraction (BF) of 0.10 was taken to be the base case for the period September 1963-March 1966. For BF = 0.10, the average penetration is estimated to be 33%. Distributions used to reflect alternative values of the BF are also shown in the lower portion of the table; these were used in calculations performed to show the effect of varying the bypass fraction. For bypass fractions of 0.05 and 0.15, the long-term average penetrations of uranium through the UAP scrubber would be 29% and 37%, respectively.

Page I-30

.

<sup>·</sup> Table	Table I–17. Distributions of Long-Term Average Penetrations (%)							
Used to	Used to Estimate Uranium Releases from Plant 8 Scrubbers, 1953-1981							
	Distribu	tion Cha	racteristic	s <sup>a</sup>	Resulta	int Values <sup>b</sup>		
Scrubber	Shape	LB	_Mode	UB	Mean	Std. Dev.		
Calciner Rotary	Triangular	0.2	2.5	17.5	6.7	4.0		
kiln UAP	Triangular	0.8	5.0	34	13.3	7.6		
furnace Oxidation	Triangular	0.2	10	<b>65</b> <sup>°</sup>	25	14		
furnaces	Uniform	15	·	95	55	23		

UAP	Furnace Scrubbe	r Calcula	tions, Sep	tember 19	63-March	1966°
BF = 0.05	Triangular	0.2	12	75	29	16
BF = 0.10	Triangular	0.2	14	85	33	19
BF = 0.15	Triangular	0.2	16	95	37	21

<sup>a</sup> For most time periods; LB: lower bound; UB: upper bound.

<sup>b</sup> Mean values and standard deviations of scrubber penetrations derived from sampling the distribution.

<sup>c</sup> Three different values of the bypass fraction (BF) were considered; the central estimate was computed using the distribution for BF = 0.10.

#### Estimates of Plant 8 Scrubber Releases During 1982–1988

For the latter years of FMPC operation, release estimates were based upon the operating times for the various scrubbers and measurements that had been made of release rates during scrubber operation. Only the set of relatively recent release rate measurements (Table I-15) was used in the calculations of releases for this time period. The values in Table I-16, from the earlier high production period, are distinctly different from those obtained in years of low throughput.

Figures I-7 through I-9 contain the distributions of measured release rates for the rotary kiln scrubber, the box furnace scrubber, and the oxidation furnace scrubbers, respectively. There is no record of measurements of releases from the muffle furnace. In estimating releases, plant personnel assigned a release rate equal to the largest average value that was used by them for other Plant 8 furnaces. In recent years, the muffle furnace release rate was set equal to that for the rotary kiln. In calculations for this time period, the distribution of release rates for the rotary kiln were also applied to the muffle furnace.

The variations in the release rates are a primary source of uncertainty in release estimates for the latter years of plant operation. Figures I-7 through I-9 illustrate the relatively broad range of release rates measured in recent years. The operating times for the furnace operations were recorded by plant staff for the purpose of making release estimates. There is much less uncertainty associated with those data than with the release rate méasurements.

Page I-31

٠.

1.1.50.4

たいい

Ŀ

Collector of



Figure I-7. Distribution of release rates from the scrubber serving the rotary kiln measured between 1970 and 1988. The distribution was used in calculations of releases during 1982–1988.

Sec. Sec.

11



Figure I-8. Distribution of measured release rates from the scrubber serving the box furnace measured between 1979 and 1988. The distribution was used in calculations of releases during 1982–1988.

Server Start St.



Figure I-9. Distribution of release rates from the scrubber serving the oxidation furnaces measured between 1981 and 1988. The distribution was used in calculations of releases during 1982-1988.

#### Results of Plant 8 Scrubber Release Calculations

. • -

Best estimates of Plant 8 scrubber releases are presented for each year in the period 1953-1988 in Table I-18. The best estimate value for a particular year is given in the second column and is the median of the distribution of estimates computed for that year. The median value lies in the center of the distribution of estimates for the year; half the estimates were higher than the median value and half were lower. These median estimates have been rounded to two significant figures. The largest release from the Plant 8 scrubbers, 10,000 kg U, was estimated for the year 1961. Estimated median annual releases exceeded 5,000 kg during each of the years between 1959 and 1963 and were nearly that large in 1958 and 1964.

The 5th, 25th, 75th, and 95th percentile values for each distribution, also rounded, are given in the third through sixth columns of the table. These percentile values indicate the spread in the distribution and the range of the estimates produced. There is a 50 percent chance that the yearly release lies between the 25th and 75th percentiles. There is only a 10 percent chance that the release lies outside the bounds defined by the 5th and 95th percentile results. Cumulative probability distributions for four years are presented as examples in Figure I-10. The vertical line marks the 50th percentile or median values reported as the best estimates. The central portions of these distributions are approximately linear, an indication that the distributions are approximately lognormal.

> Radiological Assessments Corporation "Setting the standard in environmental health"

11

Page I	-34
--------	-----

ŧ

Į

Ì.

ł

C. ....

(1996) 1

<u></u>	Tabl	e I–18. Annual Re	lease Estimates f	or Plant 8 Scrub	bers		
	Best estimate						
	of release	Other percer	itiles in distributi	ion of release esti	mates (kg U)		
Year	(kg U)	5th percentile	25th percentile	75th percentile	95th percentile		
1953	100	,13	43	210	570		
1954	1,500	340	810	2,600	5,800		
1955	2,800	660	1,600	4,900	11,000		
1956	4,300	1,100	2,500	7,400	16,000		
1957	3,400	820	1,900	5,900	13,000		
1958	4,500	1,100	2,500	7,400	16,000		
1959	6,700	2,400	-4,400	10,000	21,000		
1960	7,600	2,900	5,000	12,000	24,000		
1961	10,000	4,500	7,100	15,000	29,000		
1962	6,500	2,400	4,200	9,500	20,000		
1963 <sup>a</sup>	6,900	2,200	4,200	. 11,000	21,000		
. 1964 <sup>a</sup>	4,700	1,800	3,100	7,800	17,000		
1965 <sup>a</sup>	1,000	470	700	1,600	3,100		
1966 <sup>a</sup>	240	120	. 180	340	640		
1967	570	<b>290</b> ·	430	830	1,500		
1968	1,200	• <b>640</b>	910	1,700	3,300		
1969	270	140	200 ·	380	<b>700</b> .		
1970	73	36	53	110 /	240		
1971	62	27	43	96	230		
1972	5	2	3	7	16		
1973	5	2	4	8	17		
1974	34	5	16	72	180		
1975	330	100	200	510	800		
1976	150	65	110	200	330		
1977	460	130	280	700	1,200		
1978	76	<b>28</b> -	- 51 -	110	180		
1979	280	ស	· 150	460	900		
. 1980	<b>90</b>	26 ·	50	180	400		
1981	120	35	68	250	530		
1982	77	<b>36</b> ·	558	110	160		
1983	180	. 79	130	260	430		
1984	150	<del>59</del>	100	210	310		
1985	110	44	68	170 ·	290		
1986	, 210	93	150	310	510		
1987	120	51	84	180	<b>310</b>		
1988	110	44	· · · · · · 67	170			

Ξ.

<sup>a</sup> In making these estimates it was assumed that the bypass for the UAP scrubber operated 10 percent of the time between September 1963 and March 1966.

the second pater 1.

. .

· :







Figure I-11. Median estimates of release from Plant 8 scrubbers.

Radiological Assessments Corporation "Setting the standard in environmental health".

Page I-35

Page I-36	The Fernald Dosimetry Reconstruction Project		
	Tasks 2 and 3, Source Terms and Uncertainties		

The tails of the distributions in Figure I-10 deviate from the slope of the line defined by the center of the distribution. As noted previously, the upper ends of the distributions are subject to distortion by the instability (for high values of penetration) of Eq. (I-7), which was used for most of the computations. The distribution of estimates for 1957 is broader and the slope of the line is greater than for the other distributions shown. Both facts indicate greater uncertainty in the estimate for that year. In contrast, the distribution for 1984 is relatively flat. Lower uncertainties in estimates for years in the 1980s is due to the fact that operating data were well known for those years.

The median estimates of the yearly releases from the Plant 8 scrubbers are shown in Figure I-11. The central estimates for the years 1963-1966 correspond to results in Table I-18 and reflect a bypass fraction (BF) of 0.1 for the UAP scrubber. Table I-19 compares the results for alternative values of BF equal to 0.05 and 0.15. The value of BF affects the average penetration for that scrubber directly, but has little effect on the median release estimates for all scrubbers. The effects on total releases were greatest in 1964 and 1965 when the bypass operated throughout the year.

- <u>-</u>1151-1

· · · · · · · · ·	Mean UAP scrubber	M froi	ledian rel n all Plar	ease (kg it 8 scrúbl	U) ber <u>s</u>
BFa	penetration	1963	1964	1965	1966
).05	29	6500	4500	940	230
).10	33	6900	4700	1000	240
).15	37	7000	5200	1100 _	250

·· . : · ·

i. T

みじからい

ジュアムこ

9 . . . g

ł

<sup>a</sup> BF: bypass fraction for UAP scrubber during September 1963– March 1966; increasing values raise the long-term average penetration through that scrubber (Col. 2).

Table I-20 contains summary release estimates by decade and for the entire period from 1953 through 1988. These estimates are also rounded to two significant figures. The releases for each decade were computed as part of the Monte Carlo procedure used for the annual release estimates. The distribution for the total for 1953-1988 was obtained by Monte Carlo calculations using the distributions of releases during each of the four decades. The shapes of the distributions of the sums, particularly the one for all years, approach that of a normal distribution.

The table illustrates the importance of the releases during the 1960s when plant production was highest (see Figure I-1). The median estimate for the 1950s was second highest, about 60% of that for the following full decade of operation. Since the early 1970s, when the plant was placed on a reduced operating schedule and subsequently shut down, its utilization was only periodic and releases have been much lower than they were during the early years of operation.

Appendix I	
Releases from Plant 8 Scrubber Systems	· ·

	Best estimate of release	Other percentiles in distribution of release estimates (kg U)					
Period	(kg U)	5th percentile	25th percentile	75th percentile	95th percentile		
1950s	29,000	17,000	23,000	37,000	53,000		
1960s <sup>a</sup>	47,000	30,000	39,000	57,000	78,000		
1970s	1,700	1,000	1,400	2,100	2,700		
1980s	1,400	980	1,200	1,600	2,000		
1953–			•	· ·			
1988 <sup>a</sup>	81,000	56,000	69,000	95,000	130,000		

Page I-37

<sup>a</sup> In making these estimates it was assumed that the bypass for the UAP scrubber operated 10 percent of the time between September 1963 and April 1966.

The release estimates for the Plant 8 scrubbers that are summarized in the tables and graphs above are higher than previous FMPC estimates. The fundamental reason for the difference is that the present calculations consider ranges of individual scrubber performance that are broader than the single collection efficiency of 83 percent that had been assumed for all of the scrubbers. Sometimes the performance was better; at other times it was much worse than had previously been assumed. Inclusion of the variations in performance and of uncertainties in other parameters of the model has led to a relatively wide range of estimates for any particular year. Uncertainties for estimates of releases in the most recent years of operation are primarily associated with variations in the release rate factors for the individual scrubbers.

### ALTERNATIVE CALCULATIONS OF RELEASES

**i** 

Alternative calculations of releases from the Plant 8 scrubbers were performed to test the effect of different modeling choices on the results. The first of these involved the use of correlations between scrubber penetration and the accumulation of uranium in the scrub liquor. The second alternative approach was to derive release to production ratios for the early 1960s, when the scrubbers were studied most intensively, and to apply them to the entire period of operation. These two modeling approaches are described below and the results of the calculations are summarized.

• Alternative 1. Correlations of the type shown in Eq. (1-5) were used as part of the procedure to estimate releases for the years 1953-1981. Alternatives that employed a single correlation for all scrubbers or separate correlations for each individual scrubber were considered. The results of calculations that employed such correlations were counterintuitive. While estimated releases during years of high uranium recovery were both lower and higher than those presented above, releases during years when Plant 8 was virtually shut down were predicted to be substantial. This is shown in Figure I-12. The correlation cannot be applied to the many later years when uranium recovery operations had

declined substantially. A second factor is that the correlation is logarithmic; at low rates of uranium accumulation in scrub liquor, there can be large variations in penetration estimates obtained from the correlation.



Figure I-12. Comparison of alternative median estimates of annual releases with those given in Table I-18. Penetration estimates for Alternative 1 employed a correlation between scrubber penetration and scrub liquor accumulation rate (page I-22). With this approach, predicted releases estimated for years when Plant 8 was virtually shut down were very high and lack credibility. Alternative 2 employed a normalized release rate derived for 1960-1963. The normalized release rate for a period of high production and many operational problems is not considered a good predictor during years of lower production.

• Alternative 2. A normalized release rate based upon results for the early 1960s, when most of the scrubber efficiency measurements were made, was also used to estimate releases in other years. The normalized release rate was defined as the total scrubber release rate (kg U  $y^{-1}$ ) divided by the Plant 8 production rate (MTU  $y^{-1}$ ). Calculations of releases for the period 1961–1963, prior to installation of the bypass line for the UAP scrubber, were used to develop the normalized release rate. Calculations of the normalized release rates were performed as part of the main simulation for the 1960s and thus reflect the 3- and 6-month time intervals that were used during those three years to fit available scrub liquor data and to isolate the period of bypass installation. The median normalized release rate was  $3.1 \text{ kg U MTU}^{-1}$ . The geometric standard deviation of this parameter was about 1.6; extreme values were 0.71 and 16 kg U MTU^{-1}. Results of release calculations using this approach for the period 1953–1981 are also shown in Figure I-12.

Appendix I

ž,

ćέ

#### Releases from Plant 8 Scrubber Systems

Predicted releases using this approach are generally higher than the values in Table I-18. However, for years before 1964, the median estimates obtained for Alternative 2 lie within the central half (25th-75th percentiles) of the base case estimates in Table I-18. The differences between the two approaches during 1961-1963 reflect the different bases for the calculations and the application of a normalized release rate derived over the period to individual years within it. During later years, the normalized release approach yields overpredictions because it does not take advantage of the known scrub liquor uranium collection data. The normalized release rate for a period of high throughput and many operational problems is not considered as good a predictor of releases during periods of lower production.

### PHYSICAL CHARACTERISTICS OF THE DISCHARGES

Analysis of the Plant 8 scrubber releases suggests that two distinct types of particles were present in the emissions. The first type consisted of solid particles of  $U_3O_8$  of less than 10 micrometers in diameter which penetrated the scrubber systems. The second type was droplets of entrained scrub liquor that contained suspended uranium particles.

No reports have been found of measurements of the sizes of the particles or liquid droplets released to the atmosphere from the Plant 8 scrubbers. Limited information on the distributions of particle sizes in furnace exhausts was used, together with scrubber performance data (Lund 1971) to estimate the distribution of particle sizes that would not be captured by the scrubber. The analysis is described in Appendix D of the Task 4 report (Killough et al. 1993). Table I-21 contains the calculated size distribution for these particles.

Table I-21. Calculated Size Distribution of U308

P	Particles Expected to Penetrate the Scrubbers				
	Diameter	Frequency			
	Range (µm)	(percent)			
	0–1	71.4			
	1–2	11.8			
	2–5	14.6			
	5–10	2.1			

Using information on the expected collection efficiencies for the scrubbers, it was estimated that about 30% of the total uranium emitted from the Plant 8 scrubbers would have been small particles of  $U_3O_8$  (Killough et al. 1993). A second analysis was performed, using the same approach with more complete compilations of scrubber inlet loading data (Table I-14) and scrubber penetration estimates (summarized in Table I-17). The results of the second stochastic calculations indicated a median penetrating particle fraction of 0.25. The distribution had a GSD of 1.5. The mean value would be about 0.27, not greatly different from the initial estimate.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page I-39

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

ŝ.

....

The median fraction due to entrainment of scrub liquor was estimated in the second analysis was 75%. Based upon information in the literature, the scrub liquor droplets produced by entrainment were assumed to follow a lognormal distribution with a median diameter of 140 µm and a GSD of 1.4. Evaporation during downwind plume travel in the atmosphere would have reduced the original entrained droplets to hypothetical solid polycrystalline spheres with diameters about 46% of the diameters of the original spherical liquid droplets (Killough et al. 1993). 

The solid polycrystalline spheres would consist of a mixture of various salts such as sodium chloride, sodium phosphate, sodium carbonate, and sodium uranates as well as sodium hydroxide. The densities of a typical liquid droplet and a typical polycrystalline solid particulate resulting from evaporation of the droplet were calculated to be approximately 1.1 and 2.0 g cm<sup>-3</sup>, respectively (Killough et al. 1993).

1

#### CONCLUSIONS

Several high temperature and fume bearing exhausts in Plant 8 were treated using scrubbers that employed caustic solutions. Furnace exhausts likely to contain substantial concentrations of airborne particles were passed through ejector-venturi scrubbers. The scrubber releases were not measured routinely. However, special measurement efforts undertaken during the early 1960s and unexplained losses of uranium from the facility led to the conclusion that scrubber exhausts were an important source of routine operating losses. · . . . Lond the parts

Previous estimates of releases from these scrubber systems were reviewed. Plant records were found in storage that provided data on the amounts of uranium scrubbed from the airborne effluents during periods ranging from one month to one year. Plant 8 production (uranium recovery) data were compiled to indicate the changing scale of plant operations. Memos and analytical data sheets were located that described measurements of scrubber efficiencies performed in Plant 8, primarily during 1961–1965. These data were compiled for each scrubber for use in calculations of releases from 1953 through 1981. <sup>1</sup> Data from measurements of release rates from the various stacks collected in later years were also compiled and used for calculations for the period 1982-1988. Measured releases during these years were much lower than those observed during years of high production.

For both time periods, simple models of releases were applied to individual scrubbers. The 6- to 12-month average ratio of the amount of uranium collected in scrub liquor to plant production was found to be a reasonable link between production data and scrubber operations when information on scrub liquor collections was not available.

Monte Carlo calculations were performed to estimate uranium releases from the Plant 8 scrubbers. The ranges of all of the parameters used in calculations were relatively broad, owing both to variability and to limited historic data. The results of the calculations reflect these uncertainties. The 90-percent confidence interval for the release during a particular year is relatively wide, typically from a factor of about 2-3 lower to a factor of about 2-3 higher than the median.

Overall, it is estimated that the Plant 8 scrubbers released about 81,000 kg of uranium; the 90-percent confidence interval for this estimate is 56,000 to 130,000 kg of uranium. The decade of highest releases was the 1960s when production peaked. High releases were also · · · .

÷.

estimated for the 1950s. Estimated releases during the other two decades were very much lower.

During the first two decades, when releases were highest, it is estimated that about 25% of the releases were of small particles of  $U_3O_8$  and that the remainder were the result of entrainment of contaminated scrub liquor containing suspensions of uranium compounds. The importance of the latter process during this period is supported by the actual data on scrubber penetration and comparison of the measured performance with that expected for the scrubbers.

#### REFERENCES

÷.

- Adams, W. J. Material unaccounted for in calcining of Atlas Moab ore concentrates. Internal memorandum to R. M. Spenceley. Cincinnati, OH: National Lead Company of Ohio; 27 August 1975.
- Anonymous. Typewritten sheet of data on particle sizes at inlets to Plant 8 scrubbers. Cincinnati, OH: National Lead Company of Ohio; no date.
- Anonymous. History FMPC inventories U. Notebook of data on inventories and production. Cincinnati, OH: National Lead Company of Ohio; circa 1973–1976.
- Anonymous. Plant 8 furnace off-gas scrubbers, operating experience, uranium recovery data. Cincinnati, OH: National Lead Company of Ohio; October 1980.
- Anonymous. Four-page untitled memorandum on potential scrubber releases based upon the NLCO internal memorandum of E. W. Randle. Cincinnati, OH: Waite, Schneider, Bayless & Chesley; 9 February 1989.
- Bardo, R. W. Summary of emission data for Plant 8 wet scrubbers, 1/80 thru present. Internal memorandum to M. W. Boback. Cincinnati, OH: Westinghouse Materials Company of Ohio; 16 September 1985.
- Bardo, R. W. Procedure for reporting wet scrubber losses to the atmosphere. Cincinnati, OH: Westinghouse Materials Company of Ohio; 30 July 1986.
- Beirne, P. J. Plant 8 scrubber stack emissions. Internal memorandum to D. C. Bonfer et al. Cincinnati, OH: Westinghouse Materials Company of Ohio; 23 April 1988.
- Beers, H. M. Plant 8 off-gas systems. Internal memorandum to C. R. Chapman, P. G. DeFazio, and J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 26 September 1961.
- Bipes, R. L. Uranium loss from rotary kiln scrubber. Internal memorandum to H. M. Beers. Cincinnati, OH: National Lead Company of Ohio; 20 August 1962.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page I-41

 $\sim$ 

22

- Bipes, R. L. UAP scrubber efficiency. Internal memorandum to K. R. Brandner. Cincinnati, OH: National Lead Company of Ohio; 10 September 1963 (1963a).
- Bipes, R. L. UAP scrubber loading Plant 8. Internal memorandum to E. Mode. Cincinnati, OH: National Lead Company of Ohio; 5 November 1963 (1963b).
- Bipes, R. L. NPR furnace Doyle scrubber efficiency Plant 8. Internal memorandum to K. R. Brandner. Cincinnati, OH: National Lead Company of Ohio; 27 November 1963 (1963c).
- Bipes, R. L. UAP scrubber efficiency tests. Internal memorandum to H. M. Beers. Cincinnati, OH: National Lead Company of Ohio; 11 February 1964.
- Boback, M. W.; T. A. Dugan; D. A. Fleming; R. B. Grant; R. W. Keys. History of FMPC radionuclide discharges; Cincinnati, OH: Westinghouse Materials Company of Ohio; FMPC-2082; 1987.
- Bonfer, D. C. Plant 8 scrubbers. Internal memorandum to A. M. Schwartzman. Cincinnati, OH: Westinghouse Materials Company of Ohio; 28 April 1988.

Calhane, R. W. Process description of the Box Furnace operation. FMPC Manufacturing Standards Specification No. 8A-102.3. Cincinnati, OH: National Lead Company of Ohio; 30 September 1958 (1958a).

- Calhane, R. W. Process description for wet scrubbers process ventilation. FMPC Manufacturing Standards Specification No. 8A-204. Cincinnati, OH: National Lead Company of Ohio; 30 September 1958 (1958b).
- Calhane, R. W. Process ventilation by wet scrubbers. FMPC Manufacturing Standards Specification No. 8C-204. Cincinnati, OH: National Lead Company of Ohio; 9 April 1962.
  - Chenault, E. M. Evaluation of Plant 8 off-gas scrubber. Internal memorandum to K. R. Brandner. Cincinnati, OH: National Lead Company of Ohio; 27 June 1961.
  - CIV (Committee on Industrial Ventilation). Industrial ventilation, a manual of recommended practice. 16th Ed. Lansing, MI: American Conference of Governmental Industrial Hygienists; 1980.
  - Courtney, D. L. Summary of operating losses (SS pounds), fiscal years 1963 &1964. Handwritten tabulation of operating losses that appears to have been prepared by L. Rathgens. Cincinnati, OH: National Lead Company of Ohio; 26 October 1964.
  - Danielson, J. A. (ed.) Air pollution engineering manual. 2nd Ed. Research Triangle. Park, NC: U. S. Environmental Protection Agency; 1973.

\$.

- DeFazio, P. G. Idea letter revisions to UAP furnace ventilation systems. Internal memorandum to J. H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 18 June 1964.
- DeFazio, P. G. Feasibility study re: reduction of scrubber losses. Internal memorandum to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 17 February 1965.
- DeFazio, P. G. UAP furnace ventilation -- Plant 8. Internal memorandum to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 11 January 1966.
- Diehl, A. R. Measured losses Plant 8 furnace off-gas scrubbers. Internal memorandum to M. W. Boback. Cincinnati, OH: National Lead Company of Ohio; 21 October 1980.
- Dunning, D. E., Jr.; Schwarz, G. Variability of human thyroid characteristics and estimates of dose from ingested <sup>131</sup>I. Health Phys. 40: 661-675; 1981.
- DI (Decisioneering, Inc.). Crystal Ball<sup>®</sup>, a forecasting and risk management program for the Macintosh, version 2.0. Boulder, CO: Decisioneering, Inc.; 1991.
- Egart, J. F. SOP enriched (0.96% <sup>235</sup>U max.) high grade calciner operation 300 & 500 series. FMPC Manufacturing Standards Specification No. 8CE-104. Cincinnati, OH: National Lead Company of Ohio; 26 December 1962 with revisions to 5 April 1963.
- GFA (initials only). Drawing of ventilation system for UAP furnace. Cincinnati, OH: National Lead Company of Ohio; 6 April 1966.
- Gessiness, B. Report on the investigation of B-PID in Plant 8. Internal memorandum to C. R. Chapman and S. Marshall. Cincinnati, OH: National Lead Company of Ohio; 4 June 1964.
- Harvey, M. D.; Heareth, H. C.; Hicks, W. R. Process description Rotary Kiln. FMPC Manufacturing Standards Specification No. 8A-102.5. Cincinnati, OH: National Lead Company of Ohio; 1 September 1958.
- Hicks, W. R. Description of the multi-hearth calciner operation. FMPC Manufacturing Standards Specification No. 8A-101.2. Cincinnati, OH: National Lead Company of Ohio; 10 November 1958 (1958a).
- Hicks, W. R. Process description UAP (diuranate) furnace. FMPC Manufacturing Standards Specification No. 8A-101.9. Cincinnati, OH: National Lead Company of Ohio; 1 September 1958 (1958b).
- Hicks, W. R. Graphite Furnace. FMPC Manufacturing Standards Specification No. 8A-102.1. Cincinnati, OH: National Lead Company of Ohio; 1 September 1958 (1958c).

Page I-44

:

1

Hicks, W. R. Muffle Furnace. FMPC Manufacturing Standards Specification No. 8A-102.2. Cincinnati, OH: National Lead Company of Ohio; 1 September 1958 (1958d).

Hicks, W. R. Process description — Oxidation Furnace. FMPC Manufacturing Standards Specification No. 8A-102.4. Cincinnati, OH: National Lead Company of Ohio; 1 September 1958 (1958e).

Hicks, W. R. Process description — Green Salt Reverter. FMPC Manufacturing Standards Specification No. 8A-102.6. Cincinnati, OH: National Lead Company of Ohio; 1 September 1958 (1958f).

- Hill, C. A. Plant 8 scrubber emissions from FMPC-2082 and upper limit estimation. Internal memorandum to T. R. Clark. Cincinnati, OH: Westinghouse Materials Company of Ohio; 7 March 1989.
- Hoffman, F. O.; Gardner, R. H. Evaluation of uncertainties in radiological assessment models. In: Till, J. E.; Meyer, H. R.; eds. Radiological assessment, a textbook on environmental dose analysis. Washington, DC: U. S. Nuclear Regulatory Commission; Document NUREG/CR-3332; September 1983.
- Hyatt, E. C.; Moss, W. D.; Schulte, H. F. Particle size studies on uranium aerosols from machining and metallurgy operations. AIHA Journal 20: 99-107;1959.
- Killough, G. G.; Case, M. J.; Meyer, K. R.; Moore, R. E.; Rogers, J. F.; Rope, S. K.; Schmidt, D. W.; Shleien, B.; Till, J. E.; Voillequé, P. G. The Fernald dosimetry reconstruction project, task 4: environmental pathways—models and validation. Rep. CDC-3. Neeses, SC: Radiological Assessments Corporation; 1993.

Levy, L. M. FMPC equipment capacity charts. Internal memorandum to large distribution. Cincinnati, OH: National Lead Company of Ohio; 26 September 1975.

- Lund, H. F. Industrial pollution control handbook. New York: McGraw Hill, Inc. 1971.
- Marshall, J. E. Recovery plant scrubber loss report for the month of October 1959. Cincinnati, OH: National Lead Company of Ohio; 21 October 1959.
- Mead, J. C. History of FMPC residue recovery operations. Cincinnati, OH: National Lead Company of Ohio; NLCO-1096; 25 August 1972.

McCreery, P. N.; Gessiness, B. Request for approved inventory write-offs (requests numbered 1-51); request and authorization to remove SS material from inventory (requests numbered 52-187); authorization to remove SS material from inventory (authorizations numbered 187cc1-203). Cincinnati, OH: National Lead Company of Ohio; dated 30 October 1959 through 31 October 1978. Appendix I

9....

R-?

**Releases from Plant 8 Scrubber Systems** 

- Noyes, J. H. Idea letter electrostatic precipitators for the primary calciner and the UAP Furnace off-gas systems — Plant 8. Letter to C. L. Karl, Atomic Energy Commission. Cincinnati, OH: National Lead Company of Ohio; 7 June 1962.
- Noyes, J. H. Request for approved inventory write-offs, normal and enriched SS scrubber materials - fiscal year 1965. Letter to C. L. Karl, Atomic Energy Commission. Cincinnati, OH: National Lead Company of Ohio; 17 July 1964.
- NLCO (National Lead Company of Ohio). Analytical data sheets showing results of measurements of scrubber intake and exhaust uranium concentrations. Cincinnati, OH: National Lead Company of Ohio; 1958–1965.
- Perry, R. H., Green, D. W.; Maloney, J. O. (eds.) Perry's chemical engineers' handbook. Sixth edition. New York: McGraw Hill Book Company; 1984.
- Quality Control Group. Box Furnace process specification. FMPC Manufacturing Standard Specification No. 8B-408.1. Cincinnati, OH: National Lead Company of Ohio; 1 June 1959 (1959a).
- Quality Control Group. Oxidation Furnace (Herreschoff Roaster) process specification. FMPC Manufacturing Standard Specification No. 8B-408.2. Cincinnati, OH: National Lead Company of Ohio; 1 June 1959 (1959b).
- Quality Control Group. Hydrometallurgical system process specification. FMPC Manufacturing Standard Specification No. 8B-408.3. Cincinnati, OH: National Lead Company of Ohio; 1 June 1959 (1959c).
- Quality Control Group. Rotary Kiln process specification. FMPC Manufacturing Standard Specification No. 8B-408.4. Cincinnati, OH: National Lead Company of Ohio; 1 June 1959 (1959d).
- Quality Control Group. Graphite Furnace process specification. FMPC Manufacturing Standard Specification No. 8B-408.5. Cincinnati, OH: National Lead Company of Ohio; 1 June 1959 (1959e).
- Quality Control Group. Green salt (UF<sub>4</sub>) pyrohydrolysis system process specification.
  FMPC Manufacturing Standard Specification No. 8B-408.6. Cincinnati, OH: National Lead Company of Ohio; 1 June 1959 (1959f).
- Quality Control Group. Muffle Furnace process specification. FMPC Manufacturing Standard Specification No. 8B-408.7. Cincinnati, OH: National Lead Company of Ohio; 1 June 1959 (1959g).

. ,

15

- Rakiewicz, R. W.; Jackson, B.; Phoenix, D. Source emissions test report, box furnace scrubber stack, Westinghouse Materials Company of Ohio, Fernald, Ohio. West Chester, PA: Roy F. Weston; April 1988 (1988a).
- Rakiewicz, R. W.; Jackson, B.; Phoenix, D. Source emissions test report, oxidation furnace #1 scrubber stack, Westinghouse Materials Company of Ohio, Fernald, Ohio. West Chester, PA: Roy F. Weston; April 1988 (1988b).
- Rakiewicz, R. W.; Jackson, B.; Phoenix, D. Source emissions test report, rotary kiln scrubber stack, Westinghouse Materials Company of Ohio, Fernald, Ohio. West Chester, PA: Roy F. Weston; April 1988 (1988c).
- Rakiewicz, R. W.; Jackson, B.; Phoenix, D. Source emissions test report, rotary kiln scrubber. stack, Westinghouse Materials Company of Ohio, Fernald, Ohio. West Chester, PA: Roy F. Weston; October 1988 (1988d).

Rakiewicz, R. W.; Jackson, B.; Phoenix, D. Source emissions test report, calciner scrubber stack, Westinghouse Materials Company of Ohio, Fernald, Ohio. West Chester, PA: Roy F. Weston; October 1988 (1988e).

- Randle, E. W. Investigation of methods of measuring and reporting uranium losses to the atmosphere. Internal memorandum to A. F. Pennak. Cincinnati, OH: National Lead Company of Ohio; 12 March 1971.
  - Rathgens, L. Handwritten data sheets of waste disposal information for FMPC. Cincinnati, OH: National Lead Company of Ohio; 1970.
  - Rathgens, L. et al. (all authors not known). Typed and handwritten summaries of product deliveries and unit costs for FY-1953 through FY-1976A and production tonnage compilations for FY 1953-1984. Cincinnati, OH: National Lead Company of Ohio; 11 January 1985.
  - Ricci, J. E.; Loprest, F. J. Phase relations in the system sodium oxide-uranium trioxidewater at 50 and 75°. J. Am. Chem. Soc. 77: 2119-2129; 1955.
  - Ross, K. N. Estimated U losses through Plant 8 box furnace stack. Internal memorandum to A. R. Diehl. Cincinnati, OH: National Lead Company of Ohio; 12 March 1979.
  - Ross, K. N. Estimated uranium losses in Plant 8 box furnace stack. Internal memorandum to A. R. Diehl. Cincinnati, OH: National Lead Company of Ohio; 20 May 1980.
  - Ross, K. N. Uranium loss through Plant 8 scrubbers. Internal memorandum to R. B. Weidner. Cincinnati, OH: National Lead Company of Ohio; 1 June 1982.

Page I-46

Appendix I

Releases from Plant 8 Scrubber Systems

- Ross, K. N. Uranium loss through Plant 8 scrubbers. Internal memorandum to R. B. Weidner. Cincinnati, OH: National Lead Company of Ohio; 9 May 1983.
- Savage, F. N. FMPC equipment capacities. Cincinnati, OH: National Lead Company of Ohio; Document NLCO-1127; 26 September 1975.
- Schmidt, D. W. Plant 8 scrubber efficiencies and related information. Fernald dosimetry reconstruction project technical memorandum. Darnestown, MD: Health Physics Applications; 18 September 1992.
- Starkey, R. H. Evaluation of Plant 8 off-gas scrubbers. Internal memorandum to H. M. Beers. Cincinnati, OH: National Lead Company of Ohio; 11 April 1961.
- Starkey, R. H. Information pertaining to unmeasured uranium losses. Internal memorandum to L. M. Levy. Cincinnati, OH: National Lead Company of Ohio; 16 July 1964.
- Vath, J. E. Handwritten report on measured loss and product measurements. Initialed by B. Gessiness. Cincinnati, OH: National Lead Company of Ohio; 2 June 1964 (1964a).
- Vath, J. E. Report on the sampling of Plant 8 trailer cake. Internal memorandum to B. Gessiness. Cincinnati, OH: National Lead Company of Ohio; 3 August 1964 (1964b).
- Vath, J. E. Plant 8 scrubber losses. Internal memorandum to B. Gessiness. Cincinnati, OH: National Lead Company of Ohio; 11 August 1964 (1964c).
- Vath, J. E. Summary of operations and other reference information. Handwritten version of report to Atomic Energy Commission. Cincinnati, OH: National Lead Company of Ohio; 15 November 1966.
### APPENDIX J

# EMISSIONS OF RADON, RADON DAUGHTERS, AND GAMMA RADIATION FROM THE K-65 SILOS

#### INTRODUCTION

This appendix provides detailed descriptions of the current estimates of emissions of  $^{222}$ Rn and Rn daughters from the FMPC, and detailed information related to emissions of gamma radiation from the FMPC. These releases were primarily from the K-65 Silos and from other stored K-65 material. First, however, we present characteristics of and general information about the K-65 Silos and material (page J-2). Since the current estimates of releases utilize the same general methods for air exchange and diffusion releases as the previous estimates, we next describe the previous estimates (page J-12).

Then we discuss the current estimates of releases of  $^{222}$ Rn and daughters that have been developed in the Fernald Dosimetry Reconstruction Project, including the models used, the distributions chosen to represent parameter uncertainties, the mechanics of the calculations, and the results (page J-16). Most of the effort on Rn releases has been toward estimates of releases from the K-65 Silos for the periods 1959–1979 and 1980–1987. These two periods encompass most of the time under consideration in this Project. And, it appears that the relative impacts of Rn releases, compared to releases of uranium to air, will be highest in the 1970s and 1980s. Releases of Rn in the early 1950s from drummed K-65 material, stored at the FMPC, may also be relatively significant, compared to uranium releases, because operations at the site were just beginning in this early period. The discussion about our current estimates of  $^{222}$ Rn and Rn daughter releases, in this Appendix, includes the following subsections:

- Sources of <sup>222</sup>Rn Releases at the FMPC (page J-16)
- General Methodology for Current Estimates of Releases from K-65 Silos (page J-22)
- Calculational Strategy for Rn Emissions from K-65 Silos (page J-24)
- Implementation of Calculations (page J-27)
- Model for Air Exchange Releases from K-65 Silos for 1980–1987 (page J-27)
- Model for Diffusion Releases from K-65 Silos for 1980–1987 (page J-34)
- Total Releases from K-65 Silos for 1980–1987(page J-37)
- Model for K-65 Silo Rn Production Rates (page J-38)
- Model for Total Releases from K-65 Silos for 1959–1979 (page J-41)
- Model for 1988 Releases from K-65 Silos (page J-46)
- Models for 1952–1958 Releases from K-65 Silos (page J–53)
- Model for 1951–1953 Releases from Drummed K-65 Material (page J-55)
- Model for Rn Daughter Releases (page J-64)
- Total Rn and Rn Daughter Releases for the Operating Period 1951–1988 (page J–67)
- Summary of Current Estimates of Rn and Daughter Releases (page J-69)
- Conclusions About Current Estimates (page J-71)

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

We also discuss an alternative calculation, performed to corroborate current estimates of releases (page J-73). The last sections of the Appendix describe data that will be used later in the Project, for transport and exposure calculations: (1) parameters to be used for application of the building wake effects model to the K-65 Silos and associated berms (page J-85), and (2) parameters to be used for the assessment of direct exposures to gamma radiation emitted from the Silos (page J-86). The section on parameters for direct exposures to gamma radiation includes detailed information about the radiation sources. Calculations of exposure rates at various distances from the Silos will be discussed in the report of Task 6 of this Project. Following the reference list (page J-97) are two annexes. The first presents a detailed data table, used in our analyses (page J-104). The second provides a summary of the general approaches to the calculations, equations used, and parameters used for the current estimates of  $^{222}$ Rn and Rn daughter releases (page J-105).

In the period of consideration, 1951–1988, we have identified one potential episodic Rn release from the K-65 Silos. This release, which occurred April 25, 1986, is discussed in Appendix K.

Note that in this Appendix, when "Rn" or "radon" is used, we refer to <sup>222</sup>Rn.

\_\_\_\_

#### CHARACTERISTICS OF K-65 AND METAL OXIDE SILOS AND MATERIALS

For the current estimates of <sup>222</sup>Rn releases from the FMPC, the K-65 Silos (Silos 1 and 2) and drummed K-65 material stored on the site are considered, for reasons discussed later in this Appendix (see page J-17), to be the only significant sources of Rn releases. The previous estimates of <sup>222</sup>Rn source terms from the FMPC considered the K-65 Silos to be the only sources. The current estimates of direct exposures to people outside the FMPC boundary from radioactive materials on the site consider the K-65 Silos and the Metal Oxide Silo, Silo 3, to be the only significant sources of gamma radiation (see page J-87). Thus, the characterization information in this section focuses primarily on the K-65 and Metal Oxide Silos.

15**154**1111 - 112 - 11

#### - Facility Description

. . . . . . .

Four large concrete storage tanks, called silos, are located in the waste disposal area of the FMPC, as shown in Figure J-1 below. These silos are in a north-south line, and are about 1000 ft west of the production area. The silos are numbered one to four, with the southernmost silo being Silo 1. Silos 1 and 2 contain K-65 waste raffinate material from the extraction processing of uranium ore, and are thus referred to as the K-65 Silos (DOE 1990). The K-65 material was slurried from the refinery (Plant 2/3) through pipes into the Silos, and decanted with the use of baffles and weirs located along the height of the Silo walls. The K-65 material originated both from onsite ore processing and from processing at the Mallinckrodt Chemical Works in St. Louis. The ore processed was pitchblende from the Belgian Congo, having very high uranium (and thus uranium-chain radionuclides) concentrations. The K-65 material contains very high concentrations of  $^{226}$ Ra (DOE 1990), which decays to form  $^{222}$ Rn. The K-65 material has long been known as a significant source of  $^{222}$ Rn (Strattman 1955; Boback 1979; and others). .

1.1





<u>.</u>....

4

-

Figure J-1. Location of the waste storage silos on the west side of the FMPC site.

Silo 3, the Metal Oxide Silo, contains the metal oxide waste raffinate material from the extraction processing of uranium ores and concentrates. Unlike the K-65 material, the metal oxide material was dewatered and spray calcined to produce a dry, powder-like material (DOE 1990). The metal oxide material was conveyed from Plant 2/3 by high-pressure air, through pipes, to the Silo. All of the metal oxide material originated from onsite processing. The metal oxide material is also contaminated with radioactivity, but the concentration of  $^{226}$ Ra is much lower than in the K-65 material. Silo 4 has never been used, and contains only a small amount of water with very low levels of radioactive and chemical contaminants (DOE 1990).

A set of large scale topographic drawings of the FMPC site (Woolpert circa 1988) shows the locations of the silos and also includes the Ohio State Plane (OSP) coordinate system. We scaled approximate coordinates for the centers of the silos from these drawings. These coordinates are shown in Table J-1.

As shown in Figure J-2, each silo is 80 ft in diameter with an overall height of 36 ft, of which about 26 ft 8 in is the tank wall and about 9 ft 4 in is the domed silo roof (Preload 1951a; Shanks and Vogel 1988). The walls are 8 inch thick concrete and the domes are nominally 4 inch thick concrete (Preload 1951a; Shanks and Vogel 1988). The total volume of each silo is about 160,000 ft<sup>3</sup> (4500 m<sup>3</sup>). The K-65 Silos are roughly two thirds full (see later discussion, page J-29). In 1972 the Metal Oxide Silo was estimated to contain 150,000 ft<sup>3</sup> of material (Nelson 1972b). This is almost equal to the total volume, so the Metal Oxide Silo is considered full. Figure J-3 shows the Silos as they appeared in 1965 (DOE 1965a).

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

s.

1. 1. - 1. 11

1. C. S.



Figure J-2. General cross section of the K-65 and Metal Oxide Silos.

History of K-65 Disposal

The K-65 Silos were constructed in 1951 to 1952 for the temporary storage of K-65 materials (Catalytic circa 1950s(a); NLCO 1962; Grumski 1987a; Shanks and Vogel 1988). Originally the K-65 residues were to be returned to the African Metals Corporation, which provided the pitchblende ore, called Q-11, processed for its high uranium content. The K-65 residue is one particular waste product from the extraction of uranium from pitchblende ores, and contains high concentrations of  $2^{226}$ Ra, gold, and other metals.

The FMPC-2082 report indicated that K-65 materials were added to the silos from 1953 until 1955 (Boback et al. 1987). Additional documentation about the history of disposal of K-65 at the FMPC has been obtained. This information is summarized in Table J-2 and indicates K-65 materials were added to the silos from July 1952 through September 1958.



Figure J-3. Photograph of the waste storage silos in 1965, from the southwest (labels added to image digitized from DOE 1965a). The appearance of the Silos would have been similar to this for the period 1964 (after installation of berms) to 1979 (before removal of piping and sealing of penetrations). The drum handling building was removed in 1983 when the berms were enlarged (Geesner 1983).

#### History of Silo Structural Characteristics Affecting Rn Releases

Drum Handling Building

2

Berm

The K-65 Silos have had problems of deterioration, almost since the time of construction. Significant cracking in the walls and seepage of the contents was noted from the 1950s (Wunder 1954; Martin 1957). Because of these problems, repairs and improvements to the Silos have occurred from the 1960s through the 1980s.

The project records for FMPC project 34-9 indicate that initial construction of the berms (at slope of 1½:1, horizontal to vertical) was complete by June 1, 1964 (NLCO 1984). In 1979, planning was in progress to close and seal all penetrations in the Silo domes (Heatherton 1979). An FMPC memorandum indicates that, on the Silo domes, the gooseneck vent pipe was removed, all openings were sealed, and metal covers were sealed with gaskets and bolted shut, in June 1979 (Boback 1980b). In the report of Task 5 of this Project, we analyzed Rn measurements taken at the boundary air monitoring station BS-6, west of the Silos (Shleien et al. 1993). A fairly abrupt decrease in Rn concentrations indicated that the sealing of these Silo dome penetrations probably occurred at the end of June, 1979. The

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

Dates	Activities (reference)
August 1951–July 1952	Construction of the silos (Catalytic circa 1950s(a); NLCO 1962; Grumski 1987a; Shanks and Vogel 1988).
September 1951	Mallinckrodt Chemical Works (MCW), in St. Louis, began shipping drummed K-65 material to the FMPC (Blythe 1951; Walden 1952).
July 1952	Disposal of MCW-generated, drummed K-65 material, by slurrying to Silos, began (Davis 1952).
About June 1953	The south silo, Silo 1, was full, and storage of material in Silo 2 had begun (derived from Strattman 1953).
October 1955–January 1956	Campaign 1 of FMPC Q-11 processing and K-65 production and disposal (Lynch circa 1958).
November 1955	Drummed K-65 continued to arrive from MCW, and was still being added to silo (Madoffori 1955a; Madoffori 1955b; Madoffori 1955c).
August-October 1956	Campaign 2 of FMPC Q-11 processing and K-65 production and disposal (Lynch circa 1958).
March–April 1957	Campaign 3 of FMPC Q-11 processing and K-65 production and disposal (Lynch circa 1958).
May 1957	Campaign 4 of FMPC Q-11 processing and K-65 production and disposal (Lynch circa 1958).
September 1957	Campaign 5 of FMPC Q-11 processing and K-65 production and disposal (Lynch circa 1958).
December 1957	Campaign 6 of FMPC Q-11 processing and K-65 production and disposal (Lynch circa 1958).
March 1958	Campaign 7 of FMPC Q-11 processing and K-65 production and disposal (Lynch circa 1958).
June-September 1958	Campaign 8 of FMPC Q-11 processing and K-65 production and disposal (Lynch circa 1958).
September 1958	The north silo, Silo 2, was removed from service and decanted (Noyes 1958; NLCO 1962).

records for project 34-9 also show that the earthen berms were expanded to a slope of 3:1 (horizontal to vertical) in June 1983 (NLCO 1984). The significant changes to the Silos are summarized in Table J-3. · · · · ·

**Characteristics of K-65 Material** 

· · · · · ·

Various characterization studies have been undertaken on the K-65 materials in the past. Currently, the K-65 Silos are included as Operable Unit 4 in the FMPC Remedial Investigation and Feasibility Study (RI/FS) of the Department of Energy. Table J-4 summarizes the results of these studies for some parameters pertinent to estimates of <sup>222</sup>Rn . generation rates. ÷ ... 11

The draft Remedial Investigation Report (DOE 1990) indicates that the 1989 sampling was considered inadequate for characterization purposes, because sample cores had very low

あたのの

Appendi<del>x</del> J

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Table J–3. Summary of Historical Changes to the K-65 Storage Silos				
Date	Repairs or Improvements (reference)			
May 1964	Cracks in silo walls were patched, waterproofing sealant applied, and earthen berm constructed to counterbalance material inside silos (NLCO 1984; Shanks and Vogel 1988; Noyes 1964).			
end of June 1979	Openings in silo domes, including the gooseneck pipe and other penetrations, were sealed, with gaskets installed, to prevent Rn emissions (Boback 1980b; Shleien et al. 1993; Boback 1980a; Grumski 1987a).			
June 1983	The earthen berms were enlarged to correct erosion problems (NLCO 1984; Grumski 1987a; Shanks and Vogel 1988).			
Early 1986	Dome covers added to protect the center sections of the silo domes; neoprene membrane layer applied to part of Silo 2 (Grumski 1987a; Shanks and Vogel 1988).			
November 1987	Radon Treatment System installed to treat displaced Rn during work on Silos (not continuously operated) (Grumski and Shanks 1988; Shanks and Vogel 1988).			
December 1987	Rigid, polyurethane foam layer and urethane coating applied to exterior of silo dome surfaces to weatherproof the Silos (Grumski and Shanks 1988; Shanks and Vogel 1988).			
November 1991	Addition of layer of bentonite on top of K-65 material in Silos (WEMCO 1992).			

recoveries (fraction of the intended sample retained in the sampling device), mostly from 4 to 30%. Because of this, additional sampling was performed in 1991 by the ASI and IT team using a different sampling device. According to the field geologist for the 1991 sampling program, the 1989 sampling used a sampling device that vibrated in the vertical direction only, which allowed material to easily plug the sampler, resulting in the low recoveries (Jarvis 1992).

If the sampling device for the 1989 program was easily plugged, the material recovered may have been primarily from the upper layers of the silo contents. It is known that the material in the Silos is not homogeneous, as material was deposited in layers in the Silos, and the  $^{226}$ Ra content of the K-65 material varied with time (and thus should vary with depth in the Silos). In describing the 1989 sampling episode, the draft Remedial Investigation Report (DOE 1990) stated: "Previous attempts to sample the silo contents were unsuccessful because a continuous, representative sample core could not be recovered for inspection and analysis. The variability and inconsistency of results from previous sampling efforts precludes [*sic*] the use of the data for fully characterizing the silo contents." We thus think that the samples from the 1989 sampling episode were not representative of random samples from the Silos (i.e. the locations may be biased toward the uppermost material in the Silos), and thus should not be used to estimate the average <sup>226</sup>Ra concentrations in the Silos (the averages are what we desire).

The 1991 program used an improved sampling device that vibrated in all directions, allowing better penetration of the soft K-65 material, without plugging (Jarvis 1992). The average recovery for the 1991 sampling was roughly 64% (Jarvis 1992). We conclude that

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

Time of study	Concentration <sup>226</sup> Ra ª	Moisture content (dry weight %)	Density (g cm <sup>-3</sup> )	Reference
1952	0.3 ppm	tent tr <b>306</b> - en e duitsvise en e	1.179°	Earlier study reported by DOE (1990)
1972	0.28 and 0.36 ppm	5 <b>65<sup>4</sup>and 65<sup>d</sup></b> 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	0.53–0.72 <sup>e</sup>	<sup>226</sup> Ra from Litz (1974) treatability study
1980	0.2 ppm offenses	lig ortei <del>n,</del> ka Nadio korja na sea Nadio korja na sea	1 <sup>(</sup>	Earlier study reported by DOE (1990)
1988	0.13-0.21 ppm	en olem <del>To</del> ri e Tori olem tori		Earlier work reported by DOE (1990)
1988 1989	657–192,600 pCi g <sup>-1</sup> ; mean 110,000 pCi g <sup>-1</sup> ; GM 76,000	43 and 90 <sup>6</sup> 21.8-73.5 <sup>b</sup>		Gill (1988) RI/FS sampling effort (DOE 1990)
<b>1991</b>	pCi g <sup>-1</sup> ; GSD 4.4. <i><sup>g</sup></i> 134,900–890,700 pCi g <sup>-1</sup> ;	in ben see oor oo e Gwele w <u>erd</u> in shi bori Maa Afrika ee		RI/FS sampling

Concentrations are presented in the units given in the reference. For conversion between units for  $^{226}$ Ra concentrations, 1 ppm = 0.989 µCi g<sup>-1</sup>.

The basis of the unit (%) was not given in the reference; we assume it to be dry weight.

The reference did not state whether the value is dry or wet density. We assume dry density.

ď Moisture contents in percent dry weight for these samples were calculated, in this present work, from values of moisture loss on drying (fraction of wet weight), obtained from a laboratory analytical data sheet (NLCO 1972). The calculated moisture contents agree with those calculated (here) from "as received" [wet] and dry U concentrations reported by Nelson (1972b).

Dry bulk densities were calculated, in this present work, from values reported by Nelson (1972b), which we determined to be wet densities. Three values were reported by Nelson; a value of 60 lb  $ft^{-3}$  for both silos was attributed to Cotter Corporation, and values of 54.3 and 73.7 lb  $ft^{-3}$  for Silo 1 and Silo 2, respectively, were attributed to NLO."

<sup>1</sup> Moisture content in percent dry weight were calculated, in this present work, from values of moisture loss on drying (fraction of wet weight), from the reference.

<sup>g</sup> GM and GSD are the geometric mean and geometric standard deviation, calculated in this present

the results from the 1991 sampling more closely approximate random samples from the entire contents of the Silos, and are thus preferred for estimating the average <sup>226</sup>Ra concentrations in the Silos. (We note that in the final Remedial Investigation Report for the Silos (DOE 1993), <sup>226</sup>Ra concentrations from the two sampling programs are averaged together. Based on the above information, we do not agree with this approach.) ope et la management de 1 . 1. 11

น แม้ปมดต่อ อร์ระบาร์จะเจล

# Page J-9 Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Appendix J

• ::.

.

1

Table J-5 tabulates the radionuclide concentrations from this 1991 sampling. For the calculated means and standard deviations we ignored samples with "not detected" results. This could result in slight positive biases to the means, but should not be significant for our uses of the data. These results were obtained from an ASI/IT database (ASI/IT 1992), and are also in the final Remedial Investigation Report for the Silos (DOE 1993). Sample locations from this program are described by the zone and manhole from which the sample was obtained. Each zone refers to roughly one-third of the K-65 material in the Silo, with zone A the top third, zone B the middle third, and zone C the bottom third (Jarvis 1992). Sampling was performed through the four former influent manholes on top of each Silo, which are described by their direction from the center of the Silo (NE, SE, SW, and NW). In some cases more than one sample was obtained from a given zone of a given manhole, although in these cases information about the sample location within the zone is not available. From the information we have obtained, the 1991 sampling program did not include analyses of additional, pertinent parameters such as density, moisture content, Rn emanation fraction, and Rn diffusion coefficient. As seen in the range of <sup>226</sup>Ra concentrations found in the recent sampling of the silos (DOE 1990 and ASI/IT 1992), the K-65 material is not homogeneous. The color of the material also varied greatly (DOE 1990).

The range of moisture contents reported for the 1989 sampling is a summary of eight measurements (DOE 1990). Of the eight, five were 20-35%, one was roughly 50%, and two were between 70% and 75%. It seems likely that the two highest values were for saturated material. We note that the DOE report did not indicate the vertical location in the silos for the samples. In fact, because of the very low sample recoveries, the vertical locations can probably not be determined. Thus, no information about the vertical profile of moisture content in the K-65 material can be discerned from these recent data.

We note that the densities measured in the early studies seem anomalously low, when compared to typical values for uranium mill tailings or soils. The basis (wet versus dry bulk density) of the results for the 1952 study is not given by DOE (1990). The letter report by Nelson (1972b) does not indicate the method of determining the densities. Usually one would assume the values to be dry bulk densities. However, in the report (Nelson 1972b) the densities were used in a calculation of the total weight of U in the silos, as if they were "as received," or wet, densities. We have assumed they were wet densities, and the values presented in Table J-4 have been converted to dry densities, using the moisture content (65% dry weight) calculated from information on the related laboratory analytical data sheet (NLCO 1972). The calculated dry bulk densities of about 0.53 to 0.72 g cm<sup>-3</sup> and the value of 1.179 g cm<sup>-3</sup> (basis unknown) seem quite low, relative to a more typical value of 1.5 g cm<sup>-3</sup> for uranium mill tailings or soils. However, no results of bulk density measurements were reported in the recent RI/FS sampling (DOE 1990; ASI/IT 1992).

No specific values were reported for the porosity of the K-65 material. However, the report of the 1989 sampling (DOE 1990) reports specific gravity for eight samples (of which two are composites) to be between 2.58 and 3.37, with mean 2.98 and standard deviation 0.29 (about 10%). Porosity can be calculated from bulk density and specific gravity. Using the range of densities reported in the early studies (assumed to be dry bulk densities) and the mean specific gravity, results in relatively high (compared to typical uranium mill tailings) nominal estimates of porosity from about 0.6 to 0.8.

Page	J-10
1 ugu	0 10

14

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

Sample	identif	ication <sup>b</sup>	Radionuclide concentrations in K-65 material (pCi $g^{-1}$ )									
number	zone	location	227 <sub>Ac</sub>	210 <sub>Pb</sub> ;	210 <sub>Po</sub>	226Ra	<sup>228</sup> Th	<sup>230</sup> Th	<sup>232</sup> Th	<sup>234</sup> U	<sup>235,6</sup> U	238
						Silo 1		,				
99728	С	SE	6870	235,200	267,000	601,600	nd <sup>c</sup>	105,372	981	1548	57.4 <sup>`</sup>	
99743 ·	·Α	NE	5623	117,700	144,000	394,900	′ nd	59,274	1106	750	105	6
99870	- <b>A</b>	SE	8486	126,800	296,000	367,600	nd	54,050	nd	1466	43.7	6
99885	A	NW	4320	77,860	154,000	306,800	nd	33,100	735	489	19.1	3
99909 -	B	NE	17,390	144,300	269,000	397,900	nd	64,400	661	875	39.4	7
99930	Β.	NW	10,700	191,300	237,000	680,900	2280	52,300	nd	1089	42.1	. 6
99939	С.,	NW	8118	235,900	273,000	510,400	nd	83,627	nd	936	31.5	5
99948	C	NW	6054	$\mathbf{r}^{d}$	232,000	11 r	835	r	835	508	nd	- 4
99966	B	SE	11,130	381,400	434,000	890,700 ·	nd	75,370	982	721	29.2	· 6
99975	B	SE .	7016	248,100	276,000	503,300	nd	50,917	702	608	22.0	. 6
00004	B	NE	9931	200,900	174,000	571,700	nd	54,521	nd	758	29.2	· 6
00025	C	NE	9012	183,600	230,000	520,600	nd	97,353	nd	696	90.0	7
00039	· C	NE	5194	182,300	166,000	550,600	· nd	99,494	nd	. 746	<b>39.9</b>	. 6
lean for	Silo 1e		8450	194,000	242,000	525,000	1560	69,100	857	861	45.7	6
tandard	l deviat	ion	3420	78,700	. 77,100	158,000	1020	22,900	169	330	26.5	. 1
	•					Silo 2				. ·	• • • •	
99355	B	SE	5448	125,000	168,000	404,800	nd	93,399	. nd	1945	48	9
99356 ·	в	SE	3407	161,000	164,000	414,000	nd	95,892	1785	na	na	1
99359	В	SE	7517	194,700	188.000	481.000	nd	90.495	nd	na	na	19
99710 <sup>`</sup>	ʻC –	SE	<b>'8258</b>	129,700	104,000	285,400	nd	43,600	nd	841	93.3	8
99721	C.	SE	6722	76,210	692,000	219,700	nd,r	37,300	nd,r	1792	74.8	22
99774 <sup>g</sup>	C	NW	: 7357	179,500	93,400	252,100	nd	25,200	nd	783.	35.6	; 6
997888	C	NW	6210	121,700	57,900	191,600	nd	160,000	2140	852	98.5	8
99802	С	NW	5641	125,900	90,600	176,900	622	37,000	985	586	92.0	5
99811	Α ·	NE	4474	58,160	55,300	134,900	798	20,500	nd	671	73.8	6
99831	B	NE	5649	74,650	132,000	179,500	nd	35,500	nd	1408	80.9	8
99846	С	NE	10,450	127,800	209.000	368,200	'nd	74,200	983	1429	130 :	: 12
99861 -	C	NE	9668	133,000	241,000	405,500	7360	99100	nd	1465	172	13
lean for	Silo 2e	. •	6730	123,000	193,000	299,000	2930	65,400	1470	1220	92.4	11-
tandard	deviat	ion <sup>e</sup>	2130	40,300	175,000	119,000	3840	30,500	583	500	37.3	5
	•			Sil	os 1 and 2	considere	d togeth	er	-			
 dean for	Silos 1	and 2°	7660	160.000	220.000	417'000	2380	67 400	1080	1010	65.7	 
tandard	deviat	ione	2980	71,600	131,000	179,000	2860	26 200	464	435	38.8	4

<sup>a</sup> Ref: ASI/IT 1992. Analyses were also performed for <sup>231</sup>Pa, <sup>224</sup>Ra, and <sup>228</sup>Ra. Since these radionuclides were not detected in any samples, we do not include them in this table.

<sup>b</sup> Zone A refers to the top one-third of a complete core (thus in the top one-third of the K-65 material), zone B to the middle one-third, and zone C to the bottom one-third. The locations are the manholes, by direction, through which the sample was obtained.

<sup>c</sup> "nd" means not detected. The ASI/IT table reported a less-than value, which we do not give here.

. .....

<sup>d</sup> "r" means the data validation code, in the ASI/IT data table, indicates the analysis result was rejected (though a value was given by ASI/IT, we do not present it or use it here).

\* For our calculations of the mean and standard deviation, we ignored samples with "not detected" results.

"na" means no analysis result was reported by ASI/IT.

<sup>g</sup> Samples 099774 and 099788 were field duplicates. We averaged the results before calculating means and standard deviations.

Lots e de inde

•••

12.1.2

4

# Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Information searches and discussions with the RI/FS Operable Unit 4 staff at the FMPC have indicated that measurements of  $^{222}$ Rn emanation fraction from and diffusion coefficient in the K-65 material have not been performed (as of September 1992).

#### **Characteristics Of Metal Oxide Material**

The metal oxide material of Silo 3 has been characterized by a few studies in the past. Currently, the Metal Oxide Silo is included as part of Operable Unit 4 in the FMPC RI/FS of the Department of Energy. The 1989 RI/FS sampling included extensive sampling of the metal oxide material (DOE 1990). The sample core recoveries for this program ranged from 28% to 35%. Because all of the material in Silo 3 was produced at the FMPC in the same waste stream, and was dried and conveyed by air into the Silo, the material was expected to be relatively homogeneous. The Remedial Investigation Report (DOE 1990) concludes that the samples obtained should be adequate to characterize the material. The 1989 sampling also recovered many more samples than previous efforts.

The Remedial Investigation Report (DOE 1990) reports the radionuclide concentrations in samples from Silo 3, from the 1989 sampling effort, and those concentrations are tabulated below in Table J-6. For the calculated means and standard deviations of concentrations we ignored samples with "not detected" results. This could result in slight positive biases to the means, but should not be significant relative to our uses of the data. Sampling was performed through three of the four former influent manholes (on top of the Silo), located to the northeast, southeast, and northwest of the Silo center. The Remedial Investigation Report does not identify the location for the individual samples.

Table J-6. Radionuclide Analyses on Metal Oxide Material from 1989 Sampling of Silo 3<sup>a</sup>

	Radionuclide concentrations in metal oxide material (pCi g-1)											
number	227 <sub>Ac</sub>	<sup>231</sup> Pa	<sup>228</sup> Th	<sup>230</sup> Th	<sup>232</sup> Th	224 <sub>Ra</sub>	226 <sub>Ra</sub>	<sup>228</sup> Ra	210 <sub>Pb</sub>	<sup>234</sup> U	235,6U	<sup>238</sup> U
21	523	521	907	41,911	1451	453	2589	525	2437	1934	152	2043
22	416	401	nd <sup>b</sup>	33,881	nd	451	2192	559	2221	1618	117	1649
23	234	266	554	21,010	815	64	467	82	454	348	nd	320
24	1363	$na^b$	nd	71,650	911	213	6435	nd	6427	1524	127	1600
25	534	556	459	40,968	411 <sup>.</sup>	295	3073	392	2493	1467	54	1392
26	706	889	859	41,555	nd	335	1862	441	1910	1910	76	1860
27	421	458	nd	53,227	nđ	370	1518	325	1084	1317	<b>.</b> 80	1243
28	412	na	· 996	63,649	755	106	3702	nd	2589	1052	42	994
29	443	564	537	61,190	672	137	4169	117	3553	1843	158	1951
30	773	931	nd	68,759	581	449	2240	360	1942	1643	75	1574
33	566	431	949	65,488	672	<b>313</b> ··.	4451	415	3674	1600	118	1878
mean <sup>c</sup>	581	557	752	51.200	784	290	2970	357	2620	1480	99.9	1500
stdev <sup>C</sup>	298	220	226	16,400	309	142	1650	164	1570	456	40.1	503

<sup>a</sup> Ref: DOE 1990.

<sup>b</sup> "nd" means not detected. "na" means not analyzed for this radionuclide.

<sup>c</sup> For our calculations of the mean and standard deviation (stdev), we ignored samples with "not detected" results.

Information about moisture content in the metal oxide materials was obtained in the 1989 sampling program (DOE 1990) and in a study conducted in 1972 (Nelson 1972b). In the

> Radiological Assessments Corporation "Setting the standard in environmental health"

З

-----

200 A

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

143.000

5

NUXUA

S. 14.19

eterne Samo

÷.

1989 program, five samples, including one composite sample, were analyzed for moisture content. Results ranged from 3.7% to 10.2%, with a mean for the four individual samples of 6.9%. Though the basis of the units is not stated by DOE (1990), we assume the results are in dry weight percent. The samples were obtained from the top one-third and bottom onethird of the material in the Silo, so they are probably fairly representative of all of the material in the Silo. For the 1972 study, Nelson (1972b) reports that for the sample that was analyzed for U concentration "Material was free flowing — drying was not needed." We interpret this statement to indicate that the moisture content was very low, which corroborates the low values seen in the 1989 program.

The only source of bulk density information we have located is the letter report by Nelson (1972b) of the 1972 study. Nelson reports two densities, a "free flowing" density and a density for material "tapped to maximum density." As the metal oxide was carried into the Silo by air, we think the free flowing density is likely to be more representative of the *in situ* bulk density. The measured densities were 40.02 lb ft<sup>-3</sup> (or 0.64 g m<sup>-3</sup>) for the free flowing density and 63.68 lb ft<sup>-3</sup> ( or 1.02 g m<sup>-3</sup>) for the maximum density.

The report of the 1989 sampling (DOE 1990) reports specific gravity for five samples, including one composite sample, to be from 2.08 to 2.75. For the four individual samples, the mean was 2.32 and the standard deviation was 0.21. Porosity can be calculated from specific gravity and bulk density.

# EVALUATION OF PREVIOUS ESTIMATES OF RADON RELEASES FROM K-65 SILOS

The source term for <sup>222</sup>Rn emissions from the K-65 storage silos was previously evaluated by IT Corporation, in their assessment of doses from historical releases from the FMPC (IT 1989). This assessment by IT Corporation did not include original calculations; rather it summarized and revised calculations from two other sources. Two pathways for emissions of Rn from the silos were considered: (1) diffusion of Rn from the K-65 residue into the silo air space and subsequent diffusion through the concrete domes into the surrounding air, and (2) free air exchange between the silo air and surrounding air, through cracks in the domes. The estimate of diffusion emissions was taken directly from the calculations of Borak (1985). It is noted that the FMPC-2082 report estimated the Rn emissions from only the diffusion pathway, and incorporated the Borak report as its Appendix A (Boback et al. 1987). In the IT report, the estimate of air exchange emissions was taken from a WMCO feasibility investigation report, with minor modification (Grumski 1987a; IT 1989). Detailed descriptions of these previous assessments of Rn releases from the K-65 Silos follow.

#### **Diffusion Releases**

The calculations by Borak (1985) of diffusion releases of <sup>222</sup>Rn were based on onedimensional steady-state diffusion equations obtained from a National Bureau of Standards (NBS) summary technical report (Collé et al. 1981). The concentration of <sup>222</sup>Rn in the silo

## Appendix J

air space was first calculated from characteristics of the K-65 waste material and dimensions of the silos:

$$C_{\rm a} = \frac{\phi}{\lambda_{\rm Rn}} \left( \frac{\varepsilon_{\rm w} l_{\rm w}}{\varepsilon_{\rm w} l_{\rm w} + h} \right) \tag{J-1}$$

where:

2

÷.,

 $C_{\rm a}$  = concentration of <sup>222</sup>Rn in the silo air,

 $\phi$  = production source term of <sup>222</sup>Rn in pores of K-65 material,

 $\lambda_{Rn}$  = decay constant of <sup>222</sup>Rn,

 $\varepsilon_{w}$  = total porosity of the K-65 waste material,

 $l_w$  = diffusion length of <sup>222</sup>Rn in the K-65 waste material, and

h = height of the air space in the silos above the waste material.

This equation for the Rn concentration applies to a closed container over the Rn source, with no losses other than radioactive decay (Collé et al. 1981). Since there are releases from the silo air space, these conditions are not met for the K-65 Silos.

The production source term of <sup>222</sup>Rn in pore spaces was determined by:

$$\phi = \frac{[Ra]EF\rho_w\lambda_{Rn}}{\varepsilon_w}$$
(J-2)

where:

[Ra] = concentration of <sup>226</sup>Ra in K-65 waste material (activity per mass),

EF = emanation fraction of <sup>222</sup>Rn production in K-65 material, and

 $\rho_w$  = bulk density of K-65 waste material.

From the concentration of <sup>222</sup>Rn in the silo air, the flux of <sup>222</sup>Rn diffusion through the concrete dome was calculated by:

$$J = \frac{\varepsilon_{\rm c} \lambda_{\rm Rn} l_{\rm c} C_{\rm a}}{\sinh\left(\frac{L}{L}\right)}$$

where

 $J = {}^{222}$ Rn flux from the dome surfaces to the surrounding air (pCi m<sup>-2</sup> s<sup>-1</sup>, or similar units),

 $\varepsilon_c$  = total porosity of the dome concrete,

 $l_c$  = diffusion length of <sup>222</sup>Rn in the dome concrete, and

L = thickness of the dome concrete.

The total release rate is then the product of the  $^{222}$ Rn flux and the surface area of the domes. It was assumed that the domes approximate circles of 40 ft radii, and thus the surface area of each dome is about 5030 ft<sup>2</sup>, or 467 m<sup>2</sup>.

Radiological Assessments Corporation "Setting the standard in environmental health"

(J-3)

ċ.

Linex.

(i.v.) 2.53

Envis .

(1). A (1). A (1).

à,

The parameter values used by Borak are given in Table J-7. However, we note that the sources of these values were not documented (Borak 1985). The results of these diffusion release calculations were a  $^{222}$ Rn concentration in the silo air of  $3 \times 10^7$  pCi L<sup>-1</sup>, and a total release rate to the atmosphere of 60 Ci y<sup>-1</sup> (Borak 1985).

#### Free air exchange

As part of the investigations of the K-65 silos for controlling <sup>222</sup>Rn emissions, the FMPC performed temperature and pressure monitoring of the silos. Measurements of temperature at two depths into the silo air space, on the surface of the concrete domes, and in ambient air near the silos, and measurements of differential pressure between the silo air space and the atmosphere were obtained from March 13 to May 15, 1987 (Grumski 1987a). Due to instrument problems, much of the data was not usable. However, usable data were obtained for 11 complete days, including a three-day period, May 8 to 11, during which the daily increases in temperature were large (Grumski 1987a; Shanks 1991).

Table J-7. F in Prev	Paraméter V ious Assess	Values Used ment of
Diff	usion Relea	ses <sup>a</sup>

Parameter	Units	Value used
λ <sub>R</sub> in	s <sup>-1</sup>	$2.1 \times 10^{-6}$
Ê <sub>w</sub>		0.3
l,	cm	150
ĥ	cm :	<b>300</b>
[Ra]	pCig <sup>-1</sup>	$2 \times 10^{5}$
EF		0.2
ρ <sub>w</sub>	g cm <sup>-3</sup>	1.6
٤ <sub>c</sub>	•	0.3
l <sub>c</sub>	cm	12
$\tilde{L}$	. cm	10

<sup>a</sup> Ref: Borak 1985.

For this three-day period, the internal gas temperatures for both silos showed a maximum daily increase of about 35 °F. Using the Ideal Gas Law, it was estimated that a closed tank of air initially at a pressure of 2117 'PSF (pounds  $ft^{-2}$ ) (or 14.7 psi) and temperature of 63 °F would undergo an internal pressure increase of about 142 PSF if the internal temperature was increased 35 °F (Grumski 1987a). For this monitoring period, the pressure monitoring indicated that Silo 2 held a maximum positive differential pressure of 7.6 PSF and a maximum negative pressure of 4.9 PSF. The maximum differential pressure was about 5% of what would be expected for a sealed system. Silo 1 showed negligible differential pressure with these temperature variations. It was concluded that the silos can not hold any significant pressure and thus that increases in the temperature of the internal silo air resulted in the volumetric expansion of the air and the release of "excess" volume to the atmosphere (Grumski 1987a).

Appendix J

Page J-15

(J-4)

# Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

The calculation of free air exchange emissions of <sup>222</sup>Rn from the silos was based on the expansion of the silo gases with warming of the gases due to warming of exterior air. The Ideal Gas Law was used to calculate the volume of air that would be emitted from the silos (Grumski 1987a):

$$PV = nRT$$

where

18

1

P = pressure of the gases within the silo,

V = volume of the silo air space (not including pore spaces of the K-65 material),

n = number of atoms of the gases,

R = ideal gas constant, with appropriate units, and

T = temperature, in units of an absolute scale (K or °R).

The calculations (Grumski 1987a) assumed that the internal gas pressure does not change. If this is the case, the volume of a given quantity of gas will be directly proportional to the temperature of the gas. Thus, the change in volume for a temperature change was calculated as:

$$\Delta V = (\Delta T/T_0) V_0 \tag{J-5}$$

where

 $\Delta V$  = change in air space volume per day,

 $\Delta T$  = change in temperature per day,

 $T_0 =$  the initial temperature, and

 $V_0$  = the initial air space volume.

It was then assumed that, in the case of rising temperatures during a typical day, the complete increase in volume,  $\Delta V$ , is released from the silo to the surrounding air. In this case the <sup>222</sup>Rn released, Q, is simply calculated as:

$$Q = C_a \Delta V \tag{J-6}$$

For this calculation, the <sup>222</sup>Rn concentration used was the value of  $3 \times 10^7$  pCi L<sup>-1</sup> calculated earlier by Borak (Grumski 1987a; IT 1989). The value used for  $\Delta V$  was 1000 ft<sup>3</sup> d<sup>-1</sup>, based on a value of  $\Delta T$  of 20°F d<sup>-1</sup>. The first calculations in the feasibility study used a silo air volume of 25,000 ft<sup>3</sup> (Grumski 1987a). This resulted in a calculated release rate of 600 Ci y<sup>-1</sup>, for the two silos combined. The sources of the parameters used were not documented (Grumski 1987a).

However, the silo volume was revised to 43,758 ft<sup>3</sup> in the IT dose assessment (IT 1989). This increased the estimated release rate to 512 Ci  $y^{-1}$  for each silo, or a total of 1023 Ci  $y^{-1}$  (IT 1989).

interes in the second

# CURRENT ESTIMATES OF RADON AND RADON DAUGHTER RELEASES FROM K-65 SILOS AND DRUMMED K-65 MATERIAL

#### the at the terms of the second

In this section we first describe the sources of Rn releases at the FMPC for which we calculate releases, and the less important sources for which releases are not calculated. We discuss the general methodology used in current estimates of <sup>222</sup>Rn releases from the K-65 Silos, followed by a justification of the specific approaches to calculating releases from the Silos for different periods. The methods used to implement the calculations are reviewed. Then, in separate subsections for the different types of releases, we thoroughly discuss the models (equations) used for the calculations, the distributions chosen to represent the uncertainty of the parameters, and the calculation results. A summary of the predicted releases concludes this part of the Appendix.

#### Sources of <sup>222</sup>Rn Releases at the FMPC (1911)

The apparent source of the majority of the <sup>222</sup>Rn and Rn daughter releases from the FMPC is the K-65 Silos, in the waste storage area of the site. However, there are other potential sources that must at least be considered. In this section we briefly discuss the reasons for including some sources in our calculations, and for considering other sources to be negligible.

IT was used.

As discussed in Appendix B, most of the uranium received at the FMPC had been separated from its naturally occurring daughter radionuclides, including <sup>226</sup>Ra. The primary source of <sup>226</sup>Ra, and thus <sup>222</sup>Rn emissions, is the uranium ore received and processed in the early years of operation. The majority of this ore was from the African Metals Corporation (Afrimet), and the agreement with Afrimet stipulated that <sup>226</sup>Ra from the ores was to be retained for eventual return to Afrimet (Consiglio 1952; DOE 1990). Thus, the waste material from the uranium extraction processing of these ores was retained. The wastes were of two separate forms, the K-65 material and the metal oxides, and were stored in the two K-65 Silos and in the Metal Oxide Silo. Because of this storage, large quantities of <sup>226</sup>Ra are not expected to exist in other areas of the FMPC site, such as the waste pits. Other areas may have received small quantities of <sup>226</sup>Ra, both unrecovered radium from the ore processing and radium as a contaminant in other feed materials.

The two K-65 Silos and the Metal Oxide Silo have all received wastes from the processing of uranium ores, and thus contain significant quantities of <sup>226</sup>Ra. Thus, all three Silos are considered potential sources of <sup>222</sup>Rn releases. Recent sampling of the K-65 Silos and the Metal Oxide Silo has measured the concentrations of <sup>226</sup>Ra in the K-65 and Metal Oxide materials (see page J-6). From the 1989 sampling, the average concentrations of <sup>226</sup>Ra were determined to be about 110,000 pCi g<sup>-1</sup> in the K-65 Silos, and about 2900 pCi g<sup>-1</sup> in the Metal Oxide Silo (DOE 1990). Earlier sampling of the K-65 Silos had indicated concentrations of <sup>226</sup>Ra averaging about 350,000 pCi g<sup>-1</sup> (Litz 1974). From the 1991 sampling, the average <sup>226</sup>Ra concentration was about 420,000 pCi g<sup>-1</sup>. Additional sampling was not performed for the Metal Oxide Silo. From these measurements, the concentration of <sup>226</sup>Ra appears to be at least 40 times higher in the K-65 Silos than in the Metal Oxide Silo. Thus, a rough estimate is that the K-65 Silos have the potential for generating about 40

1997 AN 18. 18. 1

5

34.

La service de la service de la service de la service de la service de la service de la service de la service de

# Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

times more <sup>222</sup>Rn (per silo) than the Metal Oxide Silo. Thus, for this assessment, the Metal Oxide Silo, Silo 3, is considered an insignificant contributor to the <sup>222</sup>Rn releases. Silo 4 has never been used, and contains only a small amount of water with very low levels of radioactive contaminants (DOE 1990). Since Silo 4 is essentially empty, it is not considered a source of Rn releases. Thus, for this assessment, of the four waste storage silos, the K-65 Silos, Silos 1 and 2, will be considered the only significant sources of Rn releases.

As discussed earlier (see Table J-2), the K-65 Silos were completed in July 1952. However, K-65 material had been shipped to the FMPC from the Mallinckrodt Chemical Works (MCW) in St. Louis, starting in September 1951, and quite a large inventory of drummed K-65 material, about equal to half the capacity of one Silo, had been accumulated at the FMPC prior to operation of the Silos (Walden 1952). This drummed K-65 material was stored on the Plant 1 storage pad (Belmore 1951). Prior to operation of the K-65 Silos, the drummed K-65 material stored on the Plant 1 pad was apparently the only potential source of Rn releases from the FMPC. In this time period we expect that uranium releases from the site would have been quite low, since much of the site was still under construction. Thus, for this time period, Rn releases from the drummed K-65 material are likely to have been relatively significant, compared to other releases. We thus calculate releases for this stored, drummed K-65 material (see page J-55).

The majority of the K-65 material placed into the K-65 Silos was the material shipped to the FMPC from MCW (Lynch circa 1958). An operating manual for the K-65 area (Dougherty and Jennings circa 1951) indicates that the drums of K-65 material were opened and dumped, by inverting the opened drum, into a slurry tank, for makeup of a slurry for slurrying into the Silos. The dumping of the drums occurred in the drum handling building, which was located in the waste storage area generally between the Metal Oxide Silo and Silo 2. The dumping process is a source of Rn releases. A simple calculation can be performed to estimate an upper bound on the quantity of Rn that might have been released during these dumping operations.

An upper bound on the Rn released during dumping of the drums would be the quantity of Rn present in the pore spaces of the K-65 material being dumped. It is not likely that all the pore space Rn would have been released, because the moisture in the material would hold some of the Rn, and the method of dumping would presumably have exposed to the air only a small fraction of the surface area of the particles of material. The quantity of Rn in pore spaces can be calculated as the  $^{226}$ Ra concentration (we assume the total Rn present is in equilibrium) multiplied by the quantity of material, the material density, and the Rn emanation fraction. The filling of Silo 1 was completed much faster than the filling of Silo 2, and consequently would have had a greater drum dumping rate, so we look first at Silo 1. Later in this Appendix, in our calculations of the volume of the silo air space, the depth of material in Silo 1 is estimated to be about 20 ft (see page J-29). Given the 80-ft diameter of the Silo, this represents a material volume of 100,500 ft<sup>3</sup>.

From the characterization data given in Table J-4, the material density is in the range 0.53 to 1.179 g cm<sup>-3</sup>. For this rough calculation, we assume a density of 0.85 g cm<sup>-3</sup>. From Table J-5, the average  $^{226}$ Ra concentration in Silo 1 is about 525,000 pCi g<sup>-1</sup>. Later in this Appendix, we perform an alternative calculation of Rn releases from the K-65 Silos. In that

Radiological Assessments Corporation "Setting the standard in environmental health"

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

calculation, we conclude that the Rn emanation fraction of the K-65 material would be in the range 0.1 to 0.4 (see page J-76). For this calculation, we assume a value of 0.25. These values result in an estimated upper bound to the quantity of Rn released of 320 Ci. The filling of Silo 1 took about 11 months (Table J-2), so this represents a rate of about 350 Ci  $y^{-1}$ . This upper bound is relatively small, compared with the estimated 90% probability range of the Silo Rn release rate for the operational period of Silo 1 (Table J-25, later in this Appendix), 200-4200 Ci  $y^{-1}$ . For the dumping of drummed material into Silo 2, the release rate from dumping operations would be even less, because the average <sup>226</sup>Ra concentration for Silo 2 material is less than for Silo 1 (Table J-5), and the time required to fill Silo 2 was about 5 years, rather than about one year. We thus consider the K-65 drum dumping operation to be an insignificant source of Rn releases from the FMPC, and no further calculations are performed for this.

Part of the K-65 material in Silo 2 was waste from the onsite (FMPC) processing of high-grade, pitchblende uranium ore from the Belgian Congo (DOE 1990). Since the ore contained  $^{226}$ Ra, the ore processing, in the production area of the site, is another potential source of Rn releases. The processing occurred in the refinery (Plant 2/3), and included digestion of the ore in Nitric acid, followed by two solvent extraction steps (DOE 1990). We estimate an upper bound on Rn releases from this ore processing using the same method used for the drum dumping operations, described above. However, in this case, since the ore was digested, we assume that all of the Rn in the ore could have been released (i.e. not just the Rn in pore spaces).

A contemporary, handwritten spreadsheet (Lynch circa 1958) provides production and <sup>226</sup>Ra content information about the ores processed. Table J–8 compiles the applicable data.

Processing campaign <sup>b</sup>	Ore processed Dates (tons)	<sup>226</sup> Ra assay (mg ton <sup>-1</sup> )	<sup>226</sup> Ra content (mg)
1	Oct 1955-an 1956 418.4	132.5	55,451
2	Aug-Oct 1956	141.9	86,215
3	Mar–Apr 1957 252.8	129.4	32,707
4	May 1957	156.7	19 <b>,</b> 590
4, Australian	May 1957	154.9	15,818
<b>5</b>	Sep 1957 (1997) 1. 1 (1980) 204.6	133.4	27,547
	Dec 1957	nv <sup>c</sup>	27,037
······································	Mar 1958 110.8	nv	15,088
7, Australian	Mar 1958 50.8	nv	5,625
8	Jun-Aug 1958 389.1	nv	54,128
Total	1.1.2, <b>423.9</b>		

## Table J-8. Production Information on the FMPC Ore Processing a

ι. <u>ι</u>...

<sup>b</sup> All campaigns were for Belgian Congo ores, except as noted.

""" "indicates no values were available.

ويعاد والمتحلي ويعاد والدرا

Harris - Sch

5

55

1. S. S. S. S.

12037-16

1.45.4

# Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

From the data in Table J-8, the total <sup>226</sup>Ra content in the ores processed is 339,206 mg. The specific activity of <sup>226</sup>Ra is 0.989 Ci g<sup>-1</sup> (Shleien 1992). Thus, the total activity of <sup>226</sup>Ra is 335 Ci. This is then also assumed to be the total quantity of <sup>222</sup>Rn that might have been released during the ore processing. The processing occurred from October 1955 through August 1958, a period of 34 months. Thus, the average rate of Rn release could have been up to about 120 Ci y<sup>-1</sup>. This release rate is very small relative to the estimated 90% probability range of the Silo Rn release rate for the operational period of Silo 2 (Table J-25, later in this Appendix), 3100-7600 Ci y<sup>-1</sup>. We thus consider the ore processing in Plant 2/3 to be an insignificant source of Rn releases from the FMPC, and no further calculations are performed for this.

Before ores were processed in the refinery, they may have been stored for a short period of time in the Q-11 silos located just south of Plant 1 (Consiglio 1952). The ores obtained from the African Metals Corporation were referred to as Q-11 material. There were six Q-11 silos, each consisting of a cylindrical component, 10 ft in height, and 13 ft in inside diameter; on top of a conical hopper, 12 ft in height (Consiglio 1952). The silos were elevated, with the top about 48 ft above the ground. Design capacity for the silos was 100 tons of ore. Consiglio (1952) also indicates that ore material was stored in the Q-11 silos after being crushed, pulverized, and dried to less than 2% moisture (we assume dry weight percent).

•

We perform a preliminary estimate of Rn releases from the stored ores, using the method used later in this Appendix to estimate releases from K-65 material stored in drums (see page J-55 for more details). We use the forms of equation J-50, equation J-51, and equation J-52. In this case it is not known if the Q-11 silos were open to the outside air. We assume they were, and thus assume that all Rn released from the ore material is released to the atmosphere. Thus, the ratio  $[(\lambda_v + \lambda_d)/\lambda_{eff}]$  is assumed to be one.

From the data in Table J-8, the average <sup>226</sup>Ra concentration in the processed ore was about 150,000 pCi  $g^{-1}$ . We assume a normal distribution for this parameter, with an assumed relative standard deviation of 20%. Since the stored ore was very dry (2% moisture), the Rn emanation fraction would have been less than for wetter material (Rogers et al. 1984). As for the calculations for the drummed K-65 material, we use emanation fraction data compiled by Rogers et al. (1984) for uranium mill tailings. For material this dry, those data encompass a range of about 0.06–0.35, with a clustering around 0.15. We thus assume the emanation fraction has a triangular distribution, with minimum 0.06, maximum 0.35, and mode 0.15. For the specific gravity of the ore material we assume a range somewhat higher than that for K-65 material, since the ore would contain significantly more uranium. We assume a uniform distribution, with minimum 3.0 and maximum 3.5. Based on the design capacity of the silos (100 tons) and their volume, it seems that the expected material density was about 1.6 g cm $^{-3}$  (remember this was pulverized ore material). We assume a uniform distribution, with minimum 1.4 and maximum 1.8 g cm<sup>-3</sup>. With a 13 ft diameter, the surface area of ore in the silos would be about  $123,000 \text{ cm}^2$ . When the silos were full, the average thickness of material would be about 430 cm. From the information in Table J-8, it appears the average processing campaign consumed about 300 tons of ore, or the equivalent capacity of three of the Q-11 silos. We thus assume that, on the

STATISTICS IN

Ę,

average, three silos were used. We further assume, based on the timing of the campaigns, that the silos were used for ore storage about half of the time.

A Monte Carlo simulation was employed for the calculations, using the same methods described later in this Appendix. Parameters not explicitly described above were as used for the calculation of releases from drummed K-65 material (see page J-55). The result is a 90% probability interval (5th to 95th percentiles) of 30-200 Ci  $y^{-1}$  released from the Q-11 silos during the ore processing period, October 1955 to August 1958. This release rate is very small relative to the estimated 90% probability range of the Silo Rn release rate for the operational period of Silo 2 (Table J-25, later in this Appendix), 3100-7600 Ci  $y^{-1}$ . We thus consider the ore storage in the Q-11 silos to be an insignificant source of Rn releases from the FMPC, and no further calculations are performed for this.

The annual FMPC environmental monitoring report for 1990 (Byrne et al. 1991) indicates that elevated concentrations of <sup>226</sup>Ra have been found in the waste pits, in the western area of the site. (We present information about these waste pits in Appendix K of this report.) The waste pits are considered as potential sources of Rn emissions.

A characterization of the waste pits was performed recently (Solow and Phoenix 1987). Solow and Phoenix (1987) describes measured concentrations of radionuclides in boreholes in the waste pits. Table J-9 summarizes results for  $^{226}$ Ra concentrations measured the waste pits. Generally, the measurements were made on composite samples, each of which was formed from material from the complete depth of each borehole. In the case of the clearwell, samples were grab sediment samples, obtained with a dredging sampler.

Waste pit	Numbe sample	r of Mean <sup>226</sup> Ra s <sup>a</sup> concentration	Standard error of the mean <sup>b</sup>		
1	5	31	8.4	•	
2	5	120	75		
3	. 7	· · · · · · · · · · · · <b>120</b>	51		
4	. 4	. <b>&lt;15</b> ⁰	3.4	÷	
<b>5</b>	· 6	550	110		
6	. 4	<22 <sup>d</sup>	3.0		
Burn pit	6.	<2.7°	0.27		
Clearwell	4	130	110		

Table J-9. Summary of Measured <sup>226</sup>Ra Concentration (pCi g<sup>-1</sup>) in Waste Pit Contents (Solow and Phoenix 1987)

<sup>a</sup> All samples were composites, except those for the clearwell.

<sup>b</sup> For calculating the standard error, "less than" values were assumed equal to the value.

<sup>c</sup> One of the results was a "less than" value.

<sup>d</sup> All four results were "less than" values.

In Appendix K, the approximate volumes of the contents of the waste pits are provided. With the volumes and the average <sup>226</sup>Ra concentrations, the total <sup>226</sup>Ra content of the waste pits can be estimated. For this estimation, we assume the pit contents have an average bulk

# Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

density of 1.6 g cm<sup>-3</sup>, which is typical for soils. Table J–10 shows the parameters used and the results of these calculations. Also shown, from information in Appendix K, is whether the waste pit was operated as a wet pit, filled with slurried wastes, or as a dry pit, with solid wastes dumped from trucks.

Waste pit	Туре	Volume of contents (yard <sup>3</sup> )	Concentration <sup>226</sup> Ra (pCi g <sup>-1</sup> )	Quantity <sup>226</sup> Ra (Ci)
1	dry	40,000	31	1.5
· 2	dry	13,000	120	1.9
່3	weta	227,000	120	34
4	dry	53,000	<15	<0.96
5	wet	102,500	550	69
6	dry.	9,000	<22	< 0.24
Burn pit	dry	unknown	<2.7	
Clearwell	wet	unknown	130	•

Table J-10.	Calculation	of <sup>226</sup> Ra	Quantity i	n Waste Pits
-------------	-------------	----------------------	------------	--------------

<sup>a</sup> This pit was operated in a wet mode from 1959–1968, and in a dry mode for a short time, 1975–1977.

2

Two of the pits have unknown contents volumes. The quantity of  $^{226}$ Ra in the burn pit is probably insignificant, because the average concentration is very-low. The quantity in the clearwell is estimated to be much less than that in pit 3, because the clearwell is a much smaller (areal extent) pit than pit 3 (see Appendix K), and the concentrations are similar. To summarize the calculations shown in Table J-10, the  $^{226}$ Ra content in dry pits is around 5 Ci. And, the  $^{226}$ Ra quantity in wet pits is probably only slightly greater than 100 Ci.

For comparison, we estimate the total  $^{226}$ Ra content of the K-65 Silos. Later in this Appendix, we estimated the average thickness of the K-65 material in the Silos to be in the range 19.5–23.5 ft (see page J–74). Assuming an average thickness of 21.5 ft, the volume of K-65 material in the two Silos is about 220,000 ft<sup>3</sup>. From Table J–5, the average  $^{226}$ Ra concentration in the two Silos is about 417,000 pCi g<sup>-1</sup>. From the Table J–4, the bulk density of the K-65 material is in the range 0.53–1.179 g cm<sup>-3</sup>. Assuming an average density of 0.85 g cm<sup>-3</sup>, the total  $^{226}$ Ra content of the two K-65 Silos is about 22000 Ci.

The material in the K-65 Silos is not covered with water, though there is substantial moisture in the material. The Silos do have covers, which reduce Rn emissions somewhat (though in 1959–1979 the reduction was very slight, based on later calculations in this Appendix). For the wet pits, the  $^{226}$ Ra is much less effective in releasing Rn into the air, because the water cover would significantly reduce the diffusion of Rn out of the waste material. It thus seems reasonable to expect that Rn releases from the waste pits would be less than five percent of Rn releases from the K-65 Silos. We thus consider the waste pits to be an insignificant source of Rn releases from the FMPC, and no further calculations are performed for this.

Recently, the Rn flux from waste pits 1, 2, 3, and 4 have been measured. Tomczak et al. (1992) reports results for pit 4, and summarizes earlier results for pits 1, 2, and 3. The

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

ξ

1.217.1

in the second

results show total Rn releases from these four pits to be around 5 Ci y<sup>-1</sup>. This shows that releases for these pits, in recent years (releases may have been higher in earlier years, before covers were applied), are insignificant compared with releases from the K-65 Silos. In summary, the sources considered for releases of <sup>222</sup>Rn and Rn daughters are the K-65 Silos and drummed K-65 material stored on the Plant 1 pad.

General Methodology for Current Estimates of Releases from K-65 Silos

For some other releases at the FMPC, extensive data sets of direct measurements of release quantities are available. However, for radon releases there are no direct measurements of release quantities. In addition, until the 1980s there were very few measurements of parameters that can be used indirectly to calculate radon releases. Because of this limited availability of data, we use models to estimate radon release quantities.

The traditional model used to estimate radon releases from <sup>226</sup>Ra-bearing material, such as uranium mill tailings, involves calculations of the quantity of radon formed in the material, and the subsequent diffusion of the radon through the material to the outside air (Rogers et al. 1984). For the K-65 materials, measurements have not been made of the radon diffusion coefficient and radon emanation fraction, which are two key parameters to this traditional calculation. Literature values can be obtained for these parameters, but without site-specific values, the uncertainty ranges are extremely large. To reduce the uncertainties in our results, we have used different models, which we believe make the best use of the limited data that are available.

Earlier in this appendix (see page J-5), the history of structural changes to the silos was discussed. Not all of these changes to the silos would have a significant effect on the release of Rn. The most important change, in terms of Rn emissions, was the sealing of the openings in the silos in 1979. This action would have changed the ventilation rate of the silos, and thus changed the rate of  $^{222}$ Rn release. The addition of the exterior foam layer in 1987 may have further reduced the emission of Rn. This foam layer was found, through laboratory testing, to have a very low Rn diffusion coefficient (Grumski and Shanks 1988). Covering the domes and cracks (and other penetrations) of the domes with this foam would be potentially effective in reducing the emission of Rn. The addition of the earthen berms in 1964 could have slightly decreased any trace releases of Rn through the walls of the silos, although specific information regarding this has not been found. Since the Silos were open to the atmosphere in 1964, with the gooseneck vent, and other unsealed penetrations in the domes, it seems probable that the overwhelming majority of Rn releases would have been through the dome penetrations. We thus think that the construction of the berms around the Silos would have had a negligible impact on Rn releases.

For the current calculations, we assume that a major change to <sup>222</sup>Rn releases likely occurred with the sealing of penetrations in 1979. We assume that from mid-September 1958, after Silo 2 was decanted and removed from service, through June 1979, no significant changes in the Rn releases occurred. We also assume that a significant change may have occurred at the end of 1987, when the foam layer was added to the silo domes. We thus separate the calculations into five time periods, as shown in Table J-11. We place primary

# Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

emphasis on the pre-sealing (mid-September 1958–June 1979) and post-sealing (July 1979– December 1987) periods, because these two encompass most of the FMPC operating history (the time of concern of this Project). We generally refer to these two periods as 1959–1979 and 1980–1987, respectively. Table J-11 also shows the names by which we generally refer to the time periods, and the associated subscripts used for parameter names.

Time period	Description	Nominally called	Subscript for variables
mid-July 1952–mid-June 1953	Operational period of Silo 1	1952-1953	52-53
mid-June 1953-mid-September 1958	Operational period of Silo 2	1953–1958	. 53–58
mid-September 1958–June 1979	Before sealing penetrations in Silo domes (pre-sealing)	1959–1979, or pre	pre
July 1979–December 1987	After sealing penetrations in domes	1980–1987, or post	post
1988	After addition of foam layer	1988	1988

3

×.

#### Table J-11. Time Periods for Calculations of Radon Releases from K-65 Silos

The general methods used to estimate the diffusion and free air exchange releases of Rn in the previous assessments are thought to be adequate. However, there are two significant flaws in the previous estimates of diffusion and free air exchange releases of Rn from the K-65 Silos. First, the sources of many of the parameter values used are not documented in the assessment reports (Borak 1985; Boback et al. 1987; Grumski 1987a; IT 1989). Thus, it is not possible to track the parameter values back to measurements or calculations in a primary reference. Second, the IT calculations assumed that the same release rate existed from 1953 through 1984 (IT 1989). Since it is known that openings in the silos, including the six-inch diameter gooseneck pipe, were sealed in 1979 (Boback 1980a; Boback 1980b; Grumski 1987a), it seems more reasonable to assume that a major change in release rates also occurred when these openings were sealed.

Thus the approach of the current estimates was to use the same basic calculational methods for air exchange and diffusion releases of the previous assessments (Borak 1985; IT 1989), but with changes to best incorporate the additional information located in this study. In fact, the current calculations are quite different, both in terms of the models and the values or distributions of values selected for the parameters. In general, the calculation of  $^{222}$ Rn release rates, Q, is broken into calculations of the releases through air exchange,  $Q_{\text{exch}}$ , and through diffusion,  $Q_{\text{diff}}$ . The diffusion release calculation is relatively straightforward, and we use the method used in the previous assessment by Borak (1985), although we use different parameter values. We note here that the results of our calculations indicate that releases through the diffusion pathway are smaller than releases through air exchange, but still contribute a significant fraction of the total releases (see Table J-15 and Table J-16). The calculation of air exchange releases is more complicated, and here we have deviated, in the details, from the previous methods used by Grumski

÷.

š

. N. 194

だいただ

ž

(1987a). The next subsection of this appendix presents a more detailed description and justification of the basic models used in these current calculations.

For the time periods considered in this current assessment, one could try to estimate releases to a yearly or monthly time resolution. However, essentially all of the parameters used are assumed not to vary significantly from month to month or even from year to year (within the given assessment period). Thus, we feel that any additional resolution gained by estimating releases for shorter time periods would be lost in the uncertainties of the estimates. So, for these current calculations, we will only estimate a release rate for each time period ("1952-1953," "1953-1958," "pre," "post," and "1988"), which is assumed to apply to the entire time period. For convenience, the release rate estimates will be reported in activity released per year.

Because the characteristics of the two K-65 Silos that are important in estimating Rn releases are similar, and in many cases only limited information is available, we use average characteristics to represent both Silos. The models for Rn releases are developed for a single Silo (with the average characteristics), and the results incorporate a factor of 2 to account for the two Silos.

# Calculational Strategy for Radon Emissions from the K-65 Silos

We first mention some assumptions made for the air exchange calculations. We assume that the  $^{222}$ Rn concentration in outside air is negligible compared to the silo concentration so that outside air does not provide a source of Rn to the silo air. In our preliminary work on the  $^{222}$ Rn source terms (Voillequé et al. 1991) we estimated that releases by diffusion through the silo domes were insignificant compared to releases by air exchange, and we assumed that the rate of removal of Rn from the silo air space due to diffusion releases was negligible. However, we have made changes since that initial effort, and while the diffusion releases are still estimated to be less than the air exchange releases, we no longer consider them insignificant, and the rate of removal of Rn due to diffusion releases is no longer neglected. Thus, the rate of change in the silo air Rn concentration can be described by an adaptation of a standard equation used for Rn concentration in homes (NCRP 1989):

$$\frac{dC_{a}}{dt} = \frac{P_{Rn}}{V_{0}} - C_{a}\lambda_{eff}$$
(J-7)

where

 $C_{\rm a}$  = concentration of <sup>222</sup>Rn in the silo air,

 $P_{\rm Rn}$  = the constrained (by the presence of the silo) rate of release of <sup>222</sup>Rn into the silo air (production term) from the K-65 source material (activity per time),

 $V_0$  = volume of the air space in the silo above the K-65 material, and  $\therefore$ 

 $\lambda_{\text{eff}}$  = the effective removal rate of <sup>222</sup>Rn from the silo air space (fraction per time).

The only mechanisms considered for losses of Rn from the silo air space are releases into the (outside) atmosphere, through air exchange or diffusion through the silo dome, and radioactive decay. Thus,

Appendix J

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

$$\lambda_{\rm eff} = \lambda_{\rm Rn} + \lambda_{\rm v} + \lambda_{\rm d} \tag{J-8}$$

where

2

.

2

 $\lambda_{Rn}$  = the radioactive decay constant for <sup>222</sup>Rn,

- $\lambda_v$  = ventilation rate of the silo, or fraction of the silo air exchanged with the outside per unit time (per day), and
- $\lambda_d$  = rate constant for diffusion losses, the fractional rate of Rn loss from the silo air space through diffusion through the silo dome (fraction per time).

It is recognized that the silo ventilation rate (especially during the post-sealing time period), varies with a diurnal cycle component. Thus, to a lesser extent, the <sup>222</sup>Rn concentration in the silo air space also varies with a diurnal cycle. However, over a longer period of time the variations in these parameters are expected to be insignificant. Thus, we assume that equilibrium conditions exist, and that the ventilation rate, <sup>222</sup>Rn concentration, and <sup>222</sup>Rn production rate are constant over the periods of concern. Thus, based on the inputs of Rn to the silo air space equaling the losses, we obtain:

$$P_{\rm Rn} = C_{\rm a} \lambda_{\rm eff} V_0 \tag{J-9}$$

Because the silo air space is a single compartment volume, we assume the contained air to be well mixed. Thus, the air exchange and diffusion release rates can be expressed simply as the activity in the silo air space times the silo ventilation rate or diffusion rate constant, as appropriate:

$$Q_{\rm exch} = C_{\rm a} \lambda_{\rm v} V_{\rm 0} \tag{J-10}$$

$$Q_{\rm diff} = C_{\rm a} \lambda_{\rm d} V_0 \tag{J-11}$$

where  $Q_{\text{exch}}$  and  $Q_{\text{diff}}$  are the rates of release of <sup>222</sup>Rn from the silo through air exchange and diffusion through the silo dome, respectively.

These can be summed and rewritten:

$$Q_{\text{exch}} + Q_{\text{diff}} = C_{a} \lambda_{\text{eff}} V_{0} \left( \frac{\lambda_{v} + \lambda_{d}}{\lambda_{\text{eff}}} \right) \quad \text{or}$$

$$Q = P_{\text{Rn}} \left( \frac{\lambda_{v} + \lambda_{d}}{\lambda_{\text{eff}}} \right).$$
(J-12)

By expanding equation J-9, using equation J-8, and substituting for the products  $C_a \lambda_v V_0$  and  $C_a \lambda_d V_0$ , using equation J-10 and equation J-11, we can also obtain:

$$Q = P_{\rm Rn} - C_{\rm a} \lambda_{\rm Rn} V_0 \tag{J-13}$$

Equations J-10, J-12, and J-13 provide different methods of calculating the air exchange or total Rn release rate, depending on what information is available. We note that equation J-10 is essentially the equation used in the previous assessment (Grumski 1987a).

Radiological Assessments Corporation "Setting the standard in environmental health"

Page J-25

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

1.11

10.00 L

٩.

i.

Strategy for calculation of  $Q_{\text{post}}$  (1980–1987). For the period 1980–1987, measured concentrations of <sup>222</sup>Rn in the silo air ( $C_a$ ) are available, from a set of samples taken by the FMPC in 1987. In fact, these are the only usable measurements of <sup>222</sup>Rn concentrations in the silos that we have located. We would like to use this information, and thus should select either equation J-10 or equation J-13 to calculate  $Q_{\text{exch,post}}$  or  $Q_{\text{post}}$ . In addition, data are available on the silo temperature cycling (as discussed earlier, on page J-14) that can be used to calculate  $\lambda_v$ . There are two related problems with the use of equation J-13 for this situation. First, since the major penetrations in the silos have been sealed, we expect the ventilation rate to be very low. The diffusion rate constant is also expected to be very small. In particular, we expect  $\lambda_v$  and  $\lambda_d$  to be significantly less than  $\lambda_{\text{Rn}}$ , so that  $\lambda_{\text{eff}}$  is only slightly different from  $\lambda_{\text{Rn}}$ . If this is the case, then we expect the two terms in equation J-13,  $P_{\text{Rn}}$  and ( $C_a\lambda_{\text{Rn}}V_0$ ), to be approximately equal. For the uncertainty analysis then, we expect the uncertainty in the result, the difference of these two terms, to be large on a relative scale (relative standard deviation).

Second, the traditional method for calculating the release of Rn from a soil-like matrix into the air, for  $P_{\rm Rn}$ , requires knowledge of <sup>226</sup>Ra concentration in the material, bulk density and porosity of the material, Rn emanation fraction from the material, and Rn diffusion coefficient through the material. No measurements of the Rn emanation fraction have been made, thus one might assume a rather broad range of 0.1 to 0.4 based on typical values for uranium mill tailings (Rogers et al. 1984). The Rn diffusion coefficient for the K-65 material has not been measured either, and the moisture contents of the important upper layers of the K-65 material are also not well characterized, so that diffusion coefficients spanning about two orders of magnitude are conceivable (Rogers et al. 1984). With these uncertainties, the uncertainty in the calculation of  $P_{\rm Rn}$  would be very large.

For these reasons, we think that equation J-10, with the calculation of  $\lambda_v$  from the silo temperature cycling data, will make the best use of the available data, and will produce results with less overall uncertainty. Thus, equation J-10 will be used for the calculation of  $Q_{\text{exch,post}}$ . The releases through diffusion,  $Q_{\text{diff,post}}$ , will be calculated separately, using the methods used in the previous assessment. We note that in a later section of this Appendix, we use the standard method of calculating the release of Rn from the K-65 material, using characteristics of the material, as an alternative calculation to compare with our primary methods discussed here (see page J-73).

Strategy for calculation of  $Q_{pre}$  (1959–1979). For the period 1959–1979, no direct information is available about the Rn concentration,  $C_{a}$ , or the silo ventilation rate,  $\lambda_{v}$ . The Rn production rate,  $P_{Rn}$ , can be calculated from the release rate for the 1980–1987 period and Rn concentrations from both the pre and post periods. Indirect information about the Rn concentration is available in the exposure rate measurements on the silo domes. The short-lived daughters of <sup>222</sup>Rn, which will be present in a significant fraction of their equilibrium concentrations, emit gamma radiation. Thus Rn concentrations can be correlated to gamma exposure rates measured near the Rn source. We acknowledge that this is a rather uncertain way of estimating the Rn concentration, but it is the only approach we know of that uses the available data. Thus we will use equation J-13 for calculating  $Q_{pre}$ . This calculation includes releases by both air exchange and diffusion.

#### Appendix J

مروز ورقعه

2

# Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Strategy for calculation of  $Q_{1988}$  (1988). For 1988, we take two approaches. Preliminary calculations are performed using the same methodologies used for the 1980– 1987 period. However, the results seem inconsistent with Rn monitoring data examined. The final approach bases releases for 1988 on releases for 1980–1987 and ratios of the Rn concentrations for the two periods.

Strategy for calculation of  $Q_{52-53}$  and  $Q_{53-58}$  (1952-1958). Very little directly applicable information is available to estimate releases from the K-65 Silos during these operational years. Thus, Rn releases are estimated based on releases for 1959-1979, with factors applied to account for differences due to the operating status.

#### **Implementation of Calculations**

As for other calculations in this Task 2/3 Report, the calculations of radon releases from the K-65 Silos and the drummed K-65 material are implemented as Monte Carlo simulations, to account for uncertainties. The Monte Carlo analysis uses distributions of potential values to represent the input parameters. Each distribution is based on the available (often limited) information about the parameter. Then, many iterations of the calculations are performed; each iteration samples from the parameter distributions to obtain parameter values. Thus, the result of the analysis is a distribution of potential values of the release quantities, which can be interpreted with specified percentile ranges (e.g., 5th to 95th percentile).

The Monte Carlo calculations for these analysis were performed using spreadsheet and forecasting software on an IBM-compatible microcomputer. Ten thousand iterations of the calculations were performed. The parameter distributions were generated using Crystal Ball<sup>®</sup>, version 2.0 for Windows (Decisioneering 1992). In Crystal Ball<sup>®</sup>, uniform distributions are generated using a multiplicative congruential generator, which has a period of length 2<sup>29</sup>, and normal and lognormal distributions are generated using the Polar Marsaglia method (Decisioneering 1992).

The following sections describe the models used to perform the current estimates for the various time periods and sources. Annex 2 of this Appendix summarizes the equations and parameter distributions used for these current estimates of releases.

#### Model for Air Exchange Releases from K-65 Silos for 1980–1987

As discussed above, the air exchange releases for this period after the sealing of the silo penetrations can best be calculated by:

$$Q_{\text{exch,post}} = C_{\text{a,post}} \lambda_{\text{v,post}} V_0 \qquad (J-14)$$

During the period from 1980 through 1987, the major penetrations through the silo domes, like the six-inch gooseneck pipe, had already been sealed. However, exchange of air between the silos and the atmosphere continued, through the numerous cracks in the concrete of the domes. Radon releases for this time period are based on measured concentrations of  $^{222}$ Rn in silo air and on a silo ventilation rate calculated from the daily temperature change of silo air.

Radiological Assessments Corporation "Setting the standard in environmental health"

21. **1**5. 1. 1

. :

·4. . • • .

1<u>3 - 6</u> 6

14 *,* •

..... In this and following sections, we use the subscript "post" to refer to that parameter for the time period 1980 to 1987. : Section 2. Ch

Radon concentration in silos 1980-1987. The silo interior air was sampled on November 4, 1987, prior to the operation of the Radon Treatment System (RTS) and prior to the application of the exterior foam layer to the silo domes (Grumski and Shanks 1988). The RTS is a system that pumps air from the silos through a series of calcium sulfate and charcoal beds, which adsorb 222Rn from the circulating air (Grumski and Shanks 1988). This removes <sup>222</sup>Rn, and thus potential daughter products of <sup>222</sup>Rn, from the air space of the silos, and reduces the direct radiation exposure rates on the silo domes. The system is used to reduce radiation exposures to personnel involved in work on the silos. 👘 1. . . . . . . .

The November 4, 1987, <sup>222</sup>Rn samples were analyzed by the FMPC and by Mound Laboratories, also in Ohio (Grumski and Shanks 1988). The results are given in Table J–12. For the sample from Silo 1 that was analyzed by the FMPC (WMCO), a table of detailed counting results is also given in Grumski and Shanks (1988). This table shows that the sample was counted eight times, at times from two days after sampling to 26 days after sampling. Concentration results were decay-corrected to the time of sampling. However, for one of the counts, it appears that the decay time was listed as 19.23 days, while the counting data for this count imply a decay time of 18.23 days. It appears the incorrect decay time then resulted in an incorrect decay correction for the count, with the listed concentration,  $2.7 \times 10^7$  pCi L<sup>-1</sup>, erroneously high (this result also was inconsistent with results for the other seven counts). If the decay time is changed to 18.23 days, we calculate that the concentration for that count should have been estimated to be  $2.2 \times 10^7$  pCi L<sup>-1</sup>. If this corrected result is used, the average of the eight results is  $2.1 \times 10^7$  pCi L<sup>-1</sup>, as presented in Table J-12. . . . . . . . . . an star star st

· · · ·	Dire das builpies raken revender 1, 2001				
Silo	Sample container	WMCO Analysis	Mound Analysis		
Silo 1	sampling bag		$2.3 \times 10^{7}$		
Silo 2	sampling bag	· · · · · · · · · · · · · · · · · · ·	$1.3 \times 10^{4}$		
Silo 1	glass flask	$2.1 \times 10^{7 a}$	$2.5 \times 10^{7 b}$		
Silo 2	glass flask	$3.0 \times 10^{7}$	$2.9 \times 10^{7 b}$		

	٠.		1.145	· · · · · ·	
Table .	J-12.	Conce	ntration	s of <sup>222</sup> Rı	n (pCi L <sup>-1</sup> ) in K-65
S	ilo G	as San	ples Tak	en Nove	mber 4, 1987

The results for this sample given in the report (Grumski and Shanks 1988), appeared to contain a calculational error. The value presented here is the average of the eight measurements, after the apparent error was corrected (by the authors of this current report).

This value appears to be the average of concentrations measured for two sample flasks.

The significant difference between the sampling bag and glass flask results for Silo 2 was noted in the report (Grumski and Shanks 1988). This report indicated that the difference was "...most likely the result of dilution error associated with the sample bag and Here of the part , -

1

1. T. T. T.

いいざい

ALCONTA

÷ \_

# Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

procedure." Because of this potential error in the results for the samples taken in sampling bags, the two results for sampling bag samples will be ignored for the rest of this analysis.

Thus, the sample estimate of the average concentration of <sup>222</sup>Rn in the silos for this measurement episode is  $2.62 \times 10^7$  pCi L<sup>-1</sup> and the standard deviation of the four remaining measurements is  $4.1 \times 10^6$  pCi L<sup>-1</sup>, or about 16%. The average concentration is assumed to follow a normal distribution.

In addition to the measurement uncertainty, there is also uncertainty in the value of  $C_{a,\text{post}}$  due to the (presumed) daily variations in the Rn concentration because of daily fluctuations in the silo ventilation rate,  $\lambda_{v,post}$ . The silo ventilation rate is later estimated to be roughly 0.03 d<sup>-1</sup>, or about 3% d<sup>-1</sup>, so even relatively large changes in  $\lambda_{v,post}$  would cause only small changes in the Rn concentration in the silo head space. However, only one sampling episode was performed during the period 1980 to 1987, so our data set is very limited.

Typically, the uncertainty of an average value is expressed as the standard error of the mean, which is the standard deviation of the measured values divided by the square root of the sample size. However, because of the additional, unquantified uncertainties, we instead assume that the uncertainty of the average concentration is represented by the standard deviation for the four measured values. Thus, the distribution of values of  $C_{a,post}$  is considered to be a normal distribution with mean  $2.62 \times 10^7$  pCi L<sup>-1</sup> and standard deviation  $4.1 \times 10^{6} \text{ pCi L}^{-1}$ .

Silo air volume 1980–1987. The volume of air space in the silos,  $V_0$ , can be calculated as the sum of the volume of air in the dome part of the silo,  $V_{\rm dome}$ , and the volume of air in the cylindrical part of the silo above the K-65 residue material,  $V_{cyl}$ . We assume that the silo air space volume does not include the pore spaces of the K-65 material. Because the temperature of the K-65 material, and thus its pore spaces, would only change very slowly over time, the volume expansion in the pore spaces would be insignificant, and this assumption is reasonable. We assume the dome surface is spherically shaped, so these volumes are calculated as:

$$V_{\rm dome} = \frac{\pi h^2}{3} (3R - h) \tag{J-15}$$

where

: :

5

h = the height of the dome (above the silo walls),

 $R = (r^2 + h^2)/2h$ , the radius of the "sphere" of which the dome surface is a part, and r = the radius of the silo. And,

$$V_{\rm cyl} = \pi r^2 H \tag{J-16}$$

where H is the distance from the K-65 residue material to the top of the silo walls, which is the thickness of the cylindrical air layer.

Two drawings by the original designers and builders of the K-65 silos indicate the size of the silos to be 80 ft inside diameter, with a wall height of 26 ft 8 in, and inside dome height

of an additional 9 ft 4 in (Preload 1951a; Preload 1951b). The unloading manhole, which is located very close to the center of the dome, is shown as 36 ft above the silo floor. The four influent manholes are shown to be located equally spaced on a circle of 25 ft radius from the center of the dome, and about 32 ft above the silo floor.

From these data,  $V_{\text{dome}}$  can be directly calculated. First, with h = 9.33 ft and r = 40 ft, R is determined to be 90.4 ft. Then,  $V_{\text{dome}}$  is calculated to be 23,900 ft<sup>3</sup>.

A small number of documents have been found which can be used to estimate the value of H to calculate  $V_{cyl}$ . From a drilling and sampling episode in 1972, the depths of K-65 material were determined to be 20 ft in Silo 1 and 22 ft in Silo 2 (Nelson 1972b). Thus, for Silo 1, H = 26.67 ft - 20 ft = 6.67 ft. And, for Silo 2, H = 26.67 ft - 22 ft = 4.67 ft. With these values of H,  $V_{cyl}$  is estimated to be 33,500 ft<sup>3</sup> for Silo 1 and 23,500 ft<sup>3</sup> for Silo 2. The total volume is then estimated to be 57,000 ft<sup>3</sup> for Silo 1 and 47,000 ft<sup>3</sup> for Silo 2.

In 1978, gamma exposure rates were measured in Silo 1, at varying distances above the K-65 residue (Boback 1978). The farthest measurement location was 13 ft above the residue surface, and was also noted to be at the bottom of a manhole opening. It was not noted whether the manhole was one of the influent manholes or the unloading manhole. If the location was one of the influent manholes, the thickness of the K-65 material can be estimated to be 32 ft - 13 ft = 19 ft. Thus, H = 26.67 ft - 19 ft = 7.67 ft,  $V_{cyl} = 38,500 \text{ ft}^3$  and  $V_0 = 62,000 \text{ ft}^3$ . If the location was the unloading manhole, the K-65 material thickness can be estimated to be 36 ft - 13 ft = 23 ft. Thus, H = 26.67 ft - 23 ft = 3.67 ft,  $V_{cyl} = 18,400 \text{ ft}^3$ , and  $V_0 = 42,000 \text{ ft}^3$ .

In 1958, Silo 2 was decanted and removed from service, with a stated content of 883,400 gallons of residue (Noyes 1958). Since the residue was pumped into the silos as a slurry, we assume the residue occupied a cylindrical shape. Thus, the thickness of residue can be estimated to be 23.5 ft. Thus, H = 26.67 ft -23.5 ft = 3.17 ft,  $V_{cyl} = 15,900$  ft<sup>3</sup>, and  $V_0 = 40,000$  ft<sup>3</sup>.

The air volumes of the silos have also been determined by WMCO to be 55,815 ft<sup>3</sup> for Silo 1 and 45,762 ft<sup>3</sup> for Silo 2 (Shanks 1988). These volumes were based on depths of the residue of 20 ft in Silo 1 and 22 ft in Silo 2. These residue depths are the same as those of Nelson (1972b), but were not referenced in the WMCO calculations.

As part of the FMPC Remedial Investigation, the silos were sampled by WMCO in 1989 (DOE 1990). During this sampling episode, the average penetration into the K-65 residue material was 20 ft. No individual values of the penetration were given in the report. The value of 20 ft results in an estimate of  $V_0$  of 57,000 ft<sup>3</sup>, as noted earlier.

The range of these estimates of  $V_0$  is from 40,000 ft<sup>3</sup> to 62,000 ft<sup>3</sup>. Since we have no information that more definitively determines  $V_0$ , we assume the distribution of potential values of  $V_0$  to be uniform, with minimum 40,000 ft<sup>3</sup> and maximum 62,000 ft<sup>3</sup>.

Silo ventilation rate 1980-1987. As noted earlier, monitoring of the temperature and pressure differential of the K-65 Silos was performed in 1987 by WMCO (Grumski 1987a). It was concluded that the silos cannot hold any significant pressure and thus that increases in the temperature of the internal silo air resulted in the volumetric expansion of the air and the release of "excess" volume to the atmosphere (Grumski 1987a). Since the silos can not hold any significant pressure, it is certainly plausible that the cracks and other remaining

Page J-30

#### Appendix J

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

penetrations in the silo domes are large enough and numerous enough that additional ventilation of the silos occurs, due to winds across the silo domes. For the present work, it is assumed that the silo ventilation rate is the sum of a ventilation rate due to the temperature effects and a ventilation rate due to wind effects. That is,

$$\lambda_{v,\text{post}} = \lambda_{v,\Delta T} + \lambda_{v,\text{wind}} \tag{J-17}$$

We note that the previous assessments did not specifically calculate a silo ventilation rate, although the ventilation rate was implicit in their <sup>222</sup>Rn release calculations (Grumski 1987a; IT 1989).

The ventilation rate due to the daily temperature changes,  $\lambda_{v,\Delta T}$ , is the fraction of the silo air exhaled due to the temperature changes per some unit time period, with units of (air changes) per time. Thus:

$$\lambda_{v,\Delta T} = \Delta V / V_0 \tag{J-18}$$

As discussed earlier in the evaluation of previous estimates (see equation J-5), the ideal gas law gives:

$$\Delta V = (\Delta T/T_0)V_0 \tag{J-19}$$

thus

$$\lambda_{\mathbf{v},\Delta \mathbf{T}} = \Delta T / T_0 \qquad - \qquad (J-20)$$

where we define

 $\Delta V =$  the increase in volume per day,

 $\Delta T$  = the increase (only) in temperature of silo head space air, per day (K d<sup>-1</sup>),

 $V_0$  = the initial silo air volume above the K-65 material, and

 $T_0$  = the initial temperature of the silo air (K).

As noted earlier in the discussion of previous estimates (see page J-14), usable temperature and pressure monitoring data for the two K-65 silos were obtained for 11 complete days (and a few shorter periods also) (Grumski 1987a; Shanks 1991). From this data, which was collected every two hours, the silo daily temperature increase and the initial temperature of the silo air can be determined. However, since only 11 days of data were obtained, the direct use of these data to estimate the annual average value of  $\Delta T/T_0$  for the silos could introduce a significant bias. Instead, the daily silo values of  $\Delta T/T_0$  can be correlated to daily temperature changes at the Cincinnati airport. Then, the correlations can be used to estimate the average value of  $\Delta T/T_0$  for the silos from the Cincinnati temperature data.

Since we are interested only in the increase in silo temperature each day, ideally we would correlate the daily silo values of  $\Delta T/T_0$  with the increase (only) in temperature at the Cincinnati airport. However, it is impractical to determine the airport temperature increase for each day of a full year, as would be required. Instead, we determine the difference between the maximum and minimum airport temperature for each day, and then correlate

NG 22

Sec. 10

the daily silo values of  $\Delta T/T_0$  to this difference. It is recognized that there are uncertainties introduced by performing the correlation in this manner. For example, on many days, the temperature falls during the day so the silo temperature increase, and  $\Delta T/T_0$ , is zero, but the airport temperature difference (maximum temperature – minimum temperature) is still positive.

The data obtained to perform the correlation are given in Table J-13 and Table J-14. The silo temperature increase and minimum temperature data were obtained from the previous temperature and pressure monitoring of the silos (Shanks 1991). For each silo, the monitoring results included a "bottom" temperature, near the bottom of the air space in the silo, and a "top" temperature, near the top of the silo air space. The average value of  $\Delta T/T_0$ , given in Table J-13, has been calculated as follows. First, for each silo, the top and bottom temperatures at each measurement time were averaged, as a best estimate of the temperature in the silo air for that point in time. Next, the increase in temperature and the initial temperature were determined for each silo for each of the 11 days, and were converted to the (absolute) Kelvin scale (K). Then, the values of  $\Delta T/T_0$  for each silo for each silo for each day, was calculated as the average of the values for the two silos for that day.

Records of the hourly temperature at the Cincinnati airport have been obtained for the period 1948 to 1987, by year (NCDC 1991). The maximum temperature,  $T_{\rm max}$ , and the minimum temperature,  $T_{\rm min}$ , were extracted for each of the 11 days on which the silo temperature was measured, and are shown in Table J-14. The difference  $T_{\rm max} - T_{\rm min}$ , in Table J-14, has been calculated for this analysis.

			Data Use	d for a L	inear Co	rrelation	<b>3</b>		- •
			Silo 1 data	Ь	Silo 2 data <sup>b</sup>		ь <sup>:</sup>	Average	
. '	Date	(°F)	∆ <i>T</i> (°F d <sup>-1</sup> )	Δ <i>T/T</i> <sub>0</sub> (d <sup>-1</sup> )	" T <sub>0</sub> (°F)	∆ <i>T</i> (°F d <sup>-1</sup> )	∆ <i>T/T</i> 0 (d <sup>-1</sup> )	$\frac{\Delta T/T_0}{(d^{-1})}$	
	3/27/87	50.65	20.15	0.0395	52.35	22.85	0.0447	0.0421	<b>.</b> .:
	3/29/87	53.6	21.6	0.0421	56.25	23.65	0.0459	0.0440	
	3/30/87	42.85	0	0	41.9	0	0 .	0	• *
	3/31/87	40.8	<b>4.6</b>	0.0092	<b>39.1</b>	5.15	0.0103	0.0098	•• :
	4/01/87	38.85	14.2	0.0285	36.6	16.2	0.0327	, 0.0306	:
	4/02/87	43.95	12.	0.0238	43.3	14.1	0.0280	0.0259	
	4/03/87	· `38.5	11.3 <sup>na</sup>	<sup>°</sup> 0.0227 <sup>1</sup>	<sup>1</sup> 37.55	12.6	0.0254	0.0240	•
• *	4/04/87	40.25	3.15	0.0063	~3 <b>9.</b> °	3.6	0.0072	0.0068	Ċ.
	5/09/87	61.95	30.9	0.0593	63.1	35.1	0.0672	0.0632	11
	5/10/87	65.25	30.1	£0.0574 ·	: 6 <b>7.5</b>	34.1	0.0647	. 0.0610	
	5/11/87	68.35	27.1	0.0514	71.25	28.8	0.0543	0.0528	; ; ·

Table J-13. K-65 Silo Values of  $\Delta T/T_0$ ; Data Used for a Linear Correlation<sup>a</sup>

<sup>a</sup> The values of  $\Delta T$  and  $T_0$  must be expressed in absolute temperature units (K) before the ratio is computed.

 $^{b}$   $T_{0}$  and  $\Delta T$  data obtained from Shanks (1991). C

Appendix J	Page J-33
Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silo	s .

Date	Maximum T <sub>max</sub> (°F)	Minimum T <sub>min</sub> (°F)	Difference $T_{\text{max}} - T_{\text{min}}$ (°F)
3/27/87	65	44	21
3/29/87	77	44	33
3/30/87	48	<b>29</b>	19
3/31/87	33	24	9
4/01/87	47	24	23
4/02/87	43	31	· 12
4/03/87	37	27	10
4/04/87	41	28	13
5/09/87·	80	43	· 37
5/10/87	85	53	<b>32</b> ·
5/11/87	84	. <b>60</b>	24

Table J-14. Temperature Difference at Cincinnati

 $^a \ T_{
m min}$  and  $T_{
m max}$  data obtained from NCDC (1991).

We note that some relationship is expected between the minimum temperature and the daily temperature change at the Cincinnati airport. A linear regression of the values of  $(T_{\rm max} - T_{\rm min})$  versus the values of  $T_{\rm min}$  for 1987 was performed. The regression coefficient was determined to be R = 0.075. With this small value of the regression coefficient, we assume the relationship between  $(T_{\text{max}} - T_{\text{min}})$  and  $T_{\text{min}}$  is weak enough to be considered insignificant for our analysis. Thus, we neglect this possible relationship.

A linear correlation of the average values of  $\Delta T/T_0$  (dependent variable) to the Cincinnati airport temperature difference (independent variable),  $T_{\rm max} - T_{\rm min}$ , was performed using a least squares regression. The regression coefficient is R = 0.80. The regression line is given by:

$$\Delta T/T_0 (d^{-1}) = (0.00179 \text{ °F}^{-1} d^{-1}) \times (T_{\max} - T_{\min} (\text{°F})) - 0.00516 d^{-1} \qquad (J-21)$$

For this regression line, the standard error of the estimate,  $S_{Y|X}$ , is 0.0138 d<sup>-1</sup>.

From the hourly records of temperature at the airport, additional data were obtained for the complete year 1987 (NCDC 1991). The average of the daily maximum temperatures was determined to be 65.08 °F. The average of the daily minima was determined to be 45.62 °F. The average daily difference (average of  $(T_{max} - T_{min})$ ) is equal to the difference of the averages of the maxima and minima. Thus, the average daily difference for 1987 is 65.08 -45.62 = 19.46 °F. This value is also assumed to represent the average daily difference for the assessment period 1980 to 1987.

Thus, the annual average value of  $\Delta T/T_0$ , and thus  $\lambda_{v\Delta T}$  for the period 1980 to 1987 is estimated from the regression line and the average daily difference as:

> $\lambda_{v,\Delta T} = \Delta T / T_0$  $=(0.00179 \text{ °F}^{-1} \text{ d}^{-1}) \times (19.46 \text{ °F}) - 0.00516 \text{ d}^{-1}$ (J-22)  $= 0.0297 \text{ d}^{-1}$

> > Radiological Assessments Corporation "Setting the standard in environmental health"

• . . . . .

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

It is assumed that the conditional distribution of  $\Delta T/T_0$ , at the given value of  $T_{\max} - T_{\min} = 19.46$  °F, is a normal distribution with standard deviation  $S_{YIX}$ . Thus, we consider the distribution of potential values of  $\Delta T/T_0$  to be a normal distribution with mean 0.0297 d<sup>-1</sup> and standard deviation 0.0138 d<sup>-1</sup>. However, with this mean and standard deviation, there is a significant chance that negative values of  $\Delta T/T_0$  might be selected from the distribution. Since such negative values are meaningless for the calculation of the ventilation rate, we truncate the distribution at 0, disallowing negative values.

As discussed earlier, it is plausible that the cracks in the silo domes are numerous enough and large enough that the action of winds on the domes could create additional ventilation in the silos, represented by  $\lambda_{v,wind}$ . However, no data have been found to substantiate an estimate of  $\lambda_{v,wind}$ . In our preliminary source term work (Voillequé et al. 1991) we arbitrarily assumed that  $\lambda_{v,wind}$  ranges from zero to the value of  $\lambda_{v,\Delta T}$ , with a uniform distribution. However, that assumption introduced a multiplicative factor, with mean 1.5, into the estimate of  $Q_{exch}$ , that we now think cannot be substantiated. Since additional information has not been located to substantiate a value for  $\lambda_{v,wind}$ , we now assume a value of zero.

**Results for 1980–1987.** Table J–15 summarizes the frequency distribution for the air exchange Rn release rate for 1980–1987. The uncertainty range for this release rate is fairly broad, with a 90% probability interval spanning a factor of seven range.

	Percent			
Period	5th 25th	median	75th	95th
July 1979-December 1987	230 550	810	1100	1600

# Table J-15. Summary of Predicted Air Exchange Radon ReleaseRate (Ci y<sup>-1</sup>) from the K-65 Silos for the 1980–1987 Period

#### Model for Diffusion Releases from K-65 Silos for 1980-1987

The diffusion releases for the period 1980 to 1987 are calculated using the same methods used in the previous assessment (IT 1989; Borak 1985). However, since the concentration of <sup>222</sup>Rn in the silos has been measured, the calculated releases are based on the measured <sup>222</sup>Rn concentration, rather than on a concentration calculated from characteristics of the K-65 waste material. As was described earlier, the flux of <sup>222</sup>Rn diffusion through the concrete dome of the silos can be calculated by (Borak 1985; Collé et al. 1981):

$$J = \frac{\varepsilon_{\rm c} \lambda_{\rm Rn} l_{\rm c} C_{\rm a}}{\sinh\left(\frac{L}{l_{\rm c}}\right)}$$

(J-23)

学会

アンドン

144.50

#### where

 $J = \frac{222}{\text{Rn}}$  flux from the head space through the silo dome surfaces to the surrounding air (pCi m<sup>-2</sup> d<sup>-1</sup>, or similar),

 $\varepsilon_c$  = total porosity of the dome concrete,

Appendix J

1

- K

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

 $\lambda_{Rn}$  = decay constant of <sup>222</sup>Rn (d<sup>-1</sup>, or other as appropriate),

 $l_{\rm c}$  = diffusion length of <sup>222</sup>Rn in the dome concrete (cm),

 $C_{2}$  = concentration of <sup>222</sup>Rn in the silo air (pCi L<sup>-1</sup>), and

L = thickness of the dome concrete (cm).

The diffusion release rate is then calculated as:

$$Q_{\rm diff,post} = JA_{\rm dome} \tag{J-24}$$

Page J-35

where  $A_{\text{dome}}$  is the surface area of the silo domes (ft<sup>2</sup>, or other). These equations are applied to the 1980–1987 period by using  $C_{a,\text{post}}$  for the <sup>222</sup>Rn concentration in the silo air.

The porosity of the dome concrete,  $\varepsilon_c$ , and the Rn diffusion length in the dome concrete,  $l_c$ , are dependent on the physical characteristics of the dome concrete. A number of documents indicate that the quality of the dome concrete is poor, and apparently has been from the earliest years. Memoranda from the 1950's indicated that there were many cracks in the K-65 Silo walls, and that small quantities of liquid seeped from some of them (Wunder 1954; Martin 1957). In 1984, the Mound Laboratory, a DOE facility, made measurements of the Rn fluence rate (flux) through the domes of the K-65 Silos (Hagee et al. 1985). Mound indicated that the domes had many obvious cracks and fissures, and their measurements showed greatly increased Rn transport through these cracks. Structural studies of the K-65 Silos have been completed more recently. In one study, Pulse-Echo tests were performed on the tanks to determine the concrete quality (Camargo 1986). Results showed general thinning of the domes, with a sharply irregular interior surface, indicating significant deterioration of the domes.

In another study, samples of concrete from Silo 4 (the unused one) were subjected to laboratory analyses (BNI 1990). The samples from Silo 4 were considered to be reasonably representative of the K-65 and Metal Oxide Silos, since they were all built at the same general time, and have been exposed to the same weathering conditions. Results indicated that the concrete was originally placed with medium to high slump. High slump concrete is, in general, less dense, more porous, and less durable overall. Results of the petrographic analysis indicated that reactivity was responsible for expansion of the concrete, which resulted in microcracking, which then allowed ingress of water into the concrete. The reactivity generally occurs within 90 days after the concrete is placed. Freeze-thaw conditions were thought to aggravate these conditions and increase the deterioration of the concrete.

This evidence indicates that the dome concrete has had fairly poor quality since the earliest days, and has deteriorated more over the years. No specific data on the porosity and Rn diffusion length for the K-65 Silos dome concrete have been obtained, so we must rely on literature values. However, we choose values from the literature that are more representative of poor quality concrete.

**Concrete porosity.** A National Bureau of Standards (NBS) review report cited a measured value of concrete porosity of 0.265 from one study and an assumed range of 0.05 to 0.25 from another study (Collé et al. 1981). The porosity used in the previous assessment was 0.3 (Borak 1985), although the source of the value was not cited. Because of the very

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

limited amount of data found, and the lack of data specific to the FMPC K-65 silos, we assume that the potential values of  $\varepsilon_c$  follow a uniform distribution. Based on the poor quality of the dome concrete, we assume the upper half of the range cited in the NBS report would apply, as poor concrete quality would be associated with higher porosity. Thus, the porosity,  $\varepsilon_c$ , is assumed to follow a uniform distribution, with minimum 0.16, and maximum 0.265.

Radon diffusion length in concrete. The NBS review report cited measurements of the  $^{222}$ Rn diffusion coefficient in concrete, that would equate to diffusion lengths from 7.43 cm to 12.7 cm (Collé et al. 1981). Nazaroff and Nero (1988) cite values of the diffusion length in concrete from 6 cm to 20 cm. The diffusion length in concrete used in the previous assessment was 12 cm (Borak 1985). This value was justified by Borak based on a referenced range of values from 6 cm to 23 cm measured for intact concrete (Borak 1986; Jonassen and McLaughlin 1978 [cited by Borak 1986]; Krisiuk et al. 1971 [cited by Borak 1986]). Again, the data found are limited; and are not specific to the K-65 domes. Poor quality concrete would be associated with greater diffusion through it, and thus larger values of the Rn diffusion length. We thus use the upper half of the range of literature values. The potential values of  $l_c$  are assumed to be represented by a uniform distribution with minimum 14.5 cm and maximum 23 cm.

Silo dome thickness. A review of the K-65 Silos' history indicated that the thickness of the domes was 4 in (Shanks and Vogel 1988). However, an FMPC report about proposed stabilization activities on the silos indicated that the domes were designed to be 8 in thick at the silo wall, tapering to 4 in thick at the dome center (Grumski 1987a). However, we have reviewed some of the original engineering drawings for the silo construction, and this latter characterization appears to be a misinterpretation. The silo design drawing indicates that the domes would be 8 in thick at the silo wall, but would taper to a thickness of 4 in within about 2 ft from the wall (Preload 1951a). Thus, the thickness of 8 in is only at the very edge of the domes, and is ignored for this analysis.

In addition, a structural assessment of the silo domes was performed in 1985. As part of this assessment, the thicknesses of the domes were measured, and were indicated to be as thin as 3 inches for portions of the centers of the domes, where deterioration has occurred (Camargo 1986). As an estimate of the mean thickness of the domes is not available, we consider the potential values of L to be represented by a uniform distribution with minimum 3 in and maximum 4 in.

Dome surface area. The silo dome surfaces are assumed to be portions of a sphere. As such, their surface area,  $A_{dome}$ , can be calculated as:

 $A_{\text{dome}} = 2\pi R^2 \left( 1 - \sqrt{1 - \frac{r^2}{R^2}} \right)$ 

(J-25)

where

 $R = (r^2 + h^2)/2h$ , the radius of the "sphere" of which the dome surface is a part, h = the height of the dome (above the silo walls), and

r =the radius of the silo.
.

.

÷.

## Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

As discussed earlier, h = 9.33 ft and r = 40 ft, and so R is determined to be 90.4 ft. Thus,  $A_{\text{dome}} = 5300$  ft<sup>2</sup>. For the purposes of these calculations, the uncertainty in  $A_{\text{dome}}$  is assumed negligible.

**Radon decay constant.** The half life of <sup>222</sup>Rn is 3.8235 d (Walker et al. 1989). Thus, the decay constant for <sup>222</sup>Rn,  $\lambda_{Rn}$ , is 0.18129 d<sup>-1</sup>. For purposes of our calculations, this value is assumed to have negligible uncertainty.

**Results for 1980–1987.** Table J-16 summarizes the calculated distribution of the predicted diffusion Rn release rate from the K-65 Silos for the 1980–1987 period. As expected, the release rate for diffusion releases is substantially smaller than the release rate for air exchange releases, though not insignificant.

	· .	Percentiles of distribution			· .
Period	5th	25th	median	75th	95th
July 1979–December 1987	.72	100	130	170	240

# Table J-16. Summary of Predicted Diffusion Radon Release Rate (Ci y<sup>-1</sup>) from the K-65 Silos for the 1980–1987 Period

# Total Releases from K-65 Silos for 1980–1987

The total Rn release rate from the K-65 Silos for the 1980–1987 period is the sum of the release rates due to air exchange and diffusion:

$$Q_{\text{post}} = Q_{\text{exch,post}} + Q_{\text{diff,post}}$$

Table J-17 summarizes the frequency distribution of the calculated total Rn release rate from the K-65 Silos for the 1980-1987 period. Also shown are predictions of the fraction of the total removal of Rn from the Silos that occurs through release to the outside air through air exchange and diffusion (the rest is "removed" by radioactive decay),  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{post}$ . The results for this fraction indicate that only a small fraction of the Rn in the Silos is released to the outside air.

Parameter		ibutions				
	Units	5th	5th 25th		75th	95th
Q <sub>post</sub>	Ciy <sup>-1</sup>	360	690	950	1200	1700
$[(\lambda_{\nu}+\lambda_{d})/\lambda_{eff}]_{post}$		0.071	0.13	0.16	0.20	0.24

Table J-17. Summary of Frequency Distributions of Calculations of Total Radon Release Rates from the K-65 Silos for 1980–1987

Radiological Assessments Corporation "Setting the standard in environmental health"

Page J-37

(J-26)

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

## Model for K-65 Silo Radon Production Rates

In order to calculate the total Rn releases for the 1959–1979 period,  $Q_{pre}$ , using equation J-13, we must first determine the Rn production rate,  $P_{\rm Rn,pre}$ , for this period. By "Rn production rate" we mean the rate of release of <sup>222</sup>Rn from the K-65 material into the silo air space. The production rate is generally constrained by existing Rn in the silo air spaces. For comparison with an alternative calculation of releases from the Silos, discussed later in this Appendix, we also wish to calculate an unconstrained production rate (no Silo and no Rn to inhibit release from the K-65 material),  $P_{\rm Rn,0}$ , which is equivalent to an unconstrained release rate from the Silos.

The Rn production rate can be determined for the 1980-1987 period based on the Rn concentration and effective removal rate of Rn from the head space. In our preliminary source term work (Voillequé et al. 1991), we assumed that the Rn production rate was the same for the two periods 1959-1979 and 1980-1987, even though the Rn concentrations had changed: It is recognized that the release of Rn from the K-65 material into the silo air space would be higher for a lower silo Rn concentration because the diffusion of Rn out of the K-65 material is a process constrained by the Rn concentration in the silo air. In this current assessment, we account for different Rn production rates for the different time periods. To do this, we use the relationship between the silo Rn concentration and the Rn production rate, and we use the Rn production rate for 1980-1987 as a baseline.

We first calculate the Rn production rate,  $P_{\text{Rn,post}}$ , for 1980–1987. This is calculated based on the concentration of <sup>222</sup>Rn measured after the sealing of the silo openings. From an assumption of an equilibrium <sup>222</sup>Rn concentration in the silo air, the release rate of <sup>222</sup>Rn into the silo air is equal to the rate of loss of <sup>222</sup>Rn from the silo air by decay and by release to the atmosphere. As given in equation J-9, this is represented as (see also Collé et al. 1981):

$$P_{\text{Rn,post}} = C_{a,\text{post}} V_0 \lambda_{\text{eff,post}}$$

(J-27)

.

ŕ.

ź

•

\* 1

10-10-11

1.11

State State

1000

where

 $P_{\rm Rn}$  = the constrained (by the presence of the silo) rate of release of <sup>222</sup>Rn from the source material into the silo air (Rn production rate) (pCi d<sup>-1</sup>),

 $C_{a,post}$  = the concentration of <sup>222</sup>Rn in the silo air (pCi L<sup>-1</sup>),

 $V_0$  = volume of the silo air space, as used earlier, and

 $\lambda_{eff,post}$  = the effective removal rate of <sup>222</sup>Rn from the silo air space: the sum of the <sup>222</sup>Rn decay constant,  $\lambda_{Rn}$ ; the ventilation rate,  $\lambda_{v,post}$ ; and the rate constant for diffusion losses,  $\lambda_{d,post}$  (d<sup>-1</sup> or similar).

The <sup>222</sup>Rn concentration,  $C_{a,post}$ ; silo air volume,  $V_0$ ; and silo ventilation rate,  $\lambda_{v,post}$ , were discussed previously in this appendix.

The half life of  $^{222}$ Rn is 3.8235 d (Walker et al. 1989). Thus, the decay constant for  $^{222}$ Rn,  $\lambda_{Rn}$ , is 0.18129 d<sup>-1</sup>. For purposes of our calculations, this value is assumed to have negligible uncertainty.

The rate constant for diffusion Rn losses from the silo air space,  $\lambda_{d,post}$ , can be calculated from a rearrangement of equation J-11, as follows.

Appendix J

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

$$\lambda_{d,post} = \frac{Q_{diff,post}}{C_{a,post}V_0}$$
(J-28)

The rate of diffusion release, Q<sub>diff. post</sub>, was discussed earlier in this Appendix (page J-34).

We next develop the relationship between the Rn production rate and the Rn concentration in the silo air. A National Bureau of Standards (NBS) review report on Rn transport in building materials (Collé et al. 1981) provides useful models for this purpose. For a Rn concentration in air above a Rn source material, the constrained Rn diffusion fluence rate (often simply called Rn flux) from the source material into the air is given by the following equation (Collé et al. 1981). For this relationship, it is assumed that the bottom of the source material is impervious to Rn transport, an assumption that seems reasonable for the K-65 Silos, which have concrete floors.

$$j_{\rm D} = \sqrt{\frac{D_{\rm e}\varepsilon_{\rm w}}{\lambda_{\rm Rn}}} (\phi - C_{\rm a}\lambda_{\rm Rn}) \tanh\left(\frac{L_{\rm w}}{l_{\rm w}}\right) \tag{J-29}$$

where

.

- $j_{\rm D}$  = constrained (by Rn in silo air) diffusion fluence rate of Rn (Rn flux). The quantity of Rn per unit time per unit area transported by diffusion from the source material (in this case the K-65 material) into the ambient air (silo air space in this case) (pCi m<sup>-2</sup> s<sup>-1</sup>, or similar),
- $D_e$  = effective diffusion coefficient of Rn through the porous source material (cm<sup>2</sup> s<sup>-1</sup>, or similar),
- $\varepsilon_{w} = \text{porosity of the source material},$
- the pore space Rn production rate. Quantity of Rn produced in pore spaces of the source material per unit time per unit volume that is free to migrate through the pores of the material (pCi m<sup>-3</sup> s<sup>-1</sup>). Depends on characteristics of the source material, including <sup>226</sup>Ra concentration, Rn emanation fraction, bulk density, and porosity, and on the Rn decay constant,
- $L_w$  = thickness of the source material (cm, or similar), and

 $l_w$  = diffusion length of Rn in the source material (related to  $D_e$ ) (cm, or similar).

P

The other parameters have been described earlier. The Rn production rate is then just:

$$P_{\rm Rn} = j_{\rm D} A_{\rm w} \tag{J-30}$$

where  $A_w$  is the surface area of the source material (the K-65 material) exposed to the (silo) air. With a slight rearrangement we have:

$$P_{\rm Rn} = A_{\rm w} \sqrt{D_{\rm e} \varepsilon_{\rm w} \lambda_{\rm Rn}} (\phi/\lambda_{\rm Rn} - C_{\rm a}) \tanh\left(\frac{L_{\rm w}}{l_{\rm w}}\right)$$
(J-31)

Equation J-27 and equation J-28 can be used to calculate  $P_{\text{Rn,post}}$ , but we must also calculate  $P_{\text{Rn,pre}}$ . We assume that the characteristics of the K-65 material have not changed since the Silos were decanted, and thus that  $D_e$ ,  $l_w$ ,  $\varepsilon_w$ , and  $\phi$  are the same for the 1959-

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

1979 period as they are for the 1980-1987 period. Of the characteristics of the K-65 material that impact these parameters, the one most likely to have changed over this long period is probably the moisture content of the uppermost part of the K-65 material in the silos. The moisture content affects the diffusion coefficient,  $D_e$ , and could affect the pore Rn production,  $\phi$ , through the emanation fraction. However, no applicable information has been located that could be used to determine the time history of this moisture content. We thus assume that it has not changed enough to significantly alter  $D_e$  or  $\phi$ . The surface area,  $A_w$ , and thickness,  $L_w$ , of the K-65 material in the Silos also would not have changed over time. With these assumptions of invariant characteristics of the K-65 material, we apply equation J-31 to the two time periods, and ratio the two resultant equations to obtain:

$$P_{\rm Rn,pre} = P_{\rm Rn,post} \left( \frac{\phi / \lambda_{\rm Rn} - C_{\rm a,pre}}{\phi / \lambda_{\rm Rn} - C_{\rm a,post}} \right)$$
(J-32)

The calculation of  $C_{a,pre}$  is discussed later (page J-41).

In order to calculate  $(\phi/\lambda_{Rn})$ , we make use of the relationship between  $\phi$ ,  $\lambda_{eff}$ , and  $C_a$  for a contained air space (like the Silos) above the Rn source material (Collé et al. 1981):

$$C_{\rm a} = \frac{\phi}{\lambda_{\rm eff}} \left( \frac{\varepsilon_{\rm w} l_{\rm w}}{\varepsilon_{\rm w} l_{\rm w} + h} \right) \tag{J-33}$$

1977 No. 3412

Sucher. Thomas

where h is the effective height of the contained air space above the source material. For the 1980–1987 period, with rearrangement, we obtain:

$$\frac{\phi}{\lambda_{\rm Rn}} = C_{\rm a,post} \left( \frac{\lambda_{\rm eff,post}}{\lambda_{\rm Rn}} \right) \left( \frac{\varepsilon_{\rm w} l_{\rm w} + h}{\varepsilon_{\rm w} l_{\rm w}} \right)$$
(J-34)

In a later section of this Appendix we discuss an alternative calculation which is based on the characteristics of the K-65 material, including  $\varepsilon_w$  and the diffusion coefficient, which is related to  $l_w$  (see page J-73). As part of the alternative analysis, calculations of the quotient  $[(\varepsilon_w l_w + h)/\varepsilon_w l_w]$  were performed. The median value of this quotient was determined to be 6.35 (see page J-82). For the calculation of  $(\phi/\lambda_{\rm Rn})$  here, we use this median value. Since this quotient is significantly greater than 1,  $(\phi/\lambda_{\rm Rn})$ , from equation J-34, will be significantly greater than  $C_{a,post}$ , which in turn is greater than  $C_{a,pre}$ . Thus, the resultant estimate of  $P_{\rm Rn,pre}$ , from equation J-32, is not very dependent on the exact value of this quotient. Thus we think the use of the median value of this quotient is adequate for the calculation in equation J-34.

For comparison with the alternative calculation of Rn releases performed later, we additionally calculate the unconstrained Rn production rate, which we call  $P_{\text{Rn},0}$ . This is done by using equation J-32, and substituting a value of 0 for  $C_{\text{a.pre.}}$ . Thus:

$$P_{\rm Rn,0} = P_{\rm Rn,post} \left( \frac{\phi/\lambda_{\rm Rn}}{\phi/\lambda_{\rm Rn} - C_{\rm a,post}} \right)$$
(J-35)

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Table J–18 summarizes the calculated Rn production rate frequency distributions.

	Trates	110m A-00 I	laterial in	the Root	51105	
			Percent			
Parameter	Units	5th	25th	median	75th	95th
P <sub>Rn,post</sub>	pCi d <sup>-1</sup>	$5.6 \times 10^{12}$	$7.0 \times 10^{12}$	$8.1\times10^{12}$	$9.3  imes 10^{12}$	$1.1 \times 10^{13}$
P <sub>Rn.pre</sub>	pCi d <sup>-1</sup>	$6.4 imes10^{12}$	$8.0\times10^{12}$	$9.2\times10^{12}$	$1.1 imes10^{13}$	$1.3 imes10^{13}$
$P_{\mathrm{Rn,0}}$	Ci y <sup>-1</sup>	4700	5900	6800	7900	9400

Table J-18. Summary of Frequency Distributions of Rn Production Rates from K-65 Material in the K-65 Silos

# Model for Total Releases from K-65 Silos for 1959-1979

Appendix J

۰.

In 1958 the second silo was decanted, with the excess water removed through the weirs in the sides of the silo. Thus, during the period 1959 to 1979 the K-65 material in the silos should not have been covered with standing water. The six-inch gooseneck pipe vent was open from the silos to the atmosphere. For this time period, the total Rn releases, through air exchange and diffusion, are estimated using equation J-13 with the  $^{222}$ Rn concentration based on exposure rate measurements on the domes of the silos. That is,

$$Q_{\rm pre} = P_{\rm Rn, pre} - C_{\rm a, pre} \lambda_{\rm Rn} V_0 \tag{J-36}$$

The calculations of  $P_{\text{Rn,pre}}$ ,  $V_0$ , and  $\lambda_{\text{Rn}}$  were previously discussed. The rest of this section discusses the calculation of the Rn concentration in the silo head space for 1959–1979. Here, and in the following sections, the subscript "pre" refers to that parameter for the time period 1959 to 1979.

No useful measurements of the <sup>222</sup>Rn concentration in the silos for the period 1959–1979 have been located. However, an alternative is to make use of the fact that two of the shortlived daughters of <sup>222</sup>Rn, <sup>214</sup>Pb and <sup>214</sup>Bi, emit gamma radiation in significant quantities. Based on our later calculations, the rate constants for losses of <sup>222</sup>Rn from the silo air space are relatively small, compared to the decay constants of the Rn daughters. Thus, these daughters would be present essentially in equilibrium with <sup>222</sup>Rn, and the high <sup>222</sup>Rn concentration in the silo air will have an associated, significant gamma exposure rate.

If measurements of the exposure rate are obtained for a consistent geometry, for a time period when the <sup>222</sup>Rn concentration is also known, an exposure rate factor (mR h<sup>-1</sup> per pCi L<sup>-1</sup> <sup>222</sup>Rn, or similar) can be developed. Then, the <sup>222</sup>Rn concentration can be estimated for other time periods when only exposure rate data exist. This is the approach taken. The exposure rate factor (ERF) will be developed based on <sup>222</sup>Rn concentration and exposure rate data for the period around 1987. Then, the <sup>222</sup>Rn concentration will be estimated for the period 1959 to 1979. That is:

$$ERF = \frac{X_{\text{post}} - X_{\text{bkg}}}{C_{\text{a,post}}}$$
(J-37)

Page J–42

where

## $ERF = exposure rate factor (mR h^{-1} per pCi L^{-1}),$

 $X_{\text{post}}$  = the average gross exposure rate on the silo domes during the period 1980-1987 (mR h<sup>-1</sup>), and

 $X_{\rm bkg}$  = the average "background" exposure rate on the silo domes (mR h<sup>-1</sup>). This exposure rate would include contributions from sources other than the <sup>222</sup>Rn daughters in the silo air space. Since this would include contributions from <sup>222</sup>Rn daughters in the K-65 residues, this background exposure rate will be much greater than a typical environmental background exposure rate.

Then

$$C_{a, pre} = \frac{X_{pre} - X_{bkg}}{ERF}$$

(J-38)

£

----

free service

ボシン

1.5.1.5.1

where

15111

 $C_{a,pre}$  = concentration of <sup>222</sup>Rn in the silo air (pCi L<sup>-1</sup>), and

 $X_{\text{pre}}$  = the average gross exposure rate on the silo domes during the period 1959-1979 (mR h<sup>-1</sup>).

These two equations can be simplified to:"

$$C_{\rm a,pre} = C_{\rm a,post} \left( \frac{X_{\rm pre} - X_{\rm bkg}}{X_{\rm post} - X_{\rm bkg}} \right)$$
(J-39)

Searches through historical records of the FMPC have located some results of radiation exposure rate measurements on the K-65 Silo domes, which are summarized in Table J-19. The "contact" measurement data will be used in this analysis because the only measurements made after <sup>222</sup>Rn had been removed from the silos were made on contact. The measurements made at 4 ft above the surface, and the measurements for which the height was not specified, will not be included in this analysis. Two other measurements will also be disregarded. First, the low value of those made on contact with Silo 2 (85 mR h<sup>-1</sup>) in November 1980 was made on the edge of the silo dome (Green 1980b), and is thus not considered comparable to the other measurements, which were taken closer to the middle of the domes. Second, the extremely high result of April 1986 was obtained at a crack in the dome surface (Fleming 1986), through which <sup>222</sup>Rn was probably moving, and in which decay products had probably plated out. Thus, this measurement is also not considered indicative of the silo <sup>222</sup>Rn concentration in the same manner as the other measurements. The contact exposure rates that will be used in this analysis are plotted in Figure J-4.

The data for the period prior to sealing the openings, 1959 to 1979, do not indicate a significant variation in exposure rate. These measurements ranged from 65 to 90 mR h<sup>-1</sup>. Little information exists about the number and location of measurements made for each measurement episode. Some results were averages, while others were ranges.

0.000

Appendix J

8

# Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Date of Measurement	Silo	Height of Measurement	Exposure rate	Comments (reference)
		Р	rior to Seali	ing Silo Openings
April 1964	1	contact	75	Average value, probably silo 1. (Starkey 1964)
March 1972	nsa	ns .	30	(Levy 1972)
March 1972	ns	contact	75	Maximum reading, assumed to be on contact. (Nelson 1972a)
May 1973 .	1	contact	65–90	Assumed on contact since other locations were. (Boback 1973)
May 1973	2	contact	7075	(Boback 1973)
July 1973	2	ns	35	Near center of dome. (Levy 1973)
ns	ns	contact	<b>90</b> .	Specified as before sealing of openings in 1979. (Boback 1980a)
		·	After Sealin	g Silo Openings
April 1980	1	contact	250	(Green 1980a)
April 1980	1	4 ft	150	(Green 1980a)
April 1980	2	contact	20 <b>0–250</b>	(Green 1980a)
April 1980	2	4 ft	150 ·	(Green 1980a)
ns	ns	contact	250	Specified as after sealing of openings in 1979. (Boback 1980a)
November 1980	1	contact	175	(Green 1980b)
November 1980	1	4 ft	• 140	(Green 1980b)
November 1980	2	contact	85-175	The low value was near edge, rather than center. (Green 1980b)
November 1980	2	4 ft	45100	The low value was near edge, rather than center. (Green 1980b)
May 1982	1	contact	290	(Grant and Stevens 1982)
May 1982	1	3 ft	18-250	Low value was near edge. (Grant and Stevens 1982)
May 1982	2	contact	400	(Grant and Stevens 1982)
May 1982	2	3ft	35–280	Low value was near edge. (Grant and Stevens 1982)
April 1986	2	contact	850	Measured at crack in dome; other results not legible. (Fleming 1986)
November 1987	1	contact	168-208	Baseline, average 193. (Grumski and Shanks 1988)
November 1987	1.	contact	35.5-68	After operation of RTS <sup>b</sup> , average 55. (Grumski and Shanks 1988)
November 1987	·· 2.	contact	221-250	Baseline, average 232. (Grumski and Shanks 1988)
November 1987	2	contact	60-76	After RTS; average 68. (Grumski and Shanks 1988)

<sup>b</sup> RTS is the acronym for the Radon Treatment System.

For the period after sealing the openings, 1980 to 1987, the data show considerable variation (Figure J-4), but no clear trend is evident. The variation seen is not excessive,

Radiological Assessments Corporation "Setting the standard in environmental health"

Page J-43



# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

ź

01.XV.---

. . .



Figure J-4. Contact exposure rate measurements on the K-65 Silo domes prior to and after sealing of Silo penetrations.

considering the uncertainty and response characteristics of typical survey instruments. These measurements ranged from 168 to 400 mR  $h^{-1}$  (not including the measurements after operation of the Radon Treatment System (RTS)).

The data taken after operation of the RTS, in November 1987, can be used to estimate the "background" exposure rate due to sources other than the <sup>222</sup>Rn in the silo air. As discussed earlier, the RTS is a system to remove Rn and potencial daughter products from the silo air space (see page J-28).

The RTS was operated in November 1987, prior to the installation of a foam layer on the silo domes (Grumski and Shanks 1988). The system operated on one silo at a time, with a flow rate of about 1000 ft<sup>3</sup> min<sup>-1</sup>, and was operated until radiation levels on the dome surface stopped decreasing (Grumski and Shanks 1988). With this flow rate and an average nominal silo volume of 51,000 ft<sup>3</sup>, the ventilation rate was (1000 ft<sup>3</sup> min<sup>-1</sup>)/(51000 ft<sup>3</sup>) =  $0.020 \text{ min}^{-1}$ , or  $1.2 \text{ h}^{-1}$ . The exposure rate measurements were taken during operation of the RTS, but after it had been operating 4.6 h for Silo 1 and after 3.5 h for Silo 2 (Grumski and Shanks 1988). With these flow rate and operating times, and an assumed removal efficiency close to 100%, the <sup>222</sup>Rn concentrations in the silo air space should have been reduced to less than 3% of the initial concentrations. Also, in this operating time, any <sup>222</sup>Rn daughter radioactivity deposited on surfaces in the silos would have decayed to less than 2% of its original activity.

Thus, for this analysis, the exposure rate measurements made after operation of the RTS are considered to represent the "background" exposure rate, in the absence of <sup>222</sup>Rn

.

## Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

daughters in the silo air. This background is primarily due to radiation from the radioactivity contained in the K-65 material in the silos (including trapped  $^{222}$ Rn daughters). This set of measurements consists of four measurements, regularly spaced, on each silo dome. The range of the eight measurements was from 35.5 to 76 mR h<sup>-1</sup> (Grumski and Shanks 1988).

Page J-45

For all of these exposure rate measurements, there is uncertainty in the results due to lack of knowledge about what instruments were used, and how the instruments were calibrated. It is noted that most survey instruments tend to have biases at varying energies, because their response varies with radiation energy. In addition, the measurements of the gross exposure rate before and after the vent sealing have uncertainties due to lack of knowledge about the exact measurement locations. These uncertainties combine to produce uncertainty about the comparability of the measurements made at different times. It seems reasonable that the true average exposure rates would lie within the range of measured values. We thus assume that the potential values of  $X_{pre}$ ,  $X_{post}$ , and  $X_{bkg}$  are all represented by uniform distributions, with ranges equal to the observed ranges.

Thus,  $X_{bkg}$  is considered to be represented by a uniform distribution with minimum 35.5 mR h<sup>-1</sup> and maximum 76 mR h<sup>-1</sup>.

The range to be used for  $X_{pre}$  overlaps the range of  $X_{bkg}$ , which could result in calculated values of  $C_{a,pre}$  that are less than zero. To correct this, the distribution used for  $X_{pre}$  is a uniform distribution with a minimum that is the greater of 65 mR h<sup>-1</sup> and  $X_{bkg}$ . This ensures that  $X_{pre}$  is always at least as great as  $X_{bkg}$ . The maximum value of the distribution is 90 mR h<sup>-1</sup>.

And,  $X_{\text{post}}$  is considered to be represented by a uniform distribution with minimum 168 mR h<sup>-1</sup> and maximum 400 mR h<sup>-1</sup>.

Table J-20 summarizes the frequency distributions of the calculations associated with predicted total Rn releases for 1959-1979. Included are the calculated Rn concentration in the Silos; the sum of the rate constants for releases by air exchange and diffusion; the fraction of the total removal of Rn from the Silos that occurs through release to the outside air through air exchange and diffusion (the rest is "removed" by radioactive decay),  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{pre}$ ; and the Rn release rate. The results for the fraction  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{pre}$  indicate that, for this period, almost all of the Rn released into the Silos from the K-65 material is released to the outside air.

Parameter	·	Percentiles of distributions				
	Units	5th	25th	median	75th	95th
$\lambda_{v,pre} + \lambda_{d,pre}$	d-1	0.83	1.5	2.4	4.3	16
$[(\lambda_v + \lambda_d)/\lambda_{eff}]_{pre}$		0.82	0.89	0.93	0.96	0.99
$C_{\rm a, pre}$	pCi L <sup>-1</sup>	$3.9 imes10^5$	$1.4 imes10^6$	$2.5 imes10^6$	$3.8  imes 10^6$	$6.3 imes10^6$
Qpre	Ci y <sup>-1</sup>	<b>4200</b>	5300	6200	7200	8700

## Table J-20. Summary of Frequency Distributions of Calculations of Total Radon Release Rates from the K-65 Silos for 1959–1979

## **Radiological Assessments Corporation**

"Setting the standard in environmental health"

÷

S. Sandar .

1.1.1

.

.....

127.....

(J-41)

## Model for 1988 Releases from K-65 Silos

At the end of 1987, the foam layer was applied to the K-65 Silo domes (see page J-5). It is expected that the foam provides significant insulation and therefore reduces the magnitude of the temperature cycling of the head space air. To estimate Rn releases for 1988, we first perform a preliminary calculation, using the same methodology as was used for releases for the 1980-1987 period, but using temperature change data specific to the period after the foam layer was installed. Air exchange releases are calculated based on a head space ventilation rate, which is estimated from head space temperature monitoring data. For the preliminary calculation, diffusion releases are assumed to be equal to diffusion releases for the 1980-1987 period. Thus,

$$Q_{1988,\text{prelim}} = Q_{\text{exch},1988} + Q_{\text{diff}} \tag{J-40}$$

**Preliminary calculation of 1988 releases.** The calculation of air exchange releases for 1980–1987 are discussed earlier in this Appendix (page J-27). We use the same equation to calculate air exchange releases for 1988:

 $Q_{\text{exch},1988} = C_{a,1988} \lambda_{v,1988} V_0$ 

with the same variables as before, except the "1988" subscript indicates parameters for 1988. In the FMPC environmental restoration work, Operable Unit 4 includes the waste storage silos. Conversations with Operable Unit 4 staff indicated that no measurements were made of the Rn concentration in the K-65 Silo head spaces during the period 1988– 1991. At the end of 1991, a layer of bentonite was added on top of the K-65 material inside the Silos (WEMCO 1992). After this addition, Rn monitoring of the head spaces was initiated. However, the bentonite significantly reduces the Rn concentrations so that concentrations after the bentonite was added are not representative of concentrations for the 1988–1991 period.

In the absence of measurements of the Rn concentration for 1988-1991, we assume that the Rn concentration for the 1980-1987 period would not have changed significantly, and can be used as a substitute. For 1980-1987, calculation results (see page J-37) indicated that the rate of Rn release (by air exchange plus diffusion) is small relative to the rate of Rn decay in the head space air. If the releases were smaller, as expected for 1988, the Rn concentration would only increase slightly. Thus, this seems to be a reasonable first approximation. So, we assume the distribution of the Rn concentration in the head space,  $C_{a,1988}$ , is a normal distribution, with mean  $2.62 \times 10^7$  pCi L<sup>-1</sup> and standard deviation  $4.1 \times 10^6$  pCi L<sup>-1</sup> (for previous discussion, for 1980-1987, see page J-28).

Since no material was added to the inside of the Silos in 1988, the head space volume is assumed to be the same as that used for the 1980–1987 calculation (see page J-29). Thus,  $V_0$  is considered to have a uniform distribution, with minimum 40,000 ft<sup>3</sup>, and maximum 62,000 ft<sup>3</sup>.

For the silo ventilation rate,  $\lambda_{v,1988}$ , we use the same methods as for the period 1980–1987 (see page J-30). Thus, from equation J-17:

Page J-47

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

$$\lambda_{\nu,1988} = \lambda_{\nu,\Delta T,1988} + \lambda_{\nu,\text{wind},1988} \qquad (J-42)$$

where the variables are as used before, except that the subscript "1988" indicates parameters for 1988. Also, from equation J-20:

$$\lambda_{\mathbf{v},\Delta \mathbf{T},1988} = \left(\Delta T/T_0\right)_{1988}$$
 (J-43)

where

>

....

ŝ

 $\Delta T$  = the increase (only) in temperature of silo head space air per day (K d<sup>-1</sup>), and

 $T_0$  = the initial temperature of the silo air (K).

Monitoring of the temperature of the K-65 Silos' head spaces was not instituted until October 1991. Thus, the data for October 1991 are the only data representative of the 1988–1991 period, since the bentonite layer was added inside the Silos in November 1991. The data from October 1991 were obtained from the FMPC (Byrne 1992c). Since we again have data for only a small part of a year, daily silo values of  $\Delta T/T_0$  are correlated to daily temperature changes at the Cincinnati airport. Then, from the average temperature changes at the Cincinnati airport, the correlation can be used to estimate the average value of  $\Delta T/T_0$  for the Silos.

The temperature monitoring data obtained to perform the correlation are shown in Table J-21. For some of the days not shown, some temperature data were available, but the data were not complete enough to allow determinations of the daily temperature increase. As shown, values of  $\Delta T/T_0$  are first calculated for each Silo for each day, and then an average value is calculated for each day.

Records of the hourly temperature at the Cincinnati airport were obtained as part of the meteorological data set (NCDC 1991). The maximum temperature,  $T_{\rm max}$ , and minimum temperature,  $T_{\rm min}$ , were extracted for each of the 19 days in October 1991 for which Silo temperature data are available. These data, and the difference,  $T_{\rm max} - T_{\rm min}$ , calculated for the correlation, are shown in Table J-22.

A linear correlation of the average values of  $\Delta T/T_0$  (dependent variable) to the Cincinnati airport temperature difference (independent variable),  $T_{\max} - T_{\min}$ , was performed using a least squares regression. The regression coefficient is R = 0.56. The regression line is given by:

$$\Delta T/T_0 (d^{-1}) = (5.96 \times 10^{-5} \text{ °F}^{-1} d^{-1}) \times (T_{\max} - T_{\min} (\text{°F})) - 1.31 \times 10^{-4} d^{-1} \qquad (J-44)$$

For this regression line, the standard error of estimate,  $S_{YIX}$ , is  $6.17 \times 10^{-4} d^{-1}$ .

As for the 1980–1987 period, the average daily difference (average of  $(T_{\text{max}} - T_{\text{min}})$ ) for Cincinnati airport is assumed to be 19.46 °F. Thus, the annual average value of  $(\Delta T/T_0)_{1988}$ , and thus  $\lambda_{v\Delta T, 1988}$  is estimated from the regression line and the average daily difference as:

$$\lambda_{\nu,\Delta T,1988} = (\Delta T/T_0)_{1988}$$
  
= (5.96 × 10<sup>-5</sup> °F<sup>-1</sup> d<sup>-1</sup>) × (19.46 °F) + 1.31 × 10<sup>-4</sup> d<sup>-1</sup> (J-45)  
= 0.00129 d<sup>-1</sup>

Page J-48

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

The second s

Data Osed for a fillear correlation							
	•••	Silo 1 date	ab		Silo 2 data	a <sup>b</sup>	Average
Date	<i>T</i> 0 (°F)	Δ <i>T</i> (°F d <sup>-1</sup> )	$\frac{\Delta T/T_0}{(d^{-1})}$	(°F)	∆ <i>T</i> (°F d <sup>-1</sup> )	$\frac{\Delta T/T_0}{(d^{-1})}$	$\frac{\Delta T/T_0}{(d^{-1})}$
10/01/91	64.6	0.8	0.00153	64.2	0.7	0.00134	0.00143
10/02/91	64.7	0.7	0.00134	64.3	0.7	0.00134	0.00134
10/03/91	65.0	1.9 <sup>·</sup>	0.00362	64.5 ·	0.7	0.00134	0.00248
10/08/91	60.7	0.8	0.00154	61.2	0.7	0.00134	0.00144
10/09/91	60.9	1.1	0.00211	61.1	1.5	0.00288	0.00250
10/10/91	61.9	0.3	0.000575	62.0	0.2	0.000384	0.000480
10/11/91	61.4	0.3	0.000576	61.7	0.2	0.000384	0.000480
10/12/91	60.6	0.4	0.000769	61.2	0.3	0.000576	0.000673
10/13/91	59.9	0.6	0.00116	60.8	0.4	0.000769	0.000962
10/14/91	59.6	0.2	0.000385	59.8	1.0	0.00193	0.00116
10/15/91	59.0	0.4	0.000772	59.3	1.9	0.00366	$0.00222^{\circ}$
10/16/91	58.2	0.5	0.000966	59.7	0.4	0.000771	0.000868
10/17/91	57.6	0.8	0.00155	59.3	1.9	0.00366	0.00261
10/18/91	57.9	1.2	0.00232	59.6	0.7	0.00135	0.00183
10/22/91	57.0	1.1	0.00213	58.8	0.7	0.00135	0.00174
10/24/91	58.8	0.6	0.00116	<b>59.8</b> <sup>°</sup>	0.3	0.000578	0.000868
10/29/91	60.9	0.7	0.00135	60.9	0.7	0.00135	0.00135
10/30/91	61.5	0.3	0.000576	61.3	0.3	0.000576	0.000576
10/31/91	61.5	0.2	0.000384	61.3	0.2	0.000384	0.000384

# Table J-21. K-65 Silo Values of $\Delta T/T_0$ for 1988–1991 Period; Data Used for a Linear Correlation<sup> $\alpha$ </sup>

17.

<sup>2</sup> The values of  $\Delta T$  and  $T_0$  must be expressed in absolute temperature units (K) before the ratio is computed.

<sup>b</sup>  $T_0$  and  $\Delta T$  data obtained from Byrne (1992c).

It is assumed that the conditional distribution of  $(\Delta T/T_0)_{1988}$ , at the given value of  $T_{\max} - T_{\min} = 19.46$  °F, is a normal distribution with standard deviation  $S_{Y1X}$ . Thus, we consider the distribution of potential values of  $(\Delta T/T_0)_{1988}$  to be a normal distribution with mean 0.00129 d<sup>-1</sup> and standard deviation 0.000617 d<sup>-1</sup>. However, with this mean and standard deviation, there is a significant chance that negative values of  $(\Delta T/T_0)_{1988}$  might be selected from the distribution. Since such negative values are meaningless for the calculation of the ventilation rate, we truncate the distribution at 0, disallowing negative values.

As done for the 1980–1987 period, we assume the wind-induced ventilation of the Silo,  $\lambda_{v,wind}$ , has a value of zero. The addition of the foam layer to the Silo domes would tend to isolate the cracks in the domes, which provides additional support for this assumption.

Comparison of results of preliminary calculation with monitoring data. In the report of Task 5 of this Project (Shleiën et al. 1993), we presented results of the FMPC Rn monitoring for locations on the fenceline of the K-65 Area. This monitoring was initiated in March 1987, and has continued to the present. Because the monitoring includes some time before the installation of the foam layer, as well as for the complete 1988–1991 period, it may be useful for comparison with the estimated source terms for 1980–1987 and 1988.

e de l'anteres per de seiter su dem d'

••

-

1

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Table J-22. Temperature Difference at Cincinnati Airport

for 1988–1991 Period; Data Used for a Linear Correlation <sup>a</sup>							
Date	Maximum T <sub>max</sub> (°F)	Minimum T <sub>min</sub> (°F)	Difference $T_{\rm max} - T_{\rm min}$ (°F)				
10/01/91	80	58	22				
10/02/91	80	59	21				
10/03/91	76	60	16				
10/08/91	68	37	31				
10/09/91	74	48	26				
10/10/91	63	52	11				
10/11/91	63	46	17				
10/12/91	66	42	24				
10/13/91	60	38	22				
10/14/91	64	46	18				
10/15/91	57	39	. 18.				
10/16/91	57	., 33	. 24				
10/17/91	65	34	31 ·				
10/18/91	75	47	28				
10/22/91	75	50	25				
10/24/91	71	. 60	11				
10/29/91	80	<b>59</b> ,	21				
10/30/91	72	63	9				
10/31/91	67	58	· 9				

<sup>a</sup>  $T_{\min}$  and  $T_{\max}$  data obtained from NCDC (1991).

Descriptions of recent Rn monitoring locations (Byrne 1992b) indicate that monitoring has also been performed on or very near the K-65 Silo domes. The incident investigation report for the April 25, 1986, Rn release indicates that Rn monitoring in the area of the Silo domes had been performed in 1986 (DOE 1986). Based on this information and on discussions with FMPC staff, it appears that Rn concentrations in air on the rim of the K-65 Silo domes were measured for at least part of 1987 through 1991. However, we have been unable to obtain such data.

Results for the Rn monitoring on the K-65 Area fenceline are not provided in the annual environmental monitoring reports, but were obtained in computer spreadsheet files directly from the FMPC site (Byrne 1992a). The monitoring locations, called K65 A through K65 P (Byrne 1992b), are shown in Figure J-5, which also shows the approximate locations of "real-time" monitoring, discussed later. The monitoring was performed on a quarterly basis, using two types of alpha-track Rn detectors. As in the Task 5 Report, we only utilize the results from the Type F detectors, of which there were typically two used at each location. Table J1-1, in Annex 1 to this Appendix, provides the average measured Rn concentration for each quarter of monitoring for each location.

We would like to examine the average Rn concentrations for the two periods 1980-1987 (before foam was applied) and 1988-1991 (after foam, but before bentonite added). Since the foam layer was added to the K-65 Silo domes in December 1987, the fourth quarter of 1987 spans the two periods, and we do not consider it representative of the 1980-1987 period.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page J-49

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

10.000



Figure J-5. Locations of FMPC Rn monitoring on the fenceline of the K-65 Area, for 1987–1991. Locations of the routine, alpha-track stations were obtained from Byrne (1992b). The locations of the real-time monitoring instruments are approximate and may have changed (especially the NE and SE locations) over this period (Grumski 1987b; Grumski and Shanks 1988; Byrne 1992b).

This leaves control in the second and third quarters of 1987 to represent the first period. Based on the average quarterly measurements, there does not appear to be a consistent annual trend in the concentrations, although there is significant variability from quarter-to-quarter and year-to-year. We calculate the ratios of average concentrations for quarters two and three to average concentrations for the year, for the years 1988–1991, and then use the information to estimate an annual average concentration for 1987 and for 1980–1987.

Table J-23 shows the average concentrations for quarters two and three, the annual average concentrations, and the ratios, based on the data given in Table J1-1 (Annex 1 of this Appendix). The mean of the ratios is 1.21. The annual average for 1987 is thus estimated to be  $(7.39 \text{ pCi L}^{-1}) \times 1.21 = 8.94 \text{ pCi L}^{-1}$ . Since 1987 is the only year of this monitoring during 1980-1987, the average concentration for 1980-1987 is also estimated to be 8.94 pCi L<sup>-1</sup>. The ratio of the average Rn concentration on the K-65 Area fenceline for 1988-1991 to that for 1980-1987 is thus 5.47/8.94 = 0.61.

Later in this section (see Table J-24), the distributions of calculated results are presented. The distribution of the ratio of  $Q_{1988,prelim}$  to  $Q_{post}$  has a median of 0.18, and a 90% probability interval (5th to 95th percentile) of 0.092 to 0.47. This distribution of the ratios of the predicted source terms differs significantly from the estimated ratio of the measured Rn concentrations on the K-65 Area fenceline. The median ratio of source terms is

ور می ۱۹۹۰ می ۱۹۹۰

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

	Rn concentrati	on (pCi L <sup>-1</sup> )	
Year	Annual average (all four quarters) <sup>b</sup>	Quarters 2 and 3 only	Ratio of annual to quarters 2 and 3
1987		7.39	
1988	6.54	4.67	1.40
1989	5.06	3.92	1.29
1990	2.52	2.36	1.07
1991	7.34	6.82	1.08
mean 1988–1991	5.47		

<sup>a</sup> We do not imply that three figures in the results are significant; they are retained for further calculations.

<sup>b</sup> Values are time-weighted averages, based on the monitoring dates.

a factor of about three less than the ratio of Rn concentrations, and the 90% probability interval of the ratios of source terms does not include the ratio of the Rn concentrations. This seems to indicate that our preliminary calculations significantly underestimate Rn releases for 1988.

There are also some additional data that provide weak evidence that the nature of the Rn releases from the K-65 Silos may have changed with the installation of the foam layer and installation of the Radon Treatment System (RTS), which was installed before the foam layer, to provide the capability for reducing Rn levels in the Silo head spaces. Some "real-time," or "continuous," monitoring of Rn concentrations on the K-65 Area fenceline has been performed by the FMPC. This monitoring uses instruments to continually make short-term measurements of the Rn concentration, with results typically reported as hourly averages. Prior to and during the work associated with the installation of the RTS and the foam layer, real-time measurements were made for a small number of days in November and December 1987 (Grumski 1987b; Grumski and Shanks 1988). Routine real-time measurements were apparently initiated in 1988 (Byrne 1992a), and we have obtained detailed results for October 1991 (Byrne 1992b). The Rn monitoring instruments were located toward the northeast, northwest, southeast, and southwest corners of the K-65 Area fenceline (Figure J-5).

Six days of measurements were made in early November 1987 prior to the installation of the RTS (Grumski 1987b; Grumski and Shanks 1988). These measurements showed prominent peak Rn concentrations, of from 15 to 225 pCi  $L^{-1}$ , that occurred during daylight and early evening hours, primarily from 10 am to 8 pm. At other times of the day, concentrations were relatively stable, and were less than 10 pCi  $L^{-1}$ . This timing of the peak concentrations is consistent with major Rn releases due to the thermal expansion of head space air during daylight hours, and subsequent air exchange release, as developed for the 1980–1987 period.

The monitoring in October 1991, prior to the addition of the bentonite layer in the Silos, covered the entire month, though data were not always available for all four monitors (Byrne 1992b). Similar to the November 1987 measurements, these data also showed prominent peak Rn concentrations, to as high as 240 pCi L<sup>-1</sup>. However, these peaks occurred primarily during late night and morning hours, from 9 pm to 9 am. This timing of the peak concentrations is inconsistent with major Rn releases due to thermal expansion of <sup>th</sup> head space āir (this is expected, since the temperature increases were significantly reduced in this period). The peak concentrations during the late night and morning hours are significantly higher than the concentrations during the same hours in early November 1987. This seems inconsistent with a continuation or reduction of the same types of releases (air exchange and diffusion) that occurred in 1980–1987, and indicates that perhaps releases after the installation of the RTS and the foam layer are through a different release mechanism. Discussions with the FMPC Operable Unit 4 staff have not resulted in any explanation for this difference in results between early November 1987 and October 1991.

N 5 .4

Current estimates of 1988 releases using Rn monitoring data. Because the preliminary method seems to significantly underestimate Rn releases for 1988, and seems inconsistent with the real-time Rn monitoring data, we will instead base current estimates of releases for 1988 on estimated releases for 1980–1987 and the ratio of Rn concentrations . on the fenceline of the K-65 Area for the two periods. That is:

$$Q_{1988} = Q_{\text{post}} R_{\text{mon}} \tag{J-46}$$

where  $Q_{1988}$  is the total Rn release rate for 1988,  $Q_{post}$  is the total Rn release rate for the 1980-1987 period, and  $R_{\rm mon}$  is the estimated ratio of the average long-term Rn concentration on the K-65 Area fenceline for the 1988–1991 period to the average long-term concentration for the 1980–1987 period. We assume that the average values of  $\chi/Q$  (the ratio of air concentration at a receptor to release rate) on the K-65 Area fenceline are the same for 1988 as for the 1980–1987 period. This seems reasonable since the nature, and the timing, of the releases for 1988 are not understood.

To estimate the ratio,  $R_{mon}$ , we use:

$$R_{\rm mon} = \frac{C_{\rm f,88-91}}{C_{\rm f,87}R_{\rm ann:2\&3}R_{\rm long:ann}}$$
(J-47)

where

R<sub>long.ann</sub>

= the average Rn concentration on the K-65 Area fenceline for the period 1988- $C_{f,88-91}$ 1991.

C<sub>187</sub>

the average Rn concentration in air on the K-65 Area fenceline for the second and third quarters of 1987,

 $R_{ann:2\&3} =$ 

the average ratio of annual average Rn concentrations on the K-65 Area fenceline to average concentrations for the second and third quarters of the year, and

a factor to incorporate the additional uncertainty in a long-term average Rn concentration on the K-65 Area fenceline based on the average for only one . . . . Cape Foith 158 Education year.

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

The average Rn concentration for 1988-1991,  $C_{f,88-91}$ , was shown in Table J-23. We assume this average quantity would have a normal distribution. The uncertainty in this value is estimated based on the year-to-year variability, as seen in the annual averages for 1988 through 1991. When the four individual annual averages are considered, the coefficient of variation is 39.5%. Since there are four years of data, the relative standard error of the mean is estimated to be 19.8%. Thus,  $C_{f,88-91}$  is assumed to have a normal distribution, with mean 5.47 pCi L<sup>-1</sup>, and standard deviation 1.08 pCi L<sup>-1</sup>.

The average Rn concentration for the second and third quarters of 1987, as seen in Table J-23, is 7.39 pCi  $L^{-1}$ . The uncertainty is incorporated through the remaining terms.

Also shown in Table J-23 are the ratios of annual average concentrations of Rn on the K-65 Area fenceline to average concentrations for the second and third quarters only. The mean and standard deviation of these ratios are 1.21 and 0.16, respectively. Since  $R_{ann:2\&3}$  is an average quantity, it is assumed to have a normal distribution, with these values of mean and standard deviation.

As discussed above, the year-to-year variability of the average Rn concentrations on the K-65 Area fenceline is described by a coefficient of variation of 39.5%. For the 1980–1987 period, only one year of monitoring, 1987, is available. Thus,  $R_{\text{long:ann}}$  is assumed to have a normal distribution with mean 1.00 and standard deviation 0.395.

To calculate  $R_{mon}$ , we use the standard error propagation formula for products or quotients of independent variables with errors that are small and symmetric about zero. This results in an estimate of  $R_{mon}$  with value 0.612 and standard deviation 0.282, with distribution assumed to also be normal.

**Calculation results for 1988.** Table J-24 summarizes the frequency distributions of the calculations associated with predicted total Rn releases for 1988. The results to be used as our current estimates of releases are the values for  $Q_{1988}$ . Because of the added uncertainty in the Rn monitoring results, those results have large associated uncertainties.

Parameter		Percentiles of distributions				
	Units	5th	25th	median	75th	95th
Q <sub>exch. 1988</sub>	Ci y <sup>-1</sup>	9.8	23	35	48	69
Q <sub>1988,prelim</sub>	Ci y <sup>-1</sup>	98	140	170	210	280
Q <sub>1988,prelim</sub> /Q <sub>post</sub>		0.092	0.14	0.18	0.26	0.47
Q <sub>1988</sub>	Ci y <sup>-1</sup>	120	320	540	810	1300

## Table J-24. Summary of Frequency Distributions of Calculations of Total Radon Release Rates from the K-65 Silos for 1988

## Models for 1952–1958 Releases from K-65 Silos

The disposal history of the K-65 Silos was discussed earlier in this Appendix (see page J-4). Disposal of K-65 material in Silo 1 began July 19, 1952 (Davis 1952). From information in Strattman (1953) we estimated that Silo 1 was full around the middle of June 1953.

Radiological Assessments Corporation "Setting the standard in environmental health" £

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

ŝ

1971 V 1971

5.5

CANNO -

ŝ

ŝ

00000

Disposal of K-65 material into Silo 2 was completed and the Silo was decanted in September 1958 (Noyes 1958; NLCO 1962). For our calculations, we assume the three start and completion dates were all in the middle of the month.

-j--

Model for releases. For the operational period of the K-65 Silos, mid-July 1952 to mid-September 1958, we have not obtained any contemporary radiological monitoring data that could be used to calculate Rn releases. We base estimates of Rn releases for this period on the estimated releases from the Silos for the 1959–1979 period. After the filling of Silo 1 had been completed, we assume it was decanted. This seems reasonable since some decanting proceeded automatically through the drawoff ports in the walls of the Silos (Dougherty and Jennings circa 1951), and we assume that it would have been desirable to remove the excess slurry liquor from the Silo, to recycle it for other purposes. For this period the piping, including the six-inch diameter gooseneck vent, would have been the same as in the 1959– 1979 period. Thus, for the period after the filling of Silo 1 was completed, the Rn releases from Silo 1 can be assumed to be essentially the same as releases for 1959–1979.

For the time when the Silos were being filled, Rn releases are expected to be significantly different from releases after decanting was completed. An operating manual for the K-65 area indicates that the K-65 material was batch transferred to the Silos as a slurry (Dougherty and Jennings circa 1951). As mentioned above, this manual also indicates that some decanting of the Silos occurred automatically, through drawoff ports spaced every six inches up Silo walls, as the liquid level in the Silos passed each port level. While the Silos were operational, it thus appears that part of the time the K-65 material would have been essentially saturated with water, but with no water covering the material. And, part of the time the K-65 material would have been covered with a layer of water a few inches deep. Thus for the operational period the Rn releases would be reduced, relative to those for the 1959–1979 period, due to the quantities of water in and above the K-65 material, which would reduce the diffusion of Rn from the K-65 material.

From the most recent sampling of the Silo contents, in 1991, it appears that the  $^{226}$ Ra concentrations of the two Silos may be significantly different (see Table J-5). The releases for 1959–1979 were based on average characteristics of the two Silos (though not explicitly involving  $^{226}$ Ra concentration). For the time period under consideration here, the difference in concentrations between the two Silos will be accounted for.

Based on the above considerations, we employ the following simple model to estimate releases for these operational periods, based on releases for the 1959–1979 period. Here the Rn release rate,  $Q_{52-53}$ , is for the period mid-June 1952 through mid-July 1953, the operational period of Silo 1. The Rn release rate,  $Q_{53-58}$ , is for the period mid-July 1953 through mid-September 1958, the operational period for Silo 2.

$$Q_{52-53} = (0.5)Q_{\text{pre}}f_{\text{Ra},1}f_{\text{op}}$$
(J-48)  
$$Q_{53-58} = (0.5)Q_{\text{pre}}(f_{\text{Ra},1} + f_{\text{Ra},2}f_{\text{op}})$$
(J-49)

where

 $Q_{\rm pre}$  = total rate of Rn releases from the two K-65 Silos for the 1959-1979 period, as calculated earlier in this Appendix (see page J-41),

.....

. ....

## Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

- $f_{\text{Ra},1}$  = ratio of the average <sup>226</sup>Ra concentration in K-65 material of Silo 1 to the average concentration for the two Silos,
- $f_{\text{Ra},2}$  = ratio of the average <sup>226</sup>Ra concentration in K-65 material of Silo 2 to the average concentration for the two Silos,
- $f_{op}$  = factor to account for the reduced Silo Rn emissions in the operational phase, relative to emissions for the post-operational period (1959-1979), due to the greater quantities of water present, and
- (0.5) = factor to convert the  $Q_{pre}$  release rate for two Silos to a release rate for a single Silo.

**Parameter distributions.** For the Rn release rate for 1959–1979,  $Q_{pre}$ , we use the exact distribution of values calculated previously.

To calculate the ratios of <sup>226</sup>Ra concentrations, we use the measurement results compiled in Table J-5. For Silo 1, the average concentration was 525,000 pCi g<sup>-1</sup>, with a standard deviation of 158,000 pCi g<sup>-1</sup>, for a sample size of 12. Thus, the standard error of this mean is 45,600 pCi g<sup>-1</sup>. For Silo 2, the average was 299,000 pCi g<sup>-1</sup>, with standard deviation of 119,000 pCi g<sup>-1</sup>, for a sample size of 11, which results in a standard error of the mean of 35,900 pCi g<sup>-1</sup>. And, for the two Silos, the average and standard deviation were 417,000 and 179,000 pCi g<sup>-1</sup>, for a sample size of 23, which gives a standard error of the mean of 37,300 pCi g<sup>-1</sup>. To calculate the ratios  $f_{Ra,1}$  and  $f_{Ra,2}$ , we use the standard error propagation formula for quotients of independent variables, and the standard errors of the means for the uncertainty terms. It is recognized that the average concentration for both Silos is not independent from the averages for each Silo, but we consider the formula to be an acceptable approximation. The distributions for the ratios are considered to be normal. This results in a distribution for  $f_{Ra,1}$  with mean 1.26 and standard deviation (standard error of the mean) 0.157. And, for  $f_{Ra,2}$  the mean is 0.717 and the standard deviation is 0.107.

The determination of an appropriate distribution for  $f_{op}$  is more difficult. The amount of water that might cover the K-65 material in the Silos is unknown. The operating practices, especially the typical timing of slurrying, flushing, and decanting operations, are also unknown. We assume that a reduction factor  $(f_{op})$  of around 0.5, relative to releases for the decanted, post-operational period, is reasonable. The uncertainty is very large, so we assume that  $f_{op}$  is represented by a uniform distribution, with minimum 0 and maximum 1.

**Results of calculations.** The frequency distributions for calculated values of the Rn release rates  $Q_{52-53}$  and  $Q_{53-58}$  are summarized in Table J-25. Due to the large uncertainty in the reduction factor  $f_{op}$ , the distribution of results for the 1952-1953 period is very broad. For this period, the 90% probability interval has a range of a factor of about 20. For the 1953-1958 period, the releases are dominated by the decanted Silo 1, for which the uncertainty is significantly lower. Thus, for this period, the distribution of results is much tighter than that for the 1952-1953 period.

#### Model for 1951–1953 Releases from Drummed K-65 Material

In Table J-2 it was shown that the Mallinckrodt Chemical Works (MCW), in St. Louis, began shipping drummed K-65 material to the FMPC in September 1951, about ten months before construction of the K-65 Silos was complete. This material was thus stored onsite

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

17

3

.

14.22 W.L.S.

· · · · · · · · · · · · · · · · · · ·	Percentiles of distribution				
Period	5th	25th	median	75th	95th
mid-July 1952–mid-June 1953	200	940	1900	2900	4200
mid-June 1953-mid-September 1958	3100	4100	4900	5900	7600

Table J-25. Summary of	f Predicted Rn Release Rates (Ci y <sup>-1</sup> )
from the K-65 Silos for the C	perational Period of the Silos, 1952–1958

until it could be placed in the Silos. In this section we evaluate Rn releases from this stored, drummed K-65 material.

Description of drummed K-65 material. Walden (1952) indicates that 12,997 drums of K-65 material were received at the FMPC in the period September 25, 1951, to July 31, 1952. A U.S. Atomic Energy Commission (AEC) letter indicates that the drummed K-65 material was to be temporarily stored on the concrete ore storage pad until the K-65 Silos were completed and ready for operations (Belmore 1951). We understand this pad to be the large concrete pad around, but generally north of, Plant 1. The location of this storage pad is shown in Figure J-6. An original operating manual for the K-65 storage area indicates the K-65 material was to be delivered to the FMPC in 55-gallon drums, each containing about 500 pounds of material (Dougherty and Jennings circa 1951). This manual also indicated the material would have a bulk density of about 90 lb ft<sup>-3</sup>, and would have moisture content about 40 weight percent. Another procedures manual corroborates the weight of material contained in each drum, and also indicates that the 55-gallon drums were sealed with lids when they arrived at the FMPC (Consiglio 1952).

An internal FMPC memorandum describes the status of the K-65 Silos as of November 1953 (Strattman 1953). At that time Silo 1 was full, and filling of Silo 2 had been proceeding for some time. The rate of receipt of drummed K-65 material from MCW had slowed significantly from the apparent rate in 1951 and the first half of 1952 (from Walden 1952). There was no indication of an onsite (FMPC) inventory of drummed K-65 material. We thus assume that by the time Silo 1 was full, which we estimated occurred in June 1952, drummed K-65 material was placed in the Silos shortly after receipt at the FMPC, and so the quantity of drums stored onsite was negligible after this time. We thus calculate Rn releases from stored, drummed K-65 material for the period September 25, 1951, to about mid-June, 1953. We also assume that all of the stored K-65 material, from this period, was eventually placed into Silo 1.

Model for releases. For Rn releases from the drummed K-65 material, we use the conventional methodology for releases from bulk quantities of  $^{226}$ Ra-bearing material. This methodology is thoroughly described later in this Appendix, in the section regarding the alternative calculation of Rn releases from the K-65 Silos (see page J-73). Because we have no information about the Rn concentration in the air space of the drums, we assume that the concentration is negligible in terms of constraining the release of Rn from the K-65 material into the air space of the drum. This results in a slight upward bias in our estimates of releases, but seems reasonable for the limited data available. We thus use the form of

A second 
Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos



Figure J-6. Location of the storage pad, around Plant 1 in the production area, where drummed K-65 material was stored before placement in the K-65 Silos.

equation J-68 (originally from Collé et al. 1981) to calculate the unconstrained Rn flux from a bare layer of K-65 material, with an impervious layer (the bottom of the drum) below it:

$$j_{\rm D,dr} = \sqrt{\frac{D_{\rm e,dr} \varepsilon_{\rm dr}}{\lambda_{\rm Rn}}} (\phi_{\rm dr}) \tanh\left(\frac{L_{\rm dr}}{l_{\rm dr}}\right) \tag{J-50}$$

where the subscript "dr" generally refers to the drummed K-65 material, and:

- $j_{D,dr}$  = unconstrained diffusion fluence rate of Rn (Rn flux). The quantity of Rn per unit time per unit area transported by diffusion from the source material (in this case the drummed K-65 material) into the ambient air (pCi m<sup>-2</sup> s<sup>-1</sup>, or similar).
- $D_{e,dr} =$  effective bulk diffusion coefficient of Rn through the porous source material (cm<sup>2</sup> s<sup>-1</sup>, or similar).
- $\varepsilon_{dr}$  = porosity of the source material.

5.0

 $\phi_{dr}$  = the pore space Rn production rate. Quantity of Rn produced in pore spaces of the source material per unit time per unit pore volume that is free to migrate through

where:

and the second second

# The Fernald Dosimetry Reconstruction Project

the pores of the material (pCi cm $^3$ ,s $^-1$ ). Depends on characteristics of the source material, including  $^{226}$ Ra concentration, Rn emanation fraction, bulk density, and porosity, and on the Rn decay constant.

 $L_{dr} =$ thickness of the source material (cm, or similar).

 $l_{dr} = \text{Rn}$  diffusion length in the source material (related to  $D_{e,dr}$ ) (cm, or similar).  $\lambda_{\text{Rn}} = \text{the decay constant for } ^{222}\text{Rn.}$ 

For this case of the drummed material, the thickness of the source material,  $L_{dr}$ , will be less than 100 cm, and the tanh term in the equation will be significantly different from unity. This term will be retained in the equation (unlike was done in the alternative calculation).

As for the alternative calculation of Silo Rn releases, the pore space Rn production rate can be calculated by (see equation J-71): a obtained as

$$\phi_{dr} = \frac{[Ra]_{dr} EF_{dr} \rho_{dr} \lambda_{Rn}}{\varepsilon_{dr}}$$
(J-51)

 $[Ra]_{dr}$  = concentration of <sup>226</sup>Ra in the drummed K-65 material (activity per mass),

 $EF_{dr} = \frac{222}{Rn}$  emanation fraction in drummed K-65 material, which is the fraction of the  $EF_{dr} = \frac{222}{Rn}$  formed (from the  $\frac{226}{Ra}$  decay) that is in pore spaces and is free to migrate, and

= dry bulk density of drummed K-65 material (g cm<sup>-3</sup>, or similar).

In this equation, the <sup>226</sup>Ra concentration gives the total production rate of <sup>222</sup>Rn atoms, per mass of source material. Multiplication by the Rn emanation fraction converts this to the production of Rn in the pore spaces. The factors of  $\rho_{dr}$  and  $\varepsilon_{dr}$  convert the basis from mass of source material to volume of pore space air. Finally, the decay constant converts the quantity of Rn from atoms to activity units.

The Rn release rate from a single drum,  $Q_{dr}$ , is then calculated as:

$$Q_{\rm dr} = j_{\rm D,dr} A_{\rm dr} \left( \frac{\lambda_{\rm v} + \lambda_{\rm d}}{\lambda_{\rm eff}} \right)_{\rm dr} U_{\rm dr}$$
(J-52)

where  $A_{dr}$  is the surface area of the K-65 material exposed to the air, and  $U_{dr}$  is an uncertainty factor to account for additional uncertainty related to application of this model to the drummed K-65 material. The ratio  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{dr}$  is the fraction of Rn released from the K-65 material that is released (through the drum) into the environment. This ratio was discussed earlier, in relation to releases from the K-65 Silos for the 1959–1979 and 1979–1980 periods (see pages J-37 and J-45).

The total yearly Rn releases from the stored, drummed K-65 material can then be calculated from the release rate per drum and the time-integrated number of drums stored on the site:

 $R_{\rm dr,i} = Q_{\rm dr} N_i$ 

(J-53)

.

. : ·

2

## Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-60 Silos

where  $R_{dr,i}$  is the quantity of Rn released (Ci) for the *i*<sup>th</sup> year, of 1951–1953, and  $N_i$  is the time-integrated number of drums (units of drum months, or similar) stored on the FMPC Plant 1 pad for the *i*<sup>th</sup> year.

Parameter distributions. As described above, we assume that essentially all of the stored, drummed K-65 material was eventually placed in Silo 1. Thus, the average  $^{226}$ Ra concentration in the drummed K-65 material is assumed to be the same as the concentration measured (later) in Silo 1. As described earlier in this Appendix, the results from the 1991 sampling of the K-65 Silos are preferred over results from prior sampling episodes. The 1991 results are compiled in Table J-5. For Silo 1, the measured  $^{226}$ Ra concentrations ranged from 306,800 to 890,700 pCi g<sup>-1</sup>. Because the range of results is so broad, and because there may have been changes in the average concentration in the drummed material as a function of time, we assume that [Ra]<sub>dr</sub> has a uniform distribution, with minimum 306,800 pCi g<sup>-1</sup>.

As discussed earlier in this Appendix (see page J-11), measurements of the Rn emanation fraction for the K-65 material have not been performed. In our discussion of the alternative calculation of Rn releases from the K-65 Silos, we conclude that emanation fraction measurements for uranium mill tailings, from the literature, are the best values to use, lacking results specific to the K-65 material (see page J-76). As in the alternative calculation, we assume here that the emanation fraction is within the range compiled by Rogers et al. (1984) for mill tailings. We thus assume that  $EF_{dr}$  has a uniform distribution, with minimum 0.1 and maximum 0.4.

As discussed above, an operating manual for the K-65 area indicated the K-65 material would have a bulk density of about 90 lb ft<sup>-3</sup>, and contained about 40 weight percent moisture (Dougherty and Jennings circa 1951). We assume that the density is a *wet* bulk density, and that the moisture content is percent dry weight (most commonly used for weight percent moisture). This results in a calculated *dry* bulk density of 1.0 g cm<sup>-3</sup>. This value is within the range seen in measurements of the K-65 material in the Silos (see Table J-4), and thus seems reasonable. However, since the value here was obtained only from an operating manual, and the basis of the value is not known, we assume (arbitrarily) a range of  $\pm$  20% about the value. Thus, the bulk density,  $\rho_{dr}$ , is assumed to have a uniform distribution, with minimum 0.8 g cm<sup>-3</sup> and maximum 1.2 g cm<sup>-3</sup>.

As discussed earlier in this Appendix (see page J-9), no measurements for porosity of the K-65 material have been reported. As in the alternative calculation of Silo Rn releases, we use measured values of the specific gravity, and the relation of porosity to specific gravity and density (see page J-77):

$$\varepsilon_{\rm dr} = \frac{g_{\rm dr} - \rho_{\rm dr}}{g_{\rm dr}} \tag{J-54}$$

where  $g_{dr}$  is the specific gravity of the K-65 material, and where the density,  $\rho_{dr}$ , is expressed here as the numerical value (without units) corresponding to the density given in units of g cm<sup>-3</sup>. We use the same mean specific gravity used in the alternative calculation (based on measurements reported in DOE 1990), but we double the standard deviation.

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

Thus, the mean specific gravity of the K-65 material,  $g_{dr}$ , is assumed to follow a normal distribution with mean 2.98 and standard deviation 0.24.

As discussed above, the moisture content of the drummed K-65 material was expected to be about 40% dry weight. The moisture content is an important parameter in the determination of the Rn diffusion coefficient,  $D_{\rm dr}$  (see below). In our discussion of the moisture content of the K-65 material in the Silos, for the alternative calculation of releases (see page J-78), it appeared that the range of measured moisture contents was 21.8% to 90% dry weight. Based on that large range of values, it seems that the uncertainty in the moisture content for the drummed material might also be large. We thus assume that the range of moisture contents is 20% to 60% dry weight.

As in the alternative calculation, the moisture saturation fraction of the K-65 material,  $m_{\rm dr}$ , can be related to the moisture content in dry weight fraction (dry weight percent divided by 100%),  $M_{\rm dr}$ , from equation J-73 (Rogers et al. 1984):

$$m_{\rm dr} = \frac{M_{\rm dr}}{\frac{1}{\rho_{\rm dr}} - \frac{1}{\mathcal{B}_{\rm dr}}} \tag{J-55}$$

1.142.14

.....

where  $\rho_{dr}$  and  $g_{dr}$  are the bulk density and specific gravity of the K-65 material, as used previously. Again, the density,  $\rho_{dr}$ , is expressed as the numerical value (without units) corresponding to the density given in units of g cm<sup>-3</sup>.

For the distribution of  $M_{dr}$ , we assume a uniform distribution over the range 20% to 60% dry weight, or 0.20 to 0.60 dry weight fraction, with one constraint. The saturation fraction must be less than or equal to 1 so  $M_{dr}$  is constrained to (from equation J-74):

$$M_{\rm dr} \leq \frac{1}{\rho_{\rm dr}} - \frac{1}{g_{\rm dr}}$$
(J-56)

We thus consider  $M_{dr}$  to have a uniform distribution with minimum 0.20 dry weight fraction, and with maximum 0.60 or  $(1/\rho_{dr} - 1/g_{dr})$ , whichever is less.

No information was found on the Rn diffusion coefficient for the drummed K-65 material. As discussed earlier in this Appendix (see page J-11), measurements of the Rn diffusion coefficient in the K-65 material in the Silos have also not been made. We use the relationships used in the alternative calculation of Silo Rn releases (see page J-79 for details not repeated here).

Rogers et al. (1984) compile diffusion coefficients from about 200 measurements on various types of soils at various moisture saturations. For cases when little is known about the diffusion coefficient of a soil, they recommend the use of an empirical correlation with The pore space diffusion coefficient is estimated using the following empirical correlation (Rogers et al. 1984), based on the saturation fraction and porosity (from equation J-76):

$$\hat{D}_{dr} = (0.07 \text{ cm}^2 \text{ s}^{-1}) \exp\left[-4(m_{dr} - m_{dr} \varepsilon_{dr}^2 + m_{dr}^5)\right]$$
(J-57)

where  $D_{dr}$  is the empirically predicted pore space diffusion coefficient,  $m_{dr}$  is the saturation fraction, and  $\varepsilon_{dr}$  is the porosity.

Page J-60

# Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

The uncertainty in estimating the diffusion coefficient for a particular material (the correlation was based on many different soil types) is incorporated (from equation J-77) by:

$$D_{\rm dr} = U_{\rm D} \tilde{D}_{\rm dr} \tag{J-58}$$

where  $D_{dr}$  is the adjusted estimate of the pore space diffusion coefficient, that will be used for further calculations, and  $U_D$  is an uncertainty factor, represented by a lognormallydistributed random variable with geometric mean 1 and geometric standard deviation 2 (this results in a 95% confidence interval somewhat greater than the one order of magnitude estimated from Rogers et al. 1984). The diffusion coefficient,  $D_{dr}$ , is constrained to be less than or equal to 0.11 cm<sup>2</sup> s<sup>-1</sup>, the coefficient for pure air. The effective diffusion coefficient,  $D_{e,dr}$ , is then calculated using equation J-59 (from equation J-75).

$$D_{e,dr} = D_{dr} \varepsilon_{dr} \tag{J-59}$$

Based on equation J-79 (Collé et al. 1981), the Rn diffusion length,  $l_{dr}$ , is related to the diffusion coefficient by:

$$l_{\rm dr} = \sqrt{\frac{D_{\rm dr}}{\lambda_{\rm Rn}}} \tag{J-60}$$

The surface area of K-65 material exposed to the air in each drum is just the horizontal cross-sectional area of the drum. Thus, for the 55-gallon drums,  $A_{\rm dr}$  is about 0.25 m<sup>2</sup>, or 2500 cm<sup>2</sup>. The nominal weight of material in each drum is about 500 lb, as discussed above. The thickness of the K-65 material in the drum,  $L_{\rm dr}$ , can be calculated by:

$$L_{\rm dr} = \frac{W_{\rm dr}}{\rho_{\rm dr} (1 + M_{\rm dr}) A_{\rm dr}} \tag{J-61}$$

where  $W_{dr}$  is the wet weight of material in the drum. For this calculation, we assume that uncertainty in the weight per drum might be  $\pm$  20%. Thus,  $W_{dr}$  is assumed to have a uniform distribution, with minimum 400 lb and maximum 600 lb.

Information is not available to directly estimate the ratio  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{dr}$ . From the current estimates of releases for the period 1980–1987, the ratio  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{post}$  was estimated for the "sealed" K-65 Silos. The sealed Silos for that time period still allowed releases of Rn through cracks and small penetrations in the Silo domes. For the drummed K-65 material, it seems reasonable that the metal, 55-gallon drums would not be airtight. We do not know how lids were installed on the drums, but leakage at the joint between the lid and the drum is expected, especially after transport to the FMPC, movement from railcars to a storage location on the Plant 1 pad, and outdoor storage. We think that fractional leakage from the drums would be less than the fractional leakage from the K-65 Silos. Thus, the ratio  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{dr}$  is calculated by:

$$\left(\frac{\lambda_{v} + \lambda_{d}}{\lambda_{eff}}\right)_{dr} = \left(\frac{\lambda_{v} + \lambda_{d}}{\lambda_{eff}}\right)_{post} f_{dr}$$
(J-62)

Radiological Assessments Corporation "Setting the standard in environmental health"

where  $f_{dr}$  is a reduction factor for leakage from the drums. We think that a reduction factor of about 0.5, with very large associated uncertainty, is appropriate. We thus assume that  $f_{dr}$  has a uniform distribution, with minimum 0 and maximum 1.

Page J-62

From the previous calculations (results given in Table J-17), the ratio  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{post}$  had results with fifth and 95th percentiles of 0.071 and 0.24, respectively. The distribution was relatively symmetric. To approximate this distribution, we assume the ratio  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{post}$  has a normal distribution, with mean 0.156 and standard deviation 0.051.

It is felt that the uncertainty in the calculated Rn release rate from the drummed K-65 material has not been totally accounted for in the parameter uncertainties. For all parameters, except perhaps the <sup>226</sup>Ra concentration, there is very little directly applicable information to support the choice of parameter distributions. This is the reason for the application of the additional uncertainty factor,  $U_{dr}$ . We assume (somewhat arbitrarily)  $U_{dr}$  to have a lognormal distribution, with geometric mean 1 and standard deviation 1.4 (for a 95% probability interval, this gives an uncertainty of about x/+ 2).

The half life of <sup>222</sup>Rn is 3.8235 d (Walker et al. 1989). Thus, the decay constant for <sup>222</sup>Rn,  $\lambda_{Rn}$ , is 2.098 × 10<sup>-6</sup> s<sup>-1</sup>. For our calculations, this value is assumed to have negligible uncertainty.

To estimate the time-integrated number of stored drums of K-65 material, we create a simple model based on estimated receipt rates and production (dumping into the Silo) rate. Walden (1952) indicates that 12,997 drums of K-65 material were received at the FMPC during the period September 25, 1951–July 31, 1952. For this time period, we assume a constant receipt rate, which would be 41.8 drums d<sup>-1</sup>. Davis (1952) indicates that dumping of drums, for slurrying to the K-65 Silo 1, began July 19, 1952. Strattman (1953) indicates that about 24,000 drums of K-65 material were placed in Silo 1. From other information in Strattman (1953), we estimated that Silo 1 was full about the middle of June 1952 (assumed June 15, 1952). For the period of filling Silo 1, we assume a constant production rate, which would be 72.3 drums d<sup>-1</sup> dumped into Silo 1. As discussed earlier in this section, we assume that the onsite K-65 drum inventory had been reduced to negligible levels by the time Silo 1 was full. Thus, for the period August 1, 1952–June 15, 1953, about 11,000 additional drums of K-65 material are assumed to have been received. The receipt rate for this period would have then been 34.5 drums d<sup>-1</sup>.

From these receipt and production rates, the inventory of drummed K-65 is estimated to be 12,456 drums on July 18, 1952, and 12,060 drums on July 31, 1952. From the constant rates of receipts and production, we estimate the onsite inventory of K-65 drums as a function of time,  $n_{dr}(t)$ , by the following model:

 $\begin{cases} \text{for } 9/25/51 - 7/18/52; t = \text{ days past } 9/24/51; & n_{dr}(t) = 41.8t \\ \text{for } 7/19/52 - 7/31/52; t = \text{ days past } 7/18/52; & n_{dr}(t) = 12,456 - 30.5t \\ \text{for } 8/1/52 - 6/15/53; t = \text{ days past } 7/31/52; & n_{dr}(t) = 12,060 - 37.8t \end{cases}$ 

From this model, the average monthly inventory of K-65 drums is calculated. For October 1951 through June 1953, the results are shown in Table J-26. (We assumed that the average inventory for September 1951 was zero.)

Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Drummed K-05 Material Stored on the Plant 1 Pad								
Month	Average number of drums	Month	Average number of drums	Month	Average number of drums			
Oct 1951	880	May 1952	9,800	Dec 1952	6,900			
Nov 1951	2,200	Jun 1952	11,000	Jan 1953	5,700			
Dec 1951	3,400	Jul 1952	12,000	Feb 1953	4,500			
Jan 1952	4,700	Aug 1952	11,000	Mar 1953	3,500			
Feb 1952 ,	6,000	Sep 1952	10,000	Apr 1953	2,300			
Mar 1952	7,200	Oct 1952	9,200	May 1953	1,200			
Apr 1952	8,500	Nov 1952	8,000	Jun 1953	130			

Table J-26.	<b>Estimated Monthly Average Inventory of</b>
Drummed	K-65 Material Stored on the Plant 1 Pad

The time-integrated numbers of drums stored are calculated by summing the average monthly inventories, from Table J-26. Thus,  $N_{1951} = 6500$  drum-months,  $N_{1952} = 110,000$  drum-months, and  $N_{1953} = 17,000$  drum-months.

.....

1.1

**Results of calculations.** Table J-27 summarizes the frequency distributions for intermediate, calculated parameters. Table J-28 shows the distributions for calculated Rn release quantities for 1951, 1952, and 1953 from drummed K-65 material stored on the Plant 1 pad.

	. •	Percentiles of distributions				
Parameter	Units	5th	25th	median	75th	95th
ε <sub>dr</sub>		0.58	0.63	0.66	0.70	0.73
$m_{ m dr}$	saturation fraction	0.31	0.45	. <b>0.59</b>	0.73	0.92
D <sub>dr</sub>	$cm^{2} s^{-1}$	$5.1 \times 10^{-4}$	$4.7\times10^{-3}$	$1.3  imes 10^{-2}$	$2.6\times10^{-2}$	$6.0  imes 10^{-2}$
D <sub>e,dr</sub>	$\mathrm{cm}^2\mathrm{s}^{-1}$	$3.2  imes 10^{-4}$	$3.0\times10^{-3}$	$8.4\times10^{-3}$	$1.8\times10^{-2}$	$4.2\times10^{-2}$
ldr	cm	16	47	78	110	170
$L_{ m dr}$	cm	<b>49</b>	<b>58</b>	65	74 <sup>.</sup>	<b>89</b>
$[(\lambda_v + \lambda_d)/\lambda_{eff}]_{dr}$	·	0.0064	0.034	0.070	0.11	0.18
$\phi_{dr}$	pCi cm <sup>-3</sup> s <sup>-1</sup>	0.17	0.30	0.44	0.62	0.94
$j_{\mathrm{D,dr}}$	pCi cm <sup>-2</sup> s <sup>-1</sup>	3.9	8.7	14	21	33
$Q_{\mathrm{dr}}$	Ci month <sup>-1</sup>	$4.0\times10^{-4}$	$2.3  imes 10^{-3}$	$5.5\times10^{-3}$	$1.1\times10^{-2}$	$2.6 \times 10^{-2}$

Table J-27. Summary of Frequency Distributions of Intermediate Results: for Rn Releases from Drummed K-65 Material Stored on the Plant 1 Pad

As seen in Table J-28, predicted releases from the drummed K-65 material stored on the Plant 1 pad are much higher in 1952 than in 1951 and 1953. This occurs because the predicted inventory of stored drums peaked in July 1952, and because the inventory is assumed to be zero prior to October 1951 and after June 1953. We also note that the uncertainties in the predicted release quantities are very large. The 90% probability intervals (5th to 95th percentiles) have a range of a factor of about 70. This is not

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page J-63

32

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

144.24.5

No. No.

Ş

(J-64)

Fable J-28. Summary of Predicted Rn Release Quantities (Ci)
from Drummed K-65 Material Stored on the Plant I Pad

Year	5th	25th	median	75th	95th
1951ª	2.6	15	35	<b>73</b> ·	170
1952	42	· 240 👘	580	1200	2800
1953 <sup>b</sup>	6.9	39	95	190	450

through December.

<sup>b</sup> Releases for 1953 are assumed to have occurred in January

through June.

unexpected, as a number of the parameters had significant associated uncertainties, primarily due to the extremely limited information available to describe the releases.

# Model for Radon Daughter Releases

For releases of <sup>222</sup>Rn, the short-lived daughters of Rn are primarily responsible for the inhalation doses delivered, because the Rn does not remain in people's lungs for a significant length of time. With fairly short half-lives, the Rn daughters grow in to significant fractions of equilibrium within reasonable distances from the release point. However, for outdoor air at points close to the Rn release point, where the transport time is short enough, Rn daughters will only grow in to very small fractions of equilibrium. At these close-in locations, the direct releases of Rn daughters will be important to outdoor concentrations of Rn daughters, and thus to doses to people. No direct measurements have been made of Rn daughter releases or Rn daughter concentrations in the K-65 Silo air spaces. Rn daughters in the air around the FMPC have not been routinely monitored, though some measurements were made in the late 1970's (see our Task 5 report (Shleien et al. 1993), for more about the historical measurements).

Model for releases. For this assessment, a relatively crude estimate of the releases of the short-lived <sup>222</sup>Rn daughters, <sup>218</sup>Po, <sup>214</sup>Pb, <sup>214</sup>Bi, and <sup>214</sup>Po is developed. We assume that the releases of the daughters are equal to the <sup>222</sup>Rn releases times correction factors:

# $Q_{\text{daught}} = QF_1F_2$

where  $Q_{daught}$  is the release rate of each of the four short-lived daughters, associated with the Rn release rate Q, the correction factor  $F_1$  is the Rn daughter equilibrium fraction in the head space air, and  $F_2$  is a fractional release factor, to account for deposition of Rn daughters along the release pathway (such as in the cracks or gooseneck vent), before reaching the atmosphere. This equation is applied to Rn daughter releases associated with each of the different Rn releases, both for releases from the K-65 Silos and for releases from the drummed K-65 material stored on the Plant 1 pad. In the case of releases from this drummed material, the same equation is used to calculate the release quantities,  $R_{daught,dr}$ (instead of  $Q_{daught}$ ), from the Rn release quantities  $R_{dr}$  (instead of Q).

# Appendix J Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

\$.

**Parameter distributions.** In general, no data have been located that enable the estimation of the parameters  $F_1$  and  $F_2$ . One study, conducted in 1993, may provide information to at least qualitatively corroborate the parameter distributions that we choose here. That study is discussed shortly.

Page J-65

2

1

No information about the fractional equilibrium of short-lived <sup>222</sup>Rn daughters in silo air has been found. The range of possible values of the equilibrium fraction is from 0 to 1. Much of the research into Rn daughters has been focused on homes and occupational environments. The range of equilibrium fractions measured in houses is at least from 0.1 to 0.9 (NCRP 1988). However, houses typically have ventilation rates between about 0.2 and 3  $h^{-1}$  (Nazaroff and Nero 1988), which is much greater than the calculated ventilation rates of the silos ( $\lambda_{v,post}$  nominally about 0.002 h<sup>-1</sup> and  $\lambda_{v,pre}$  nominally about 0.05 h<sup>-1</sup>). It is known that the equilibrium fraction in an enclosed space increases with decreasing ventilation (NCRP 1989). However, at very low ventilation rates, low concentrations of condensation nuclei could lead to significantly increased unattached fractions of Rn daughters, and thus to increased deposition of daughters on surfaces and decreased equilibrium fraction (Nazaroff and Nero 1988). No direct information is available about concentrations of condensation nuclei in the head space air, but this is thought to be a lesser effect. The characteristics of the silo aerosols are not well enough understood to allow a useful model of the airborne concentrations of Rn daughters in the silos. However, it seems reasonable that the equilibrium fraction will be quite close to 1. We thus assume that  $F_1$  follows a uniform distribution, with minimum 0.8 and maximum 1.0.

No information, either from FMPC-specific sources or from other sources, has been located relevant to the fractional release factor,  $F_2$ . We thus assume that uniform distributions would apply, and choose ranges for  $F_2$  based on relative differences expected for the different release scenarios. Table J-29 shows the ranges chosen and the justifications.

\*

.

بې د د د مې

. .

يت. ا

In the summer of 1993 a pilot study at the FMPC included limited onsite, outdoor measurements of Rn equilibrium ratio (Paine 1994). The preliminary data indicate that the Rn equilibrium ratio may be about 50% or less for meteorological stability classes A, B, D, and E. The samples were apparently collected near the K-65 Silos. A copy of the study report was requested from the FMPC, but has not yet been obtained. If the Rn concentrations were significantly above background, so that essentially all the Rn was from K-65 Silo releases, the measured Rn equilibrium fraction would be representative of the product  $F_1F_2$ . Some provisional information was obtained through informal discussions with FMPC staff. It appears that the gross measured Rn concentrations are only somewhat elevated above background concentrations (Tomczak 1994), indicating contributions both from releases from the K-65 Silos and from background concentrations. Since the background concentrations were not measured (Tomczak 1994), the contributions from the Silo releases can not be determined. These measurements were made in 1993 and may be generally representative of conditions that existed in 1988, though the Rn release rate was lower in 1993. Because details (especially about background contributions) are lacking, we can only indicate at this time that the measurements are not inconsistent with our parameter choices, which for 1988 result in a nominal value of  $F_1F_2$  of 0.22 (0.9 × 0.25).

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

1944 H. 1944

il.

S. MA.

Périod	To calculate:	Use $F_2$ :	Range of $F_2$	Reasoning
1951–1953	R <sub>daught,dr,i</sub>	F <sub>2,dr</sub>	363 ( <b>0-0.5</b> ) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	Penetrations in drums, primarily at joint between lid and drum, are assumed to be very small in size, allowing for significant deposition.
1952–1953 and 1953–1958	$Q_{ m daught,52-53}$ $Q_{ m daught,53-58}$	F <sub>2,52–58</sub>	0.8-1-	Gooseneck vent and other dome penetrations were open to atmosphere, so free exchange means little deposition.
1959–1979	$Q_{\rm daught,pre}$	F <sub>2,pre</sub>	0.8–1	Gooseneck vent and other dome
			and a state of the second s	atmosphere, so free exchange means little deposition.
1980 <b>–</b> 1987 <sup>•</sup>	Q <sub>daug</sub> ht,post,exch	F <sub>2,post,exc</sub>	n <sup>1</sup> 2 <b>0.5–1</b> : •	Exchange releases occurred primarily through dome penetrations. Major dome penetrations sealed, but cracks and small penetrations remained. Probably significant, but small amount of deposition.
1980–1987	Qdaught,post,diff	F <sub>2,post,diff</sub>	<b>0-0.5</b>	Diffusion releases through concrete. Slower transport (versus pressure- driven air exchange) means significantly greater deposition.
1988	Q <sub>daught,1988</sub>	F <sub>2,1988</sub>	, <sup>r</sup> , <b>0–0.5</b>	Addition of foam layer on domes should cause additional deposition, relative to 1980–1987.

**Results of calculations.** For the 1980–1987 period, the total Rn daughter release rate is the sum of release rates for air exchange releases and diffusion releases ( $Q_{daught,post,exch}$ and  $Q_{daught,post,diff}$ , respectively). The frequency distributions for these intermediate, calculations are shown in Table J-30.

		Percentiles of distributions	
Parameter	Units	5th 25th median 75th	95th
Qdaught,post,exch Qdaught,post,diff	Ci y <sup>-1</sup> Ci y <sup>-1</sup>	140     120     530     740       120     2.7     14     28     45	1100 75

 Table J-30. Summary of Frequency Distributions of Intermediate

 Calculations; for Current Estimates of Rn Daughter Releases

Table J-31 shows the distributions for calculated Rn daughter release quantities for 1951, 1952, and 1953 from drummed K-65 material stored on the Plant 1 pad. The frequency

# Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Appendix J

distributions for calculated Rn daughter release rates from the K-65 Silos are summarized in Table J-32.

## Table J-31. Summary of Predicted Rn Daughter Release Quantities (Ci)<sup>a</sup> from Drummed K-65 Material Stored on the Plant 1 Pad

		Percen	tiles of distri	ibutions	
Year	5th	25th	median	75th	95th
1951 <sup>b</sup>	0.24	-2.0	6.2	16	45
1952	3.9	33	100	250	730
1953°	0.63	5.4	17	42	120

<sup>a</sup> The release quantities are quantities of each of the short-lived daughters <sup>218</sup>Po, <sup>214</sup>Pb, <sup>214</sup>Bi, and <sup>214</sup>Po.

<sup>b</sup> Releases for 1951 are assumed to have occurred in October through December.

<sup>c</sup> Releases for 1953 are assumed to have occurred in January through June.

## Table J-32. Summary of Predicted Rn Daughter Release Rates (Ci y<sup>-1</sup>)<sup>a</sup> from the K-65 Silos

	Percentiles of distribution					
Period	5th	· 25th	median	75th	95th	
mid-July 1952-mid-June 1953	150	760	1500	2300	3400	
mid-June 1953-mid-September 1958	2400	3300	4000	4800	6300	
mid-September 1958–June 1979	3300	4200	5000	5900	7200	
July 1979–December 1987	170	380	560	770	1200	
1988	7.3	41	<u>99</u>	190	390	

<sup>a</sup> The release rates are quantities of each of the short-lived daughters <sup>218</sup>Po, <sup>214</sup>Pb, <sup>214</sup>Bi, and <sup>214</sup>Po.

## Total Radon and Radon Daughter Releases for the Operating Period 1951-1988

Total quantities of <sup>222</sup>Rn and Rn daughters released from the FMPC during the complete period 1951-1988 can be calculated by summing releases for the individual time periods. We first separately calculate total releases from the K-65 Silos and total releases from the drums of K-65 material stored on the Plant 1 pad. For the Silos:

$$R_{\rm Silos,52-88} = \sum_{i} Q_i T_i$$

Radiological Assessments Corporation "Setting the standard in environmental health"

(J--65)

•

۰.

1000

i.

where  $R_{\text{Silos},52-88}$  is the total quantity of Rn (Ci) released from the K-65 Silos for the complete period of releases from the Silos, 1952–1988;  $Q_i$  is the Rn release rate for period *i*; and  $T_i$  is the length (in time) of period *i*; with *i* representing each of the periods 1952–1953, 1953–1958, 1959–1979, 1980–1987, and 1988. For the drummed K-65 material:

$$R_{dr,51-53} = \sum_{j} R_{dr,j}$$
 (J-66)

where  $R_{dr,51-53}$  is the total quantity of Rn (Ci) released from the drummed K-65 material for the complete period of such releases, 1951–1953; and  $R_{dr,j}$  is the quantity of Rn released for year *j*; with *j* representing each of the years 1951, 1952, and 1953.

The total quantity of Rn released from the FMPC for all years (1951-1988) is then:

$$R_{\rm FMPC,51-88} = R_{\rm Silos,52-88} + R_{\rm dr,51-53} \tag{J-67}$$

The same equations are used to calculate total releases of Rn daughters, with the following substitutions:  $R_{\text{daught,Silos,52-88}}$  for  $R_{\text{Silos,52-88}}$ ;  $\dot{Q}_{\text{daught,i}}$  for  $Q_i$ ;  $R_{\text{daught,dr,51-53}}$  for  $R_{\text{dr,51-53}}$ ;  $R_{\text{daught,dr,j}}$  for  $R_{\text{dr,j}}$ ; and  $R_{\text{daught,FMPC,51-88}}$  for  $R_{\text{FMPC,51-88}}$ .

The values of  $T_i$  to be used are easily calculated from the individual periods, and are shown in Table J-33. Results of the calculations are shown in Table J-34.

	Table J	-33.	Lengths	of Perio	ds Us	ed in	
Calcu	lations	ofI	<b>Total Rn</b>	Releases	from	K-65	Silos
				· · · ·			

Period	Period length (years)
mid-July 1952–mid-June 1953	0.917
mid-June 1953-mid-September	1958 5.25
mid-September 1958-June 1979	9 20.79
July 1979-December 1987	8.50
1988	1.00

Table J-34. Summary of Frequency Distributions of Predicted Total Release Quantities (Ci) of Rn and Rn Daughters from the FMPC for 1951–1988

n <mark>a satu u 1920 - ng la ang la satu Statu ang la satu ang la satu ang la satu</mark>	Percenti	Percentiles of distributions					
Parameter	,5th and at 125th for the	median	75th	95th			
R <sub>Silos.52-88</sub>	110,000 .140,000	170,000	190,000	230,000			
R <sub>dr,51-53</sub>	54 300	720	1500	3400			
R <sub>FMPC,51-88</sub>	110,000 140,000	170,000	190,000	230,000			
Rdaught,Silos,52-88	87,000	130,000	150,000	190,000			
R <sub>daught,dr,51-53</sub> a		: • • • • <b>130</b> - • •	320				
Adaught, FMPC, 51-88	87,000 (1912) 110,000 (1923)	130,000	160,000	190,000			

<sup>a</sup> The release rates for <sup>222</sup>Rn daughters are release rates of each of the short-lived daughters <sup>218</sup>Po, <sup>214</sup>Pb, <sup>214</sup>Bi, and <sup>214</sup>Po.

n under Fritzlich In Stand Britzlich

Page J-68

# Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

# Summary of Current Estimates of Radon and Daughter Releases

The estimated Rn and Rn daughter release rates from the K-65 Silos are summarized in Table J-35. The calculated release rates are assumed to be constant over the full time periods assessed. Thus, within a given assessment period, the estimated release quantity for a given length of time is simply the time multiplied by the release rate. This also applies to the various percentiles of the distributions, since the parameter distributions are applied to the full time periods, rather than independently to each year.

	Rn release rate			Daughter release rate <sup>a</sup>		
Period	5th	median	95th	5th	median	95th
mid-July 1952-mid-June 1953	200	1900	4200	150	1500	3400
mid-June 1953-mid-September 1958	3100	4900	7600	2400	4000	6300
mid-September 1958–June 1979	4200	6200	8700	3300	5000	7200
July 1979–December 1987	360	950	1700	170	560	1200
1988	120	540	1300	7.3	99	390

# Table J-35. Summary of Percentiles of Predicted <sup>222</sup>Rn and <sup>222</sup>Rn Daughter Release Rates (Ci y<sup>-1</sup>) from the K-65 Silos

<sup>a</sup> The release rates for <sup>222</sup>Rn daughters are release rates of each of the short-lived daughters <sup>218</sup>Po, <sup>214</sup>Pb, <sup>214</sup>Bi, and <sup>214</sup>Po.

We also note that for the 1980-1987 period the majority of the Rn released would have been released during daytime hours ( $Q_{exch,post}$ ), when the warming of the silo air caused most of the ventilation of the silos. For the other periods, the majority of the releases would have been caused by other phenomena. For the 1959-1979 period, one driving force was probably wind across the silo penetrations. Thus, for all periods except 1980-1987, the releases are assumed to have occurred continually throughout the day.

The estimated total release rates of  $^{222}$ Rn from the K-65 Silos are also summarized in Figure J-7 and Figure J-8. Figure J-7 is a plot of the distributions of the total release rates. This shows the relative magnitudes of the release rates, and the slopes of the curves indicate the breadth of the uncertainty intervals. Figure J-8 shows the estimated releases versus time. The 1959-1979 period appears, based on release rate and release time, to be the most significant, with a very high release rate for a long period of time.

The estimated Rn and Rn daughter release quantities from the drummed K-65 material stored on the Plant 1 pad are summarized in Table J-36.

The predicted total quantities of Rn released from the FMPC for the entire period of concern for this Project, 1951-1988, are summarized in Table J-37. It can be seen that Rn releases from the drummed K-65 material stored on the Plant 1 pad are relatively insignificant contributors to the total Rn releases for 1951-1988. However, these releases from the drummed K-65 material occurred in 1951-1953, when operations at the FMPC were just beginning. Thus, Rn releases from the drummed K-65 material may be significant contributors to releases of all radionuclides in the earliest years of site operations.



# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty





( 'n

.

1953°

6.9

95

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

<sup>222</sup> Rn and <sup>222</sup> Rn Daughter Release Quantities (Ci) from the Drummed K-65 Material Stored on the Plant 1 Pad										
	Quantity Rn released			Quantity daughters released <sup>a</sup>						
Year	5th	median	95th	5th	median	95th				
1951 <sup>b</sup>	2.6	35	170	0.24	6.2	45				
1952	<b>42</b>	580	2800	3.9 <sub>.</sub>	100	730				

Table J-36. Summary of Percentiles of Predicted

<sup>a</sup> The release quantities for <sup>222</sup>Rn daughters are quantities of each of the shortlived daughters <sup>218</sup>Po, <sup>214</sup>Pb, <sup>214</sup>Bi, and <sup>214</sup>Po.

450

0.63

17

120

<sup>b</sup> Releases for 1951 are assumed to have occurred in October through December.

Releases for 1953 are assumed to have occurred in January through June.

# Table J-37. Summary of Percentiles of Predicted Total <sup>222</sup>Rn and <sup>222</sup>Rn Daughter Release Quantities (Ci) from the FMPC for the Entire Period 1951-1988

	Rn release quantity		Daughter release quantity <sup>a</sup>			
Source of releases	5th	median	95th	5th	median	95th
K-65 Silos	110,000	170,000	230,000	87,000	130,000	190,000
Drummed K-65 material stored on Plant 1 Pad	54	720	3,400	4.5	130	880
Both sources	110,000	170,000	230,000	87,000	130,000	190,000

<sup>a</sup> The release quantities for <sup>222</sup>Rn daughters are release quantities of each of the short-lived daughters <sup>218</sup>Po, <sup>214</sup>Pb, <sup>214</sup>Bi, and <sup>214</sup>Po.

## **Conclusions About Current Estimates**

We first make two observations regarding calculated Rn releases. First, recall that equation J-12 indicates that total Rn releases from the K-65 Silos are proportional to  $[(\lambda_v + \lambda_d)/\lambda_{eff}]$ . This ratio is the fraction of the total removal of Rn from the silo that occurs through release through air exchange and diffusion (the rest is "removed" by radioactive decay). The difference between these ratios for the 1959–1979 and 1980–1987 periods illustrates the reason for the significant difference in total releases for the two periods. For the "post" period (see Table J-17), a significant, but small fraction of the available Rn is lost by release to the outside air. For the "pre" period (see Table J-20), almost all of the Rn lost is through releases.

Second, as expected based on the previous estimates, for the 1980–1987 period, releases from the K-65 Silos through the diffusion pathway are relatively small, but not insignificant, compared to releases through air exchange (see Table J-16 and Table J-17). For the 1980–1987 period the difference of the medians of the distributions is a factor of six.

Ę

1.45

Parking

£,

Ś

÷

As shown in Table J-35, Table J-36, Figure J-7, and Figure J-8, the uncertainties in some of the release rates are quite large. In particular, the 90% probability intervals of the <sup>222</sup>Rn releases from the drummed K-65 material have ranges of a factor of about 70. This large uncertainty is due to very little direct information pertinent to estimating the releases.

The 90% probability intervals of the Rn releases from the K-65 Silos for 1952–1953, 1980–1987, and 1988 have ranges of factors of about 20, 5, and 10, respectively. For the calculations of Rn releases from the K-65 Silos, the most important contributors to the uncertainties are the lack of direct information about releases during Silo operations, for the 1952–1953 and 1953–1958 periods; the lack of complete information about  $\lambda_{v,post}$ , for the 1980–1987 period; the limited, indirect information about  $C_{a,pre}$ , for the 1959–1979 period; and the limited Rn monitoring data, for the 1988 releases.

However, even with the large associated uncertainties, it is clear that the release rate of <sup>222</sup>Rn from the K-65 Silos was much greater in the 1959–1979 period than in the 1980–1987 period. This greater release rate for the 1959–1979 period is a very important result, which was not obtained in previous studies.

We acknowledge that the Rn daughter release estimates are extremely uncertain. This is due to the incomplete knowledge about the fractional release of Rn daughters through silo dome penetrations and drum penetrations, and due to the uncertainties in the estimated Rn releases. These releases may be important for estimates of doses to receptors close to the FMPC. At very close distances, exposures of people outdoors to Rn daughters may be due primarily to daughters released from the Silos and drums, since the short travel time would lead to relatively little ingrowth, along the travel path, of daughters from releases of Rn.

Earlier in this Appendix, we discussed previous estimates of the Rn source term from the K-65 Silos (see page J-12). The previous studies estimated Rn releases from information about the Silos and the K-65 material in the Silos. A recent study has instead estimated Rn releases based on a back-calculation from measured Rn concentrations around the FMPC and models of the atmospheric dispersion of the Rn in transport to the monitoring locations (Hamilton et al. 1993). The back-calculation was a linear, least-squares regression on the equation: measured concentration = (source term)×(source coefficient). The regression forced the y-intercept to zero. Here, the measured concentrations were net concentrations measured at the sixteen FMPC boundary fenceline monitoring stations. The source coefficients were the predicted ratios of Rn concentration at the receptor point to the release rate ( $\chi$ /Q). The result was an estimated release rate of 1150 Ci y<sup>-1</sup>, for 1989 and 1990. The uncertainty in this estimated release rate was not provided. However, the range of estimated source terms when individual locations were considered (rather than the regression of all locations) was 575 to 4025 Ci y<sup>-1</sup>. The relative uncertainty in the best estimate (1150 Ci y<sup>-1</sup>) is thus probably large.

The estimated release rate of Hamilton et al. can be compared to our estimated release rate for 1988, since conditions of the K-65 Silos were unchanged for the period 1988–1991. Our results were a median estimated release rate of 540 Ci  $y^{-1}$ , with a 90% probability interval of 120–1300 Ci  $y^{-1}$ . The estimated release rate of Hamilton et al. lies within the 90% probability interval of our estimate. This provides some corroboration of the reasonableness of our estimated release rate for 1988.
32

; ; ;

.

5

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

#### ALTERNATIVE CALCULATION OF UNCONSTRAINED RADON RELEASES, FOR COMPARISON WITH CURRENT RELEASE ESTIMATES

For assessments of releases of <sup>222</sup>Rn from bulk quantities of <sup>226</sup>Ra-bearing material, such as uranium mill tailings, one conventional calculational methodology uses models describing the generation of Rn in the material and diffusion through the material into the atmosphere (Rogers et al. 1984). Parameters for the calculations are based on characteristics of the <sup>226</sup>Ra-bearing material, including density, moisture content, porosity, Ra concentration, Rn emanation fraction, and Rn diffusion coefficient through the material.

The current estimates of radon releases from the K-65 Silos, discussed earlier in this Appendix, do not use this conventional methodology. For the preliminary source term work (Voillequé et al. 1991), the data on the characteristics of the K-65 material were quite limited, and the current approach was chosen to make better use of the other available data.

Since our preliminary work, some additional data on K-65 characteristics have been obtained. Thus we perform an alternative calculation (alternative to our current estimate) of Rn releases, using the more conventional methodology. To allow comparison with our current estimates, we calculate an unconstrained Rn release rate, that would exist if the Silo domes did not cover the K-65 material. An evaluation of the results of this alternative calculation indicates that the alternative methodology is not as satisfactory as the current methodology. However, the alternative calculation results do provide some corroboration of the reasonableness of the current estimates. The rest of this section describes the model used for the alternative calculation, parameter values chosen, and results of the calculation, and compares the results to those of the current estimates.

#### Model for Unconstrained Radon Releases

Since we intend to compare the results of this alternative calculation to our current estimates of Rn releases, the calculated end points must be the same. For this purpose, we calculate an unconstrained Rn release rate, which is an estimate of the release rate that would exist if the K-65 Silos were open to the atmosphere, rather than covered (with the silo domes). With Silos covering the K-65 material, Rn concentrations build up in the silo air space, and this Rn constrains the diffusive release of Rn from the K-65 material into the silo air space.

The conventional methodology uses the following equation to calculate the Rn diffusion fluence rate (often simply called Rn flux) from a bare layer of source material, with an impervious layer below it, into air above the source material (Collé et al. 1981).

$$j_{\rm D,0} = \sqrt{\frac{D_{\rm e}\varepsilon_{\rm w}}{\lambda_{\rm Rn}}}(\phi) \tanh\left(\frac{L_{\rm w}}{l_{\rm w}}\right) \tag{J-68}$$

where

 $j_{D,0}$  = unconstrained diffusion fluence rate of Rn (Rn flux). The quantity of Rn per unit time per unit area transported by diffusion from the source material (in this case the K-65 material) into the ambient air (pCi m<sup>-2</sup> s<sup>-1</sup>, or similar).

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

 $D_e$  = effective bulk diffusion coefficient of Rn through the porous source material (cm<sup>2</sup> s<sup>-1</sup>, or similar).

 $\epsilon_{w}$  = porosity of the source material.

Page J-74

- = the pore space Rn production rate. Quantity of Rn produced in pore spaces of the source material per unit time per unit pore volume that is free to migrate through the pores of the material (pCi cm<sup>-3</sup> s<sup>-1</sup>). Depends on characteristics of the source material, including <sup>226</sup>Ra concentration, Rn emanation fraction, bulk density, and porosity, and on the Rn decay constant.
- $L_w$  = thickness of the source material (cm, or similar).
- $l_w$  = Rn diffusion length in the source material (related to  $D_e$ ) (cm, or similar).

 $\lambda_{Rn}$  = the decay constant for <sup>222</sup>Rn.

We note that equation J-68 is equivalent to equation J-29 for the case when the constraining air concentration,  $C_{a}$ , is equal to zero, which is the case of unconstrained release.

In an earlier section of this Appendix, about current estimates of Rn releases, we estimated that the average volume in the K-65 Silos occupied by head space air (average for the two Silos) was between 40,000 and 62,000 ft<sup>3</sup> (see page J-29). The volume of the dome of each Silo was calculated to be 23,900 ft<sup>3</sup>. Thus the head space volume includes an estimated 16,100 to 38,100 ft<sup>3</sup> that is in the cylindrical part of the Silo, which would be the top 3.2 to 7.6 ft of the cylindrical section. With the total height of the cylindrical section of the Silo being 26 ft 8 in, this implies that the average thickness of K-65 material in the Silos would be 19.1 to 23.5 ft. These are thus the potential values for  $L_w$ . Later in this section the results of calculations are discussed. The distribution of the calculated Rn diffusion length in the K-65 material,  $l_w$ , has fifth and 95th percentiles of 13.6 and 180 cm; respectively. With these values of  $L_w$  and  $l_w$ , the tanh term in equation J-68 will be very close to unity, being greater than 0.995. This indicates that the K-65 material is essentially infinitely thick in terms of producing Rn flux, in that an increase in thickness would not significantly increase the Rn flux. For simplicity then, we assume the tanh term is equal to one, and equation J-68 is reduced to:

$$j_{\rm D,0} = \sqrt{\frac{D_e \varepsilon_w}{\lambda_{\rm Rn}}}(\phi)$$

(J–69)

(J-70)

12.45

24.00

Contra .....

7

Store in

The unconstrained Rn release rate is then just:

## $P_{\rm Rn,0} = j_{\rm D,0} A_{\rm w}$

where  $A_w$  is the surface area of the source material (the K-65 material) exposed to the air. We use the  $P_{\rm Rn}$  notation because as for the constrained Rn production rates,  $P_{\rm Rn,pre}$  and  $P_{\rm Rn,post}$ , the releases are from the K-65 material to the air above it. The subscript 0 indicates unconstrained releases to ambient air.

1)

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

The pore space Rn production rate can be calculated by:

$$=\frac{[Ra]EF\rho_{w}\lambda_{Rn}}{\varepsilon_{w}}$$
 (J-7)

where:

.7

م مېچې د

. .

[Ra] = concentration of <sup>226</sup>Ra in K-65 waste material (activity per mass),

 $EF = {}^{222}$ Rn emanation fraction in K-65 material, which is the fraction of the Rn formed (from the  ${}^{226}$ Ra decay) that is in the pore spaces and is free to migrate, and

 $\rho_w$  = bulk density of K-65 waste material (g cm<sup>-3</sup>, or similar).

In equation J-71, the <sup>226</sup>Ra concentration gives the total production rate of <sup>222</sup>Rn atoms, per mass of source material. Multiplication by the Rn emanation fraction converts this to the production of Rn in the pore spaces. The factors of  $\rho_w$  and  $\varepsilon_w$  convert the basis from mass of source material to volume of pore space air. Finally, the decay constant converts the quantity of Rn from atoms to activity units.

Radium-226 concentration. Concentrations of <sup>226</sup>Ra in the K-65 material in the two K-65 Silos were presented earlier in this Appendix (see page J-7). We concluded that the results from the 1991 ASI/IT sampling program are preferred for further use. The depths of these samples are identified only by the zone; either A, B, or C, where zone A is roughly the top third of the K-65 material in the Silo, zone B the middle third, and zone C the bottom third. Based on the overall thickness of the K-65 material, discussed above, the thickness of each zone is roughly 7 ft, or 2 m. If this thickness is used for  $L_w$  in equation J-68, with the fifth and 95th percentile values of  $l_w$ , as used above, the tanh term is fairly close to one, this time being greater than about 0.8. This indicates that the Rn releases are primarily due to  $^{226}$ Ra in the top zone. We note that from this approach it also follows that the concentrations of <sup>226</sup>Ra in the upper parts within zone A (closest to the surface) would be more important to Rn releases than would those in the lower parts of zone A. Computer programs are available to perform Rn diffusion release calculations for multilayer systems (Rogers et al. 1984). However, the available data are not sufficient for such a multilayer calculation, and we continue to use the equation for a single layer of source material (equation J-69).

Thus we would like to use the average  $^{226}$ Ra concentration of zone A of the K-65 material. In some cases there were multiple samples from a given zone and given manhole, though the difference in location within the zone is not known. We thus average the concentrations, from Table J-5, by zone. Table J-38 shows the average concentrations by zone and by manhole. For four of the locations in zone A, no sample results were available. Thus, the available results for zone A may be less than adequate to characterize the average concentration for all of zone A. Instead we use the range of average concentrations, from Table J-38, to represent the average for zone A. The assumed distribution for [Ra] is uniform, with minimum 134,900 pCi g<sup>-1</sup> and maximum 697,000 pCi g<sup>-1</sup>. This distribution seems quite broad, but it is justified by the limited characterization data. We also feel confident that it includes the average concentration in zone A material. We note that the

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

#### Page J-76

implied mean concentration, 416,000 pCi  $g^{-1}$ , is very similar to the mean of all samples from both Silos, as given in Table J-5.

Table J-38. Average Concentrations of <sup>226</sup>Ra by Zone

	tion in the A-05		16 II-05 SI105
	· · · · · · · · · · · · · · · · · · ·	<sup>226</sup> Ra Concent	tration (pCi g <sup>-1</sup> )
Zonea	Locationa	Silo 1	Silo 2
<b>A</b> .	NE	394,900	134,900
. <b>A</b>	SE	367,600	•
·A .	SW		
Α	NW	306,800	
· <b>B</b>	NE DOUG NE	484,800	179,500
` B '	SE	697,000	433,300
Β.	Stand B SW (1996)	to the second	
B	NW T	• 680 <b>,9</b> 00	· · · · · · · · ·
C	NE		386,800
С	SE	601,600	252,600
C	SW	the Care I	· · · ·
Ċ	NW	510,400	199,400

<sup>a</sup> Zone A refers to the top one-third of the K-65 material, zone B to the middle third, and zone C to the bottom third. The locations are the manholes, by direction from center, through which samples were obtained.

**Radon emanation fraction.** As discussed earlier in this Appendix (see page J-11), measurements of the Rn emanation fraction for the K-65 material have not been performed. In the absence of emanation fraction data for the K-65 material, values for similar materials must be used.

DOE (1990) briefly describes the process flow in the refinery (Plant 2/3) at the FMPC, and the processing of the waste products which contributed the K-65 and metal oxide materials. Feed materials (ores or concentrates) were first digested (or leached) with nitric acid. When pitchblende uranium ore was processed, "hot" raffinates (those that contained significant radioactivity, mostly due to <sup>230</sup>Th, <sup>226</sup>Ra, and daughter products) were produced from the solvent extraction step (using TBP kerosene) in the process. Further processing of the hot raffinates resulted in both K-65 and metal oxide materials. Thus, the K-65 material is only part of the "tailings" from the ore processing at the FMPC. It is assumed that similar processing formed the K-65 material that was brought to the FMPC from the Mallinckrodt Chemical Works in St. Louis.

Conventional methods for milling uranium from ores are described in NRC (1980). The general process in conventional uranium mills is similar to that used at the FMPC, with leaching of the ore (either acid leach or alkaline leach) followed by solvent extraction (using amine, kerosene, or alcohol, for acid leach process) or precipitation (for alkaline leach) to remove the uranium. The solids-containing tailings are removed after the leach process.

age 0-10

Sec. 15.

S. 11. 3.

たいとう

2

Dell's internet

¥

`×`

......

.75

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Page J-77

Raffinates from the solvent extraction process are generally recycled back to the leach process.

It thus appears that the general processing of ores in the FMPC refinery was similar to conventional acid-leach processing in uranium mills. One difference is that at the FMPC the solid waste materials were separated into two streams, the K-65 and metal oxide materials, while conventional mills produced a single tailings waste.

Radon emanation fraction measurements have been made for samples of tailings from various uranium mills. Since the processing to produce the K-65 material was relatively similar to that to produce uranium mill tailings, we think that emanation fraction measurements for uranium mill tailings are the best substitute for measurements specific to the K-65 material.

Rogers et al. (1984) compiles Rn emanation fraction measurements for tailings from nine different uranium mills in the western U.S. It is well known that the Rn emanation fraction is dependent on moisture content, particularly at very low moisture content (Rogers et al. 1984; Nazaroff and Nero 1988). Since the K-65 material was placed into the Silos as a slurry, and was somewhat protected from drying out, the moisture content in the K-65 material is expected to be relatively high. For moisture saturation fraction above 20%, emanation fractions ranged from about 0.1 to about 0.4, with a relatively uniform distribution of values across the range (Rogers et al. 1984). We thus assume that the emanation fraction for the K-65 material, EF, has a uniform distribution with minimum 0.1 and maximum 0.4.

Bulk density of K-65 material. Measurements of bulk density of the K-65 material were discussed earlier in this Appendix (page J-9). The three results, from studies in 1952 and 1972, ranged from 0.53 to 1.179 g cm<sup>-3</sup> dry density (assumed dry in one case). Although these values seem quite low, no other values were located. Because we feel that knowledge about the bulk density of the K-65 material is incomplete, we assume the bulk density,  $\rho_w$ , has a uniform distribution, with minimum 0.53 g cm<sup>-3</sup> and maximum 1.179 g cm<sup>-3</sup>.

Specific gravity and porosity of K-65 material. As discussed earlier in this Appendix (page J-9), no measurements of porosity of the K-65 material have been reported. However, the report of the 1989 sampling episode (DOE 1990) presents specific gravity measurements for eight samples of K-65 material. Table J-39 shows these results.

Porosity, dry bulk density, and specific gravity of the K-65 material are related by:

$$\varepsilon_{w} = \frac{g_{w} - \rho_{w}}{g_{w}} \tag{J-72}$$

where  $g_w$  is the specific gravity of the K-65 material, and where the density,  $\rho_w$ , is expressed here as the numerical value (without units) corresponding to the density given in units of g cm<sup>-3</sup>. Porosity will be calculated using this equation. For the specific gravity, the six individual samples had a mean of 2.98 and standard deviation of 0.295. The standard error of the mean is thus 0.12. The range of values is from 2.58 to 3.37, which is fairly narrow. We assume the mean specific gravity of the K-65 material,  $g_w$ , follows a normal distribution with mean 2.98 and standard deviation 0.12.

K-65 Material from the K-65 Silos					
Sample identification Sp	ecific gravity				
S1-NE-1A	3.19				
S1-NE-1C	2.74				
S1-SE-2T	3.37				
S1-Compos.ª	2.58				
S2-NW-1A	2.87				
S2-NE-2BT	. 2.59				
S2-SW-1A	3.11				
S2-Compo <sup>a</sup>	. 2.78 , -				
mean <sup>b</sup> - and that a strate of	2.98				
standard deviation <sup>b</sup>	0.295				

These appear to be composite samples, though there was no indication of what they were composed.

<sup>b</sup> We calculate the mean and standard deviation for the six individual samples only (not composites).

Moisture content of K-65 material. The moisture content of the K-65 material, in units of saturation fraction, is needed for the estimation of the Rn diffusion coefficient through the K-65 material, which will be discussed in the next section. Measurements of moisture content that have been located were summarized earlier, in Table J-4 and subsequent text (see pages J-8 and J-9). As discussed earlier, the top 2 m (or so) of the K-65 material in the Silos will have the most impact on Rn diffusion releases into the ambient air, so we would like to determine moisture content for this top layer of material. As discussed earlier, however, the vertical locations of the moisture content samples are not known, so the profile of moisture content with depth in the K-65 material is unknown. For some of the values given in Table J-4, we made reasonable assumptions about the units of the values as presented in the references. With that caveat, it appears that the range of measured moisture content in the K-65 material is 21.8% to 90% dry weight.

The moisture saturation fraction is the moisture content of a material expressed as the fraction of the maximum moisture content, which occurs when all the pore spaces in the material are filled with water (this condition is saturation). The moisture saturation fraction of the K-65 material,  $m_w$ , can be related to the moisture content in dry weight fraction (dry weight percent divided by 100%),  $M_w$ , by (Rogers et al. 1984):

$$m_{\rm w} = \frac{M_{\rm w}}{\frac{1}{\rho_{\rm w}} - \frac{1}{\beta_{\rm w}}}$$

(J-73)

.

第二方

where  $\rho_w$  and  $g_w$  are the bulk density and specific gravity of the K-65 material, as used previously. Again, the density,  $\rho_w$ , is expressed as the numerical value (without units) corresponding to the density given in units of g cm<sup>-3</sup>.

·..-

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

For the distribution of  $M_w$ , we assume a uniform distribution over the range of measured values, 21.8% to 90% dry weight, or 0.218 to 0.90 dry weight fraction, with one constraint. The saturation fraction must be less than or equal to 1. Thus, the constraint on  $M_w$  is:

$$M_{\rm w} \le \frac{1}{\rho_{\rm w}} - \frac{1}{g_{\rm w}} \tag{J-74}$$

We thus consider  $M_w$  to have a uniform distribution with minimum 0.218 dry weight fraction, and with maximum 0.90 or  $(1/\rho_w - 1/g_w)$ , whichever is less.

**Radon diffusion coefficient and diffusion length.** As discussed earlier in this Appendix (see page J-11), measurements of the Rn diffusion coefficient in the K-65 material have apparently not been made. We must use values obtained from the literature.

Since there has been confusion in the literature regarding the nomenclature and symbols used for diffusion coefficients, the definitions of diffusion coefficient that we use in this Appendix are reviewed. Per Rogers et al. (1984), the diffusion coefficient for Rn in the total pore space of the material is designated by the symbol D. The effective bulk diffusion coefficient of the material is designated  $D_e$ . The two are related by:

$$D_e = D\varepsilon \tag{J-75}$$

where  $\varepsilon$  is the porosity of the material. This usage is also consistent with that of Collé et al. (1981).

Rogers et al. (1984) compile diffusion coefficients from about 200 measurements on various types of soils at various moisture saturations. For cases when little is known about the diffusion coefficient of a soil, they recommend the use of an empirical correlation with saturation fraction and porosity, given by:

$$\hat{D} = (0.07 \text{ cm}^2 \text{ s}^{-1}) \exp\left[-4(m - m\epsilon^2 + m^5)\right]$$
 (J-76)

where  $\hat{D}$  is the empirically predicted pore space diffusion coefficient, *m* is the saturation fraction, and  $\varepsilon$  is the porosity. The characterization of the K-65 material indicates it is generally similar to soil. Thus, this equation is used to determine the nominal estimate of the pore space diffusion coefficient.

Rogers et al. (1984) indicate that the uncertainty in individual estimates of the diffusion coefficient for a particular soil at a given moisture may be as much as an order of magnitude, especially at higher moisture saturation fractions. We incorporate this uncertainty by:

$$D = U_{\rm D} \hat{D} \tag{J-77}$$

where D is the adjusted estimate of the pore space diffusion coefficient, that will be used for further calculations, and  $U_D$  is an uncertainty factor, represented by a lognormallydistributed random variable with geometric mean 1 and geometric standard deviation 2 (this results in a 95% confidence interval somewhat greater than one order of magnitude).

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page J-79

1

11

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainty

We think that this degree of uncertainty is reasonable, given that very little is known about the K-65 material and its similarity (or lack of) to the soils measured by Rogers et al. The pore space diffusion coefficient cannot exceed the free space diffusion coefficient. The diffusion coefficient for Rn in pure air is  $0.11 \text{ cm}^2 \text{ s}^{-1}$  (Nielson and Rogers 1982). Thus, D is constrained to be less than or equal to  $0.11 \text{ cm}^2 \text{ s}^{-1}$ . The effective diffusion coefficient,  $D_e$ , is then calculated using equation J-75.

The Rn diffusion length,  $l_w$ , is related to the diffusion coefficient by (Collé et al. 1981):

		• • •
which	1S -	equivalent to:

conversion factor is:

$\mathbf{j} = 1$	<b>D</b> :
" ī.)	$\lambda_{Rn}$
•	• • • • •

The latter equation is used in our calculations.

Surface area of K-65 material in Silos. The physical size of the K-65 Silos was discussed earlier in this Appendix (see page J-3). The inside diameter is 80 ft. Since the K-65 material was placed as a slurry, we assume that the surface is flat. Thus, the surface area of a single silo,  $A_w$ , is just the area of a circle of radius 40 ft, which is  $4.67 \times 10^6$  cm<sup>2</sup>. For our calculations, this value is assumed to have negligible uncertainty.

Radon decay constant. The half life of  $^{222}$ Rn is 3.8235 d (Walker et al. 1989). Thus, the decay constant for  $^{222}$ Rn,  $\lambda_{Rn}$ , is  $2.098 \times 10^{-6}$  s<sup>-1</sup>. For purposes of our calculations, this value is assumed to have negligible uncertainty. (This is the same as was used previously, for the current estimates, but with different units.)

Calculation of quotient needed for current estimate of Rn releases. To calculate the silo Rn production rates,  $P_{\text{Rn,pre}}$  and  $P_{\text{Rn,0}}$ , discussed earlier (see page J-40), the quotient  $[(\varepsilon_w l_w + h)/\varepsilon_w l_w]$  is required. This quotient is calculated here. Here h is the effective height of the contained (by the Silo) air space above the source (K-65) material. In an earlier section of this Appendix, about current estimates of Rn releases, we estimated that the average volume in the K-65 Silos occupied by head space air (average for the two Silos) was between 40,000 and 62,000 ft<sup>3</sup> (see page J-29). For the calculation of h, we assume the mean value of 51,000 ft<sup>3</sup>. Since the Silos have an internal radius of 40 ft, h is 10.15 ft = 309 cm.

Implementation and Results of Calculations

The equations used for the calculations are as described above, except that in the case of equation J-70, a units conversion factor is added, as follows.

#### $P_{\text{Rn.0}} = j_{\text{D.0}} A_{\text{w}} CF$

arthin all as

rdy (**J-80)** 

where CF is the units conversion factor. The units desired for the result,  $P_{\text{Rn},0}$ , is Ci y<sup>-1</sup>. The units of the parameters are pCi cm<sup>-2</sup> s<sup>-1</sup> for  $j_{\text{D},0}$ ; and cm<sup>2</sup> (per silo) for  $A_{w}$ . Thus, the units

#### 

Page J-80

(J-78)

....

17 X X

1012200

è.

1.1

(J-79)

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

$$CF = (2 \text{ silos})(3.156 \times 10^7 \text{ s y}^{-1})(10^{-12} \text{ Ci pCi}^{-1})$$
  
= 6.312 × 10<sup>-5</sup> s Ci y<sup>-1</sup> pCi<sup>-1</sup> (J-81)

Page J-81

As for the current estimates of releases, the Monte Carlo calculations for this analysis were performed using spreadsheet and forecasting software on an IBM-compatible microcomputer. Ten thousand iterations of the calculations were performed. The parameter distributions were generated using Crystal Ball<sup>®</sup>, version 2.0 for Windows (Decisioneering 1992).

The parameter distributions used in the calculations are summarized in Table J–40.

Parameter	Units	Distribution	Descriptive statistics
[Ra]	pCi g <sup>-1</sup>	uniform	minimum = 134,900; maximum = 697,000.
EF	·	uniform	minimum = 0.1; maximum = 0.4.
ρ <sub>w</sub>	g cm <sup>-3</sup>	uniform	minimum = 0.53; maximum = 1.179.
g <sub>w</sub>	. '	normal	mean = $2.98$ ; standard deviation = $0.12$ .
$M_{w}$	fraction, dry weight	uniform	minimum = 0.218; maximum = 0.90 or $(1/\rho_w - 1/g_w)$ , whichever is smaller.
$U_{\rm D}$		lognormal	geometric mean = 1; geometric standard deviation = 2.
A <sub>w</sub>	$cm^2$	known <sup>a</sup>	value = $4.67 \times 10^6$ .
$\lambda_{Rn}$	s <sup>-1</sup>	known <sup>a</sup>	value = $2.098 \times 10^{-6}$ .
h	cm	knowna	value = 309.

# Table J-40. Parameter Distributions for the Monte Carlo Calculation: Alternative Calculation of Unconstrained K-65 Silo 222Rn Releases

<sup>a</sup> "known" indicates that a single value is used in the calculations.

Table J-41 presents the results of the calculations, including intermediate results and the alternative estimate of unconstrained Rn releases from the K-65 Silos. Figure J-9 shows the distribution of estimates of the unconstrained Rn release rate,  $P_{\rm Rn,0}$ .

As seen in Table J-41 and Figure J-9, the distribution of estimates of unconstrained Rn releases from the K-65 Silos is quite broad, indicating substantial uncertainty in these estimates. The 90% probability interval (from the 5th to the 95th percentile) has a range of a factor of about 20. Equation J-69 and equation J-70 are the primary equations for calculating the unconstrained Rn release rate,  $P_{\rm Rn,0}$ . Of the parameters in these equations, we see in Table J-41 that the effective Rn diffusion coefficient,  $D_e$ , and the pore space Rn production rate,  $\phi$ , have very significant uncertainties, with 90% probability intervals having ranges of factors of about 200 and about 9, respectively. These large uncertainties in turn result because of the significant uncertainties in the <sup>226</sup>Ra concentration in the K-65 material, [Ra], the Rn emanation fraction, *EF*, the bulk density of the K-65 material,  $\rho_w$ , the moisture content in the K-65 material,  $M_w$ , and the uncertainty factor applied to the predicted diffusion coefficient,  $U_{\rm D}$  (see Table J-40).

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

 $\leq :$ 

2000 V

1.....

1999 - No.

Table J-41. Summary of Frequency Distributions of Calculated Results:for Alternative Calculation of Unconstrained K-65 Silo 222Rn Releases

		Percentiles of distributions						
Parameter	Units	5th	25th	median	75th	95th		
ε		0.61	0.66	0.71	0.76	0.81		
m <sub>w</sub>	saturation fraction	0.26	0.43	0.59	0.76	0.95		
$\boldsymbol{D}^{(1)}$ and $\boldsymbol{D}^{(1)}$	cm <sup>2</sup> s <sup>-1</sup>	$3.9  imes 10^{-4}$	4.1 × 10 <sup>-3</sup>	$1.4  imes 10^{-2}$	$3.1  imes 10^{-2}$	$6.9\times10^{-2}$		
<b>D</b> <sub>e</sub> D=37-95	cm <sup>2</sup> s <sup>-1</sup>	$2.7 \times 10^{-4}$	$2.8  imes 10^{-3}$	$1.0  imes 10^{-2}$	$2.3\times10^{-2}$	$5.2\times10^{-2}$		
1	-cm	- 14		82	120	180		
$[(\varepsilon_w l_w + h)/\varepsilon_w l_w]$		3.23	4.46	6.35	11.2	35.2		
φ.	pCi cm <sup>-3</sup> s <sup>-1</sup>	0.070			0.36	0.63		
P <sub>Rn,0</sub>	Ci y <sup>-1</sup>	580	1800	3500	6100	12,000		



Cumulative probability (percent)

19.30

Figure J-9. Probability distribution of alternative estimates of unconstrained Rn releases from the K-65 Silos. In Junior and the definition of the second state of th

Clark and

Discussion

Results of the alternative calculation of unconstrained Rn releases from the K-65 Silo are compared to results using the current methodology, in Table J-42 and Figure J-10, which summarize the distributions of results from the two methodologies.

Table

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Pocults of Fet

Unconstrained <sup>a</sup> <sup>222</sup> Rn Release Rates (Ci y <sup>-1</sup> ) from K-65 Silos							
	. Percentiles of distributions						
Method	5th	25th	median	75th	95th		
Current estimates Alternative calculation	4,700 580	5,900 1,800	6,800 3,500	7,900 6,100	9,400 12,000		

<sup>a</sup> The "unconstrained" Rn release rate is the release rate estimated to occur if the K-65 material were open to the atmosphere, rather than covered by the K-65 Silos.



Figure J-10. Summaries of distributions of unconstrained Rn release rate from K-65 Silos, for current estimates methodology and alternative methodology. The "unconstrained" Rn release rate is the release rate estimated to occur if the K-65 material were open to the atmosphere, rather than covered by the K-65 Silos.

Table J-42 and Figure J-10 show that the results of the alternative calculation of unconstrained Rn releases are significantly different from the results using the current methodology. The results of the alternative calculation have a much lower median estimate, and a much broader uncertainty distribution. For the current methodology, the 90% probability interval (5th to 95th percentile) spans a factor of about two, while the same interval for the alternative calculation spans a factor of about 20. The 90% probability interval of the alternative calculation includes the 90% interval of the current estimates.

Knowledge of the Rn concentration in the head space air can be quite important to establishing, either explicitly or implicitly, the lower bound of the distribution of release rate results. The alternative calculation does not make use of the Rn concentration in the Silo head space air (measured in 1987), which has been used in the current estimates for  $C_{\bullet}$ 

Radiological Assessments Corporation "Setting the standard in environmental health" 11

÷.,

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

(see page J-28). As shown in the following paragraphs, this appears to be an important omission of the alternative methodology.

The Rn concentration in head space air can be used to estimate a lower bound for the constrained release of Rn from the K-65 material into the head space of the Silos, as follows. If the Rn concentration in the head space is assumed to be an equilibrium concentration, then we can calculate the equilibrium Rn rate of release of Rn from the K-65 material into the head space required to sustain the Rn concentration. This equilibrium release rate (production term) was previously shown to be:

$$P_{\rm Rn} = C_{\rm a} \lambda_{\rm eff} V_0 \tag{J-9}$$

where

 $P_{Rn}$  = the constrained (by the presence of the silo) rate of release of <sup>222</sup>Rn into the silo air (production term) from the K-65 source material (activity per time),

 $C_a$  = concentration of <sup>222</sup>Rn in the silo air,

 $V_0$  = volume of the air space in the silo above the K-65 material, and

 $\lambda_{eff}$  = the effective removal rate of <sup>222</sup>Rn from the silo air space (fraction per time). The effective Rn removal rate is:

$$\lambda_{\rm eff} = \lambda_{\rm Rn} + \lambda_{\rm v} + \lambda_{\rm d} \tag{J-8}$$

where.

 $\lambda_v$  = ventilation rate of the silo, or fraction of the silo air exchanged with the outside per unit time, and

 $\lambda_d$  = rate constant for diffusion losses, the fractional rate of Rn loss from the silo air space through diffusion through the silo dome (fraction per time).

To estimate a lower bound for  $P_{\text{Rn}}$ , which we call  $P_{\text{Rn,min}}$ , we use the minimum possible value of  $\lambda_{\text{eff}}$ , which is just  $\lambda_{\text{Rn}}$ , assuming no releases through ventilation or diffusion. We thus have:

$$P_{\rm Rn,min} = \dot{C}_{\rm a,post} \lambda_{\rm Rn} V_0 \qquad (J-82)$$

where  $C_{a,post}$  is the head space Rn concentration for the 1980–1987 period. Using the mean values of the distributions previously estimated for  $C_{a,post}$  and  $V_0$  (see page J-109), we estimate:

$$P_{\text{Rn,min}} = (2.62 \times 10^7 \text{ pCi L}^{-1})(2.098 \times 10^{-6} \text{ s}^{-1})(51,000 \text{ ft}^3 \text{ (per silo)})$$
$$\times (10^{-12} \text{ Ci pCi}^{-1})(28.317 \text{ L ft}^{-3})(3.156 \times 10^7 \text{ s y}^{-1})(2 \text{ silos})$$
$$= 5000 \text{ Ci y}^{-1}$$

It is noted that this is only a nominal estimate, and there would be some associated uncertainty, although the uncertainty should be relatively small, since the uncertainties in  $C_{a,\text{post}}$  and  $V_0$  are relatively small.

: :

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

If the distribution of estimates of the unconstrained Rn release rate, based on the alternative calculation (see Table J-41 and Figure J-9), is compared to this nominal estimate of  $P_{\rm Rn,min}$ , it appears that the alternative calculation significantly underpredicts the unconstrained Rn release rate. It is not feasible to determine which of the parameters are responsible for this underprediction. It is also not apparent how the information on Rn concentration in the silo air space could be incorporated into the calculations. It is not appropriate to simply constrain the results to be greater than  $P_{\rm Rn,min}$ , because the results then would not follow from the parameter distributions.

#### **Conclusions About the Alternative Calculations**

Because of the very large uncertainties and the apparent underprediction of the alternative calculation of the unconstrained Rn releases, we conclude that the alternative calculation methodology is not as satisfactory as the current methodology. Thus, we continue to use the current methodology for calculations of Rn releases, and perform no further calculations using the alternative methodology. The 90% probability interval of the alternative calculation distribution includes the 90% interval of the current estimates distribution, and this does provide some corroboration of the reasonableness of the current methodology.

#### PARAMETER VALUES TO BE USED FOR BUILDING WAKE EFFECTS MODEL

As discussed in the report of Task 4 of this Project, our model for atmospheric transport of Rn (and particulate releases) from the FMPC site includes a building wake effects model (Killough et al. 1993). For implementing this wake effects model, the cross-sectional area of the FMPC building from which material is emitted is required. For the K-65 Silos, the "building" is considered to be the combination of the K-65 Silos and the surrounding berms.

As described earlier in this Appendix, the berms around the K-65 Silos were constructed in May 1964, and enlarged in June 1983. The monthly project record report for this work (NLCO 1984) indicates that construction was 90% complete on May 1, 1964. It also indicates that the expansion work occurred between May 16 and June 27, 1983 (both construction and expansion were under the same project). For simplicity, we thus assume that on May 1, 1964, conditions changed from no berm to the initial berm, and that on June 1, 1983, conditions changed from the initial berm to the enlarged berm.

Engineering drawings have been obtained, which show dimensions of the berms. A drawing from December 1963 shows the plans for construction of the berms (NLCO 1963). The plans indicate that the earthen embankment (we call it berms) was to be built up to the level of the top of the Silo walls. There was to be a ring, 8 ft wide, with very slight slope (2 inches in 8 ft) next to the Silos, and then a slope of  $1\frac{1}{2}$ :1 (horizontal to vertical) away from the Silos to the toe of the berms. From two aerial photographs of the K-65 Silos, taken in 1965, it appears that the berms were up to the tops of the Silo walls, and the slope of the berms looks close to  $1\frac{1}{2}$ :1 (DOE 1965a; DOE 1965b).

A drawing from 1983 shows the plans for expansion of the berms (Geesner 1983). This drawing indicated that the berms were to be expanded in areal extent, to change the slope

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page J-85

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

from 1½:1 to 3:1 (both slopes horizontal to vertical). An aerial photograph of the Silos, from 1987 (DOE 1987), and a topographic map of the site (Woolpert circa 1988) generally corroborate the areal expansion of the berms. Figure J-11 is a drawing of the Silo berms, based on the information in the engineering drawings cited above.



Figure J-11. Plan and cross sections of the K-65 Silo berms.

From the cross sections in Figure J-11, the cross-sectional area of the combined Silos and berms can easily be calculated. The results are shown in Table J-43. For the building wake effects model, the cross-sectional area is represented by an effective height and effective width of the "building." The height of the top of the Silos, above the original ground surface, is about 11 m, so this is used as the effective height. The effective width is then the width that would produce the correct average cross-sectional area. The effective dimensions, to be used in the modeling, are also shown in Table J-43.

the second second second second

#### PARAMETER VALUES TO BE USED FOR DIRECT EXPOSURE CALCULATIONS

The elevated concentrations of <sup>226</sup>Ra and other radionuclides in the K-65 and metal oxide materials produce significant emissions of gamma radiation, which may have exposed

·· . .

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

- -	Cross-	sectional area	Modeled dimensions (m)		
Period	North/south	East/west	Average	Height	Width
1952–April 1964	459	230.	344	11	31
May 1964-May 1983	686	360.	523	11	48
June 1983–1988	778	452	615	11	56

Table J-43. Calculated Cross-Sectional Area and Effective Dimensions of the Combined K-65 Silos and Berms

people outside the FMPC. In our Task 4 Report (Killough et al. 1993), we described the methodology to be used to calculate exposures and doses due to this direct radiation. In this section of this Appendix, we provide additional information, necessary to complete those calculations. In the report of Task 6 of this Project (work in progress), results of calculations, including exposure rate as a function of distance from the Silos, will be provided.

For assessments of direct exposures to people outside the FMPC boundary due to sources on the site, we consider the two K-65 Silos and the Metal Oxide Silo, Silos 1, 2, and 3 in the waste storage area, to be the only significant sources. We base this on two types of information: results of aerial radiation surveys of the FMPC site and surrounding area, and results of penetrating radiation monitoring performed by the FMPC.

Aerial radiation surveys are performed using thallium-activated sodium iodide radiation detectors, from small airplanes or helicopters, flying at relatively low altitudes (Feimster 1979; Shipman 1985). Because the measurements are made significantly above the ground surface, they are not true measures of the exposure rates at or near (a meter or so above) the ground. However, the results can be used to approximate exposure rates on the ground. When radiation spectrum data are collected, the results can also be used to estimate concentrations of some radionuclides in the soil. For our purposes, the results can help identify where exposure rates outside the site boundary are above background, and help identify the onsite sources of the radiation.

It appears that three aerial radiation surveys have been completed over the FMPC area. An FMPC memorandum (Starkey 1962) indicates that a survey was to be performed at the very end of October, or early in November, 1962. Attached to this memorandum, we found a handwritten drawing of the FMPC area, with count rates (presumably from some type of radiation detector) along what appear to be flight lines east and west across the FMPC area (Anonymous circa 1962). A date on the back of the drawing indicates that it was received by the Atomic Energy Commission in November 1962. The second survey was performed in August 1976 and May to June 1977 (Feimster 1979). The third was performed in April 1985 (Shipman 1985).

Results of the three surveys were qualitatively similar (Anonymous circa 1962; Feimster 1979; Shipman 1979). Over the production area of the FMPC, relatively high exposure rates, to a few hundred  $\mu$ R h<sup>-1</sup>, were measured. From the production area to the boundaries of the site, exposure rates generally decrease to background levels. Very high exposure rates were also measured above the K-65 and Metal Oxide Silos. Exposure rates around the Silos remained somewhat above background at the western boundary of the site. At the FMPC

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

2

いたと

boundary, exposure rates were not significantly above background, except for near the Silos. These elevated offsite exposure rates are ascribed to radiation from the waste storage Silos. A Department of Energy memorandum provides a figure of results of the 1985 survey with the site boundary added, and this also clearly shows offsite exposure rates around the Silos that are greater than background (Stern 1985). From the aerial surveys, it appears the only FMPC sources of offsite, direct radiation are the K-65 and Metal Oxide storage Silos.

In the report of Task 5 of this Project (Shleien et al. 1993), we compiled exposure rate monitoring data from the FMPC annual environmental monitoring reports. Routine, quarterly exposure rate monitoring had been performed at locations on the FMPC boundary since 1976. Figure J-12 shows the monitoring locations. Based on a review of the exposure rate data from 1976 through 1990, we concluded that exposure rates at locations AMS-1 through AMS-5, and AMS-7, were similar to background exposure rates. Only location AMS-6 showed exposure rates that were clearly elevated above background concentrations. The K-65 and Metal Oxide Silos are the closest substantial radiation source to this monitoring location. It again appears that the K-65 and Metal Oxide Silos are the only FMPC sources of offsite, direct radiation.



Figure J-12. Onsite locations of FMPC routine exposure rate monitoring, reported in FMPC annual environmental monitoring reports. Through 1985, locations AMS-1 through AMS-7 were called BS-1 through BS-7, respectively.

3

-

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Calculations of exposure rates to which people were exposed will be performed with the MicroShield 4 computer software (Negin and Worku 1992), using the methodology described in our report of Task 4 of this Project (Killough et al. 1993). In the rest of this section we describe properties of the Silos and the Silo contents, that are required for the MicroShield calculations, including those related to the source and shield geometries, some materials properties for sources and shields, the integration quadrature order (which describes the fineness of the volumetric mesh used for the numerical integrations), material density, moisture content, and radionuclide concentrations. As MicroShield does not support Monte Carlo uncertainty analyses, single values of parameters will be used.

Page J-89

#### **Parameters Applicable to All Calculations**

The Task 4 report (Killough et al. 1993) developed some of the generally applicable parameters required for the MicroShield calculations, including those related to the source and shield geometries, some materials properties for sources and shields, and the integration quadrature order. These generally applicable parameters are summarized in Table J-44. The K-65 Silos are generally modeled as a single Silo, with height equal to twice the physical height. For the period before the addition of berms, the K-65 Silos are modeled as three stacked cylinders: the bottom cylinder representing the K-65 waste material, the middle representing the cylindrical part of the Silo air space, and the top representing the dome part of the air space (more information can be found in the Task 4 Report).

Cylinder g	eometry		Source properties		Shield properties			
designation	height (ft)	radius (ft)	material	density (g cm <sup>-3</sup> )	material	thickness (in)	density (g cm <sup>-3</sup> )	quadrature order <sup>a</sup>
			K-65 Silos	before Ber	ms Added			
dome head space cylinder air space K-65 waste	18.67 <sup>b</sup> 10.8 <sup>b</sup> 42.6 <sup>b</sup>	28.5 40 40	air air concrete	0.001293 0.001293 variable	concrete concrete concrete	9.805 8 8	2.35 2.35 2.35 2.35	10, 10, 10 10, 10, 10 12, 12, 12
			K-65 :	Silos with I	Berms			
dome head space	18.67 <sup>b</sup>	28.5 .	air	0.001293	concrete	9.805	2.35	10, 10, 10
·			Me	tal Oxide S	51lo ·			
waste	31.4	40	concrete	variable	concrete	8	2.35	10, 10, 10

Table J-44. Generally Applicable Input Parameters for MicroShield Calculations

<sup>a</sup> Integration quadrature orders for radial, circumferential, and axial directions.

<sup>b</sup> As mentioned in the text, this height is twice the physical height, to allow the treatment of the two K-65 Silos as a single Silo. This does not apply to the Metal Oxide Silo.

Since the Task 4 work, we have determined that the previously reported quadrature orders for calculations of exposures rates due to the K-65 waste material (Killough et al. 1993; Shleien et al. 1993), are inadequate. The integration quadrature order describes the number of increments into which the source geometry is divided for the numerical

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

オンシー

÷.

ŝ.

100.000

į.

S. S. S.

integrations. For cylindrical sources, we must specify quadrature order for radial, circumferential, and axial directions. As recommended by the MicroShield manual (Negin and Worku 1992), we have made test calculations using a range of quadrature orders. The tests indicate that for the head space sources and the Metal Oxide Silo source, with quadrature orders of 10 for the three parameters, the exposure rate results obtained were within 1% of the results for higher quadrature order of 10 for the radial, circumferential, and axial directions. However, for the K-65 material source (in the Silos), similar tests indicate that quadrature order. Thus, for calculations involving the K-65 material source, we will use a quadrature order. Thus, for calculations involving the K-65 material source, we will use a quadrature order of 12 for the radial, circumferential, and axial for higher quadrature order of 12 for the radial, circumferential, and axial source, we will use a quadrature order of 12 for the radial, circumferential, and axial for higher quadrature order of 12 for the radial, circumferential, and axial source, we will use a quadrature order of 12 for the radial, circumferential, and axial for higher quadrature order of 12 for the radial, circumferential, and axial source, we will use a quadrature order of 12 for the radial, circumferential, and axial directions. These revised values are shown in Table J-44.

#### Silo Fill Fraction

The model for calculations of direct radiation exposures due to the K-65 and Metal Oxide Silos was described in the report of Task 4 of this Project (Killough et al. 1993). Some of the important parameters are the heights of the cylinders used to represent the waste material and Rn and Rn daughters (in head space air) of the Silos, and these are generally invariant. However, during the period when the Silos were still being filled with material, these heights were changing. We account for this by incorporating a silo fill fraction, as follows.

The disposal history of the K-65 Silos was discussed earlier in this Appendix (page J-4). The information located indicates that filling of Silo 1 began in July 1952, filling of Silo 1 was completed and filling of Silo 2 began in June 1953, and filling of Silo 2 was completed in September 1958. We make the assumption that each Silo was filled at a uniform rate between these dates. Since the exact dates are not available, we also assume that the beginning and ending dates are represented by the middle of the month in which they occur. With these assumptions, the silo fill fractions, which are the fraction of the eventual total quantity of waste material that has been placed, are calculated. The estimated, annual average silo fill fractions for each of the two Silos are shown in Table J-45.

As described in the Task 4 report (Killough et al. 1993), the two Silos are generally modeled as a single Silo, but with twice the height. (The justification for modeling the two Silos as a single Silo is provided in that report.) As described in that report, for conditions after filling of both Silos was completed (1959 and later), the heights to be used in the model are 42.6 ft for the cylinder representing the K-65 material, 10.8 ft for the cylinder representing the Rn and daughters in the cylindrical part of the head space air, and 18.7 ft for the cylinder representing the Rn and daughters in the dome part of the head space air. For earlier years (1952–1958), silo fill fractions are applied separately to each silo.

For 1954-1958, when both Silos were in use (by "use" we only mean the Silo was storing material, whether or not material was still being added), the heights of K-65 material in each Silo are estimated by multiplying each fill fraction by 21.3 ft (the height when "full"). The two heights are then summed to get the height to be used for the model. The height to

an sluerdri () Marsult geven () su

. N

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

be used in the model for the cylinder part of the air space is then 53.4 ft minus the combined K-65 material height. The height to be used for the dome part of the sir space is 18.7 ft.

For 1952, only Silo 1 was in use. The height of K-65 material is calculated as the fill fraction multiplied by 21.3 ft. That result is used for the model. The height to be used in the model for the cylinder part of the air space is then 26.7 ft minus the K-65 material height. The height to be used for the dome part of the sir space is 9.3 ft. These model values are only applied to that part of the year for which exposures could have occurred (July through December).

For 1953, part of the year one silo was in use and part of the year two silos were in use. For each Silo, the model heights are first calculated as done for 1952. Since Silo 2 was only in use for about 7 months of the year, the model heights for Silo 2 are then multiplied by 7/12 to give effective model heights. The (effective) model heights for the two Silos are then summed to obtain the total model heights to be used.

These calculated heights, to be used in the model, are also shown in Table J-45.

	Silo fill	fraction	Model heights (ft)ª			
Year	Silo 1	Silo 2	K-65 material	Cylindrical air	Dome air	
1952 <sup>b</sup>	0.23	0.00	4.9	21.8	9.3	
1953	0.89	0.048°	19.5°	22.8°	14.8°	
1954	1.00	0.20	25.5	27.9	18.7	
1955	1.00	0.39	29.6	23.8	18.7	
1956	. <b>1.00</b>	0.58	33.6	19.8	18.7	
1957	1.00	0.77	37.7	15.7	18.7	
1958	1.00	0.95	41.6	11.8	18.7	
1959 and later	1.00	1.00	42.6	10.8	18.7	

# Table J-45. Estimated Annual Average Silo Fill Fractions andCylinder Heights for Modeling K-65 Silos

<sup>a</sup> The "K-65 material" cylinder represents the K-65 material in the Silos. The "cylindrical air" represents that part of the head space that is in the cylindrical part of the Silos. The "dome air" represents that part of the head space in the dome part of the Silos.

<sup>b</sup> Values for 1952 are not annual averages. They apply only to the period July through December, which is the period of emissions, after filling of the Silo began.

<sup>c</sup> The average fill fraction for Silo 2 for 1953, 0.048, is not an annual average. It applies only to June to December, when Silo 2 was in use. The model heights are calculated to be annual averages (heights for Silo 2 were multiplied by 7/12), to be applied to all of 1953.

As shown in the preliminary calculations in our reports of Tasks 4 and 5 of this Project, the Metal Oxide Silo only contributes a small fraction, relative to that from the K-65 Silos, of the exposure rate at locations outside the FMPC boundary (Killough et al. 1993; Shleien et al. 1993). We have not obtained much production information related to the Metal Oxide Silo. In particular, it is not clear when filling of the Metal Oxide Silo was terminated. A document that appears to be a type of progress report or completion report, from the original site construction contractor, indicates that construction of the Metal Oxide Silo and Silo 4 was completed in July 1953 (Catalytic circa 1950s(b)). Details of the history of filling the

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page J-91

#### The Fernald Dosimetry Reconstruction Project , Tasks 2 and 3, Source Terms and Uncertainty

Ξ,

经行

222.2

1

Å

Š,

2

ų

ż

Metal Oxide Silo have not been obtained. Metal oxide materials were generated from the extraction processing (in Plant 2/3) of both uranium ores and other uranium-containing materials (DOE 1990), so metal oxide material could have been placed in Silo 3 earlier than 1955, when ore processing started. Thus, for calculations, we make the assumption that Silo 3 was full in July 1953. This will add a slight positive bias to estimated direct radiation exposure rates. But, because filling of K-65 Silo '1, which contributes more to direct exposures than the Metal Oxide Silo, was complete at this time, the overall impact is thought to be fairly small. If it turns out that this is not the case, additional investigation will be done to better model the filling of the Metal Oxide Silo.

#### Material Densities and Moisture Contents

Earlier in this Appendix we presented data related to characteristics of the K-65 and metal oxide materials. From those data we choose values to be used for the direct exposure calculations.

For the K-65 Silos, bulk densities were reported in only two studies, from 1952 and 1972 (see Table J-4). Although the results from the two studies appear significantly different, it would be difficult to disregard either data set. The range of results from the two studies was  $0.53 \text{ g cm}^{-3}$  to  $1.179 \text{ g cm}^{-3}$ . Since the number of samples involved is quite small, we choose to use the midpoint of this range,  $0.85 \text{ g cm}^{-3}$ , for the direct exposure calculations. For the Metal Oxide Silo, bulk density was reported in only one study (see page J-12). Two densities were reported, a "free flowing" density and a maximum density. We choose to use the free flowing density,  $0.64 \text{ g cm}^{-3}$ , for the direct exposure calculations, because we think it is more representative of the *in situ* density.

We note that these densities seem quite low, relative to typical densities of U mill tailings, of around 1.6 g cm<sup>-3</sup> (Rogers et al. 1984). However, the exact value may not be very important for direct exposure calculations, because of the competing factors of activity and self-shielding. That is, if the density increases, then the total amount of activity emitting radiation increases, but the mass of material shielding that radiation also increases. To evaluate the sensitivity to density, preliminary MicroShield calculations were performed. For the baseline case, we used the radioactivity mass concentrations for Silo 1, the density 0.85 g cm<sup>-3</sup>, and a dose point at a distance of 1100 ft (the site boundary). For the comparison case, we used a density of 1.6 g cm<sup>-3</sup>, the same mass activity concentrations (thus the volume concentrations required for MicroShield were adjusted), and the same distance. The results were exposure rates of  $3.55 \ \mu R \ h^{-1}$  for the baseline case, and  $3.83 \ \mu R \ h^{-1}$  for the density of 1.6 g cm<sup>-3</sup>, a fairly small difference for the large change in density.

As we showed in Table J-4, moisture content in the K-65 material was reported in a few studies. However, the values vary considerably between studies. The range of results for all studies is 21.8% to 90% dry weight. We choose to use the midpoint of this range, 56% dry weight. For the metal oxide material, quantitative results were reported in only one study, although another indicated, qualitatively, that the sample was dry (see page J-11). Since the highest moisture content reported was about 10%, we choose to ignore the moisture content in Silo 3 for the direct exposure calculations.

....

6

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

#### Radionuclide Concentrations in Silo Contents

Earlier in this appendix we discussed concentrations of radionuclides in the K-65 and metal oxide materials (see page J-7 and page J-11). From the radionuclides that have been detected in the K-65 and metal oxide materials, it is clear that all radionuclides in the naturally-occurring thorium, uranium, and actinium decay series should be assumed present. Of course, this is also expected based on the origins of the materials as waste products from uranium ore processing. Table J-5 and Table J-6 show that in the K-65 and metal oxide materials, the  $^{226}$ Ra concentrations are elevated relative to concentrations of other nuclides with gamma radiation emissions (or gamma-emitting daughter nuclides). Thus, the most important nuclides, in terms of potential direct exposures, are  $^{214}$ Pb and  $^{214}$ Bi, two short-lived daughters of  $^{222}$ Rn.

Of the many nuclides in the three decay series, many contribute negligibly to gamma radiation emissions. We have determined, through MicroShield calculations, that  $^{210}$ Pb,  $^{210}$ Bi, and  $^{210}$ Po, which are later daughters of  $^{222}$ Rn, and the short-lived daughters of  $^{227}$ Ac, contribute significantly less than 1% of the calculated exposure rates. Thallium-206 is a pure beta emitter (HEW 1970) and so does not contribute to the gamma radiation emissions. Astatine-218 and  $^{210}$ Tl have branching ratios of 0.02% (HEW 1970) and are thus not significant relative to other daughters of  $^{222}$ Rn in the uranium series. We have chosen to neglect these insignificant radionuclides. Preliminary calculations have indicated that three nuclides,  $^{214}$ Bi,  $^{214}$ Pb, and  $^{208}$ Tl, account for about 95% of the calculated exposure rates. It is clear that we could eliminate more radionuclides from consideration, but we have chosen to retain in calculations those nuclides for which measurements are available, and the short-lived daughters of  $^{220}$ Rn and  $^{220}$ Rn.

In the three decay series, there are a number of radionuclides with short half lives, relative to the storage time of the Silo materials. For these nuclides we assume concentrations equal to the parent nuclide. Table J-46 lists the (remaining) radionuclides to be considered for the K-65 and metal oxide sources, the method used to determine the concentration (either from the measured concentrations or assumed at equilibrium for short-lived daughters), along with the decay fractions for the daughters (HEW 1970).

A few nuclides require further explanation. For the metal oxide material in Silo 3, there are adequate measurements of <sup>231</sup>Pa. However, <sup>231</sup>Pa was not detected in any of the measurements of K-65 material. From the metal oxide measurements, it appears that <sup>231</sup>Pa is in equilibrium with its daughter, <sup>227</sup>Ac. Thus, for the K-65 material we assume that <sup>231</sup>Pa is present at the same concentrations as <sup>227</sup>Ac.

Similarly,  $^{224}$ Ra was not detected in any of the measurements of K-65 material. In addition, the average concentration of  $^{224}$ Ra measured in the metal oxide material seems anomalously low. Because the half life of  $^{224}$ Ra, 3.66 days (Walker et al. 1989), is short relative to the half life of its parent  $^{228}$ Th, 2.913 y (Walker et al. 1989),  $^{224}$ Ra is expected to be present in equilibrium with  $^{228}$ Th. Thus, for both the metal oxide and K-65 material, we assume that  $^{224}$ Ra is present at the same concentration as  $^{228}$ Th.

Further, the half lives of  $^{228}$ Ra, 5.76 y,  $^{228}$ Ac, 6.15 h, and  $^{228}$ Th are relatively short compared to the storage time of over 30 years, and compared to the half life of  $^{232}$ Th,  $1.40 \times 10^{10}$  y (Walker et al. 1989). Thus, these three nuclides are expected to be present (for

Page J-94

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

	·		<u> </u>		
Radionuclide	Determination	Decay fraction	Radionuclide	Determination	Decay fraction
227Ac	measurements	- <u>.</u>	<sup>-224</sup> Ra	daughter of <sup>228</sup> Th	1.00
<sup>228</sup> Ac	daughter of <sup>232</sup> Th	1.00	- 13226Ra	measurements	
<sup>212</sup> Bi	daughter of <sup>228</sup> Th	1.00	228Ra	daughter of <sup>232</sup> Th	1.00
<sup>214</sup> Bi	daughter of <sup>226</sup> Ra	1.00	220Rn	daughter of 228Th	- 1.00
<sup>231</sup> Pa	measurements <sup>a</sup> or	)*	<sup>222</sup> Rn	daughter of <sup>226</sup> Ra	1.00
•	parent of <sup>227</sup> Ac <sup>b</sup>	1.00	228Th	daughter of <sup>232</sup> Th	1.00
<sup>234</sup> Pa	daughter of <sup>238</sup> U	0.0013	230Th	measurements	
234mPa	daughter of <sup>238</sup> U	1.00	<sup>231</sup> Th	daughter of <sup>235</sup> U	1.00
<sup>212</sup> Pb	daughter of <sup>228</sup> Th	1.00	232Th	measurements	
<sup>214</sup> Pb	daughter of <sup>226</sup> Ra	1.00	<sup>234</sup> Th	daughter of <sup>238</sup> U	1.00
<sup>212</sup> Po	daughter of <sup>228</sup> Th	0.640	208 <sub>T</sub> ]	daughter of 228Th	0.360
214Po	daughter of <sup>226</sup> Ra	1.00	:a. 234U	measurements	
216Po	daughter of <sup>228</sup> Th	1.00	235U	measurements	•
<sup>218</sup> Po	daughter of <sup>226</sup> Ra	1.00	238U	measurements	
			-		

Table J-46. Radionuclid	les Considered for K-65	5 and Metal Oxide Material
Source Terms for	<b>MicroShield Direct Ex</b>	posure Calculations

.

<sup>a</sup> For the metal oxide material, adequate measurements are available and are used.

<sup>b</sup> For the K-65 material, <sup>231</sup>Pa was not detected in any measurements. It is assumed in equilibrium with its daughter, <sup>227</sup>Ac.

. . .

recent sampling, anyway) at concentrations equal to the concentration of  $^{232}$ Th. In addition, analyses were not performed for  $^{228}$ Ac,  $^{228}$ Ra was not detected in any of the K-65 samples, and  $^{228}$ Th was only detected in a few of the K-65 samples. Metal oxide samples showed that  $^{228}$ Th concentrations were similar to  $^{232}$ Th concentrations, although  $^{228}$ Ra concentrations appear anomalously low. Thus, for both the metal oxide and K-65 materials, we assume that  $^{228}$ Ra,  $^{228}$ Ac, and  $^{228}$ Th are present at the same concentrations as  $^{232}$ Th.

One of the laboratory analyses was for the combination of <sup>235</sup>U and <sup>236</sup>U. However, <sup>236</sup>U is not a naturally occurring isotope of uranium. Since the K-65 and metal oxide materials were derived from natural ores, <sup>236</sup>U should not be present in these materials. We assume that measurements of <sup>235,236</sup>U represent concentrations of <sup>235</sup>U.

The form of radionuclide concentrations that MicroShield uses is volume concentrations, in units  $\mu$ Ci cm<sup>-3</sup>. To obtain this form, we multiplied the mean mass concentrations, as shown in Table J-5 and Table J-6, by the bulk densities discussed in the previous section. We used the mean concentrations because they are the most representative of the entire volume of material from which the gamma radiations will be emitted. Of course, emissions from material in the center of the Silos, farthest from any wall, will have less impact on direct exposures due to the shielding of the outer material. However, the existing data do not provide information on the radial distribution of radionuclide concentrations. For nuclides that we base on equilibrium assumptions, the measured concentration of the base radionuclide was also multiplied by the decay fraction. The results of these conversions are shown in Table J-47 and Table J-48 for the K-65 material and metal oxide material, respectively.

and a second second second

3

÷.

.

17

Page J-95

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

Radionuclide	Concentration (µCi cm <sup>-3</sup> )	Basis	Radionuclide	Concentration (µCi cm <sup>-3</sup> )	Basis				
227 Ac 228 Ac 212 Bi 214 Bi 231 Pa 234 Pa 234 mPa 212 Pb 214 Pb 212 Po 214 Po 216 Po 218 Po 224 Ra	$\begin{array}{c} 6.51\times10^{-3}\\ 9.19\times10^{-4}\\ 9.19\times10^{-4}\\ 3.54\times10^{-1}\\ 6.51\times10^{-3}\\ 9.52\times10^{-7}\\ 7.32\times10^{-4}\\ 9.19\times10^{-4}\\ 3.54\times10^{-1}\\ 5.88\times10^{-4}\\ 3.54\times10^{-1}\\ 9.19\times10^{-4}\\ 3.54\times10^{-1}\\ 9.19\times10^{-4}\\ \end{array}$	measured equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium	226 Ra 228 Ra 220 Rn 222 Rn 228 Th 230 Th 231 Th 232 Th 232 Th 234 Th 208 Tl 234 U 235 U 238 U	$\begin{array}{c} 3.54 \times 10^{-1} \\ 9.19 \times 10^{-4} \\ 9.19 \times 10^{-4} \\ 3.54 \times 10^{-1} \\ 9.19 \times 10^{-4} \\ 5.73 \times 10^{-2} \\ 5.59 \times 10^{-5} \\ 9.19 \times 10^{-4} \\ 7.32 \times 10^{-4} \\ 3.31 \times 10^{-4} \\ 8.56 \times 10^{-4} \\ 5.59 \times 10^{-5} \\ 7.32 \times 10^{-4} \end{array}$	measured equilibrium equilibrium equilibrium measured equilibrium measured equilibrium equilibrium measured measured measured				

Table J-47. Radionuclide Concentrations in K-65 Material: for Use in MicroShield Direct Exposure Calculations

Table J-48. Radionuclide Concentrations in Metal Oxide Material: for Use in MicroShield Direct Exposure Calculations

Radionuclide	Concentration (µCi cm <sup>-3</sup> )	Basis	Radionuclide	Concentration (µCi cm <sup>-3</sup> )	Basis
227 Ac 228 Ac 212 Bi 214 Bi 231 Pa 234 Pa 234 mPa 212 Pb 214 Pb 212 Po 214 Po 216 Po 218 Po 218 Po 224 Ra	$\begin{array}{c} 3.72 \times 10^{-4} \\ 5.01 \times 10^{-4} \\ 5.01 \times 10^{-4} \\ 1.90 \times 10^{-3} \\ 3.57 \times 10^{-4} \\ 1.25 \times 10^{-6} \\ 9.60 \times 10^{-4} \\ 5.01 \times 10^{-4} \\ 1.90 \times 10^{-3} \\ 3.21 \times 10^{-4} \\ 1.90 \times 10^{-3} \\ 5.01 \times 10^{-4} \\ 1.90 \times 10^{-3} \\ 5.01 \times 10^{-4} \\ 1.90 \times 10^{-3} \\ 5.01 \times 10^{-4} \end{array}$	measured equilibrium equilibrium measured equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium equilibrium	226 Ra 228 Ra 220 Rn 222 Rn 228 Th 230 Th 231 Th 231 Th 232 Th 232 Th 234 U 235 U 238 U	$\begin{array}{c} 1.90 \times 10^{-3} \\ 5.01 \times 10^{-4} \\ 5.01 \times 10^{-4} \\ 1.90 \times 10^{-3} \\ 5.01 \times 10^{-4} \\ 3.28 \times 10^{-2} \\ 6.39 \times 10^{-5} \\ 5.01 \times 10^{-4} \\ 9.60 \times 10^{-4} \\ 1.80 \times 10^{-4} \\ 9.46 \times 10^{-4} \\ 9.46 \times 10^{-5} \\ 9.60 \times 10^{-5} \\ 9.60 \times 10^{-4} \end{array}$	measured equilibrium equilibrium equilibrium measured equilibrium measured equilibrium equilibrium measured measured measured

#### Radionuclide Concentrations in K-65 Silos Head Spaces

The direct exposures calculations also require information about the radionuclides present in the head space gases of the Silos. Since the Metal Oxide Silo was almost completely filled with waste materials, we consider its head space volume to be negligible.

For the K-65 Silos, the head space volume is significant. The Silos were relatively closed to the environment, even before the dome penetrations were sealed. Thus, there would have

#### The Fernald Dosimetry Reconstruction Project ALE AND Marks 2 and 3, Source Terms and Uncertainty

Ş

à

ें स

.

been little r: nent of air in the head space, and thus little resuspension of particulate material fr the surface of the K-65 material into the head space. Thus the only radionuclide tresent in the head spaces of the K-65 Silos would have been <sup>222</sup>Rn, which diffused out to the K-65 material, and the short-lived daughters of <sup>222</sup>Rn, <sup>218</sup>Po, <sup>214</sup>Pb, <sup>214</sup>Bi, and <sup>214</sup>Po, which are produced by the decay of the Rn. From work discussed in our Task 4 Report (Killough et al. 1993), we found that the later Rn daughters, <sup>210</sup>Pb, <sup>210</sup>Bi, and <sup>210</sup>Po, do not contribute significantly to direct exposures. These later daughters are not considered for the head space.

Earlier in this Appendix we discussed the  $^{222}$ Rn concentrations in the head spaces of the K-65 Silos. For the period 1980–1987, we determined the mean  $^{222}$ Rn concentrations based on measurements made in 1987 (see page J-29). For 1959–1979, we calculated the median Rn concentrations (see page J-45). For the earliest time period, 1952–1958, the concentrations used are the same as for 1959–1979; but recall that different heights of the K-65 material and head space are applied in the exposure calculations. For 1988, the concentrations used are the same as for 1950–1987. Because the ventilation rates of the Silo head spaces are quite low, we assume that the Rn daughters in the head space and deposited on surfaces in the Silo are in equilibrium with the Rn in the head space. We assume that the daughters are uniformly distributed in the head space gas, although some of the daughters would be plated out on the Silo walls and dome. However, since the source media in this case is air, which will provide little attenuation, the exact distribution of the radionuclides is not important. Thus, the concentrations of Rn daughters are assumed the same as the concentrations of Rn. The Rn and Rn daughter concentrations in head space to be used for direct exposure calculations are shown in Table J-49.

,		Concentrati	Concentration ( $\mu$ Ci cm <sup>-3</sup> )					
	Period	222Rn	<sup>222</sup> Rn daughters <sup>a</sup>					
1.	1952-1958	$2.5 \times 10^{-3}$	$2.5 \times 10^{-3}$					
	1959-1979	$2.5 \times 10^{-3}$	$2.5 \times 10^{-3}$					
· · .	1980-1987	$2.62 \times 10^{-2}$	$2.62 \times 10^{-2}$					
•	1988	$2.62 \times 10^{-2}$	$2.62 \times 10^{-2}$					

# Table J-49. Radionuclide Concentrationsin K-65 Silos Head Spaces: for Use inMicroShield Direct Exposure Calculations

<sup>a</sup> Concentrations of each of the short-lived daughters <sup>218</sup>Po, <sup>214</sup>Pb, <sup>214</sup>Bi, and <sup>214</sup>Po.

and and an annual state of the second second state states and state The second states and st

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

#### REFERENCES

- Anonymous. Handwritten drawing of FMPC area, with recorded exposure rate measurements, which appear to be from aerial survey. Circa November 1962.
- ASI/IT (ASI and IT Corporation). Radiological validation qualifiers for OU4. Tables of results of radiological analyses on samples, from the ASI/IT database. Fernald, Ohio: ASI/IT; 21 and 24 August 1992.

Belmore, F. M. K-65 temporary storage operation. Letter to G. W. Wunder, National Lead Company. New York, New York: New York Operations Office, U.S. Atomic Energy Commission; 30 July 1951.

Blythe, D. J. K-65 shipments. Letter to G. W. Wunder. New York, New York: National Lead Company; 13 September 1951.

BNI (Bechtel National, Inc.). Study and evaluation of K-65 silos for the Feed Materials Production Facility at Fernald, Ohio. Oak Ridge, Tennessee: Bechtel National, Inc.; Bechtel Job No. 14501; January 1990.

- Boback, M. W. Survey of K-65 silos. Handwritten radiation survey schematic. Cincinnati, Ohio: National Lead Company of Ohio; 10 May 1973.
- Boback, M. W. Gamma levels inside K-65 tank. Internal memorandum to R. C. Heatherton. Cincinnati, Ohio: National Lead Company of Ohio; 11 September 1978.
- Boback, M. W. Plans for FMPC radon monitoring and control. Internal memorandum to R. C. Heatherton. Cincinnati, Ohio: National Lead Company of Ohio; 14 May 1979.
- Boback, M. W. K-65 storage tanks. Internal memorandum to J. H. Cavendish. Cincinnati, Ohio: National Lead Company of Ohio; 20 May 1980 (1980a).
- Boback, M. W. Control of radon by tank sealing. Internal memorandum to J. H. Cavendish. Cincinnati, Ohio: National Lead Company of Ohio; 9 June 1980 (1980b).
- Boback, M. W.; Dugan, T. A.; Fleming, D. A.; Grant, R. B.; Keys, R. W. History of FMPC radionuclide discharges. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; FMPC-2082 (revision to FMPC-2058); 1987.
- Borak, T. B. Calculation of radon emission, dispersion and dosimetry from K65 Storage Tanks at the Feed Materials Production Center. October 1985. In: Boback, M. W.; Dugan, T. A.; Fleming, D. A.; Grant, R. B.; Keys, R. W. History of FMPC radionuclide discharges. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; FMPC-2082 (revision to FMPC-2058); 1987.
- Borak, T. B. Reply to comments by the EPA concerning Appendix I in history of FMPC radionuclide discharges. June 1986.
- Byrne, J. M. Letter, with enclosed computer disks, to Duane W. Schmidt. Cincinnati, Ohio: Westinghouse Environmental Management Company of Ohio; reference number WEMCO:EM:EMON:92-1274; 31 August 1992 (1992a).
- Byrne, J. M. Letter, with enclosed computer disk and drawings of Rn monitoring locations, to Duane W. Schmidt. Cincinnati, Ohio: Westinghouse Environmental Management Company of Ohio; reference number WEMCO:EM:EMON:92-1344; 15 September 1992 (1992b).

11

.

211-102.4

1002002

1. - N. A. S. A. S.

į

- Byrne, J. M. Letter, with enclosed computer disk, to Duane Schmidt. Cincinnati, Ohio: Westinghouse Environmental Management Company of Ohio; reference number WEMCO:EM:EMON:92-1400; 30 September 1992 (1992c).
- Byrne, J. M.; Dugan, T. A.; Oberjohn, J. S. Feed Materials Production Center annual environmental report for calendar year 1990. Cincinnati, Westinghouse Materials Company of Ohio; Rep. FMPC-2245; 1991.
- Camargo (Camargo Associates, Limited). NLO, Inc., K-65 silos study and evaluation, Fernald, Ohio. Volume 1, sections I through IX. 1986.
  - Catalytic (Catalytic Construction Company). Job unit no. 3034, K-65 handling and storage area. Appears to be part of a construction progress report or completion report. Philadelphia, Pennsylvania: Catalytic Construction Company; circa 1950s(a).

Catalytic (Catalytic Construction Company). Job unit no. 3035, metal oxide storage farm. Appears to be part of a construction progress report or completion report. Philadelphia, Pennsylvania: Catalytic Construction Company; circa 1950s(b).

- Collé, R.; Rubin, R. J.; Knab, L. I.; Hutchinson, J. M. R. Radon transport through and exhalation from building materials: a review and assessment. Washington, D.C: National Bureau of Standards, U.S. Department of Commerce; NBS Technical Note 1139; 1981.
- Consiglio, J. T. Procedures for handling African Metals Corporation materials at Fernald area. New York, New York: New York Operations Office, U.S. Atomic Energy Commission; August 1952.
- Davis, P. K-65 startup. Internal memorandum to R. C. Heatherton. Cincinnati, Ohio: National Lead Company of Ohio; circa 19 July 1952.
- Decisioneering, Inc. Crystal Ball<sup>®</sup> for Windows, user's manual. 1727 Conestoga Street, Boulder, Colorado 80301: Decisioneering, Inc. 1992.
- DOE (U.S. Department of Energy). Aerial photograph of the waste storage silos area of the FMPC, taken from the southwest. Oak Ridge, Tennessee: Oak Ridge Operations, U.S. Department of Energy; negative 65-467; 1965 (1965a).
- DOE (U.S. Department of Energy). Aerial photograph of the waste storage silos area of the FMPC, taken from the north. Oak Ridge, Tennessee: Oak Ridge Operations, U.S. Department of Energy; negative 65-739; 1965 (1965b).
- DOE (U.S. Department of Energy). Investigation of April 25, 1986 radon gas release from Feed Materials Production Center K-65 silos. DOE Incident Investigation Board; Rep. DOE/OR-877; 27 June 1986.
- DOE (U.S. Department of Energy). Aerial photograph of the waste storage silos area of the FMPC, taken from the north. Oak Ridge, Tennessee: Oak Ridge Operations, U.S. Department of Energy; negative 87-457; 1987.
- DOE (U.S. Department of Energy). Remedial investigation report for operable unit 4, task 6 report, Feed Materials Production Center, Fernald, Ohio, remedial investigation and feasibility study. Draft final. Oak Ridge, Tennessee: U.S. Department of Energy; October 1990.
- DOE (U.S. Department of Energy). Remedial investigation report for operable unit 4, Fernald Environmental Management Project, Fernald, Ohio, remedial investigation and

1

•

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

feasibility study. Final report. Volumes 1, 2, and 3 of 3. DOE, Fernald Field Office; November 1993.

- Dougherty, W. J; Jennings, A. S. Process engineering report, operating manual for K-65 storage area, part no. IX, section no. 24-3, job no. 3034, of the Feed Materials Production Center - Fernald, Ohio. Philadelphia, Pennsylvania: Catalytic Construction Company; circa November 1951.
- Feimster, E. L. An aerial radiological survey of the area surrounding the Feed Materials Production Center, Fernald, Ohio: dates of surveys: August 1976 / May-June 1977. EG&G Energy Measurements Group; rep. EGG-1183-1680; June 1979.
- Fleming K. N. Survey of the K-65 area Friday, April 18, 1986. Internal memorandum to S. L. Hinnefeld. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; WMCO:EH(HP):86:0086; 23 April 1986.
- Geesner, T. J. K-65 storage, K-65 tank embankment stabilization, general layout. Revision 1. Fernald, Ohio: NLO, Inc.; FMPC drawing index code 34X-1450-G-00084. 14 July 1983.
- Gill, V. R. Analytical results on K-65 probe samples. Letter to B. L. Speicher. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; WMCO:AN:88-162; 29 August 1988.
- Grant, R.; Stevens, G. Gamma survey of K-65 tanks. Handwritten note of radiation survey. Cincinnati, Ohio: NLO, Inc.; 19 May 1982.
- Green, L. E. Gamma survey of K-65 waste storage tanks. Internal memorandum to M. W. Boback. Cincinnati, Ohio: National Lead Company of Ohio; 25 April 1980 (1980a).
- Green, L. Handwritten note of radiation survey. Cincinnati, Ohio: National Lead Company of Ohio; 26 November 1980 (1980b).
- Grumski, J. T. Feasibility investigation for control of radon emission from the K-65 Silos. Revision 1. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; 30 July 1987 (1987a).
- Grumski, J. T. Summary, K-65 Silo 1 flange changeout operation. Internal report. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; 9 November 1987 (1987b).
- Grumski, J. T.; Shanks, P. A. Completion report, K-65 interim stabilization project, exterior foam application/radon treatment system operation. Draft report. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; 1988.
- Hagee, G. R.; Jenkins, P. H.; Gephart, P. J.; Rudy, C. R. Radon and radon flux measurements at the Feed Materials Production Center, Fernald, Ohio. Miamisburg, Ohio: Mound, Monsanto Research Corporation; Rep. MLM-MU-85-68-0001; 1985.
- Hamilton, L. D.; Meinhold, A. F.; Baxter, S. L.; Holtzman, S.; Morris, S. C.; Pardi, R.; Rowe, M. D.; Sun, C. Pilot study risk assessment for selected problems at the Fernald Environmental Management Project (FEMP). Upton, New York: Brookhaven National Laboratory; rep. BNL-48777, revised; May 1993.
- Heatherton, R. C. K-65 tank improvements. Internal memorandum to W. J. Adams. Cincinnati, Ohio: National Lead Company of Ohio; 26 April 1979.
- HEW (U.S. Department of Health, Education, and Welfare). Radiological health handbook. Rockville, Maryland: Public Health Service, HEW; 1970.

4

IT (IT Corporation). Appendix F, Radon dose and risk assessment for the Feed Materials Production Center, Fernald, Ohio. In: Assessment of radiation dose and cancer risk for emissions from 1951 through 1984, Feed Materials Production Center, Fernald, Ohio. Oak Ridge, Tennessee: IT Corporation; Project 303063; 1989.

Jarvis, D. Personal communication with D. W. Schmidt, consultant to Radiological Assessments Corporation. Knoxville, Tennessee: IT Corporation; 22 September 1992.

Jonassen, N.; McLaughlin, J. P. Exhalation of radon-222 from building materials and walls. In: The radiation environment III. Washington, D.C.: U.S. Department of Energy; CONF-780422; 1978. (Cited in Borak 1986).

- Killough, G. G.; Case, M. J.; Meyer, K. R.; Moore, R. E.; Rogers, J. F.; Rope, S. K.; Schmidt, D. W.; Shleien, B.: Till, J. E.; Voillequé, P. G. The Fernald dosimetry reconstruction project, task 4: environmental pathways models and validation. Draft report for comment. Neeses, South Carolina: Radiological Assessments Corporation; Rep. CDC-3; February 1993.
- Krisiuk, E. M.; Tarasov, S. I.; Shomov, V. P.; Sholok, N. I.; Lisachenko, E. P.; Gomelsky, L. G. A study of radioactivity in building materials. Leningrad, U.S.S.R.: Research Institute for Radiation Hygiene; 1971. (Cited in Borak 1986).
- Levy, L. M. Minutes of meeting, March 21, 1972. Internal memorandum to attendees. Cincinnati, Ohio: National Lead Company of Ohio; 23 March 1972.
- Levy, L. M. K-65. Handwritten memorandum to files. Cincinnati, Ohio: National Lead Company of Ohio; 23 July 1973.
- Litz, J. E. Treatment of pitchblende residues for recovery of metal values. Golden, Colorado: Hazen Research, Inc.; 1974.
  - Lynch, J. R. Q-11 campaigns. Handwritten spréadsheets. Cincinnati, Ohio: Feed Materials Production Center; circa 1958.
  - Madoffori, J. K-65 inventory. Internal memorandum to P. C. Feist. Cincinnati, Ohio: Feed Materials Production Center; 29 September 1955 (1955a).
  - Madoffori, J. K-65 inventory. Internal memorandum to P. C. Feist. Cincinnati, Ohio: Feed Materials Production Center; 28 October 1955 (1955b).
  - Madoffori, J. K-65 inventory. Internal memorandum to P. C. Feist. Cincinnati, Ohio: Feed Materials Production Center; 29 November 1955 (1955c).
  - Martin, H. K-65 storage tanks. Internal memorandum to A. Stewart. Cincinnati, Ohio: National Lead Company of Ohio; 8 November 1957.
  - Nazaroff, W. W.; Nero, A. V., eds. Radon and its decay products in indoor air. New York: John Wiley & Sons; 1988.

NCDC (National Climatic Data Center). Hourly weather observation data for the Greater Cincinnati, Ohio, Airport for 1948 through 1991. Asheville, North Carolina: NCDC, National Oceanic and Atmospheric Administration, U. S. Department of Commerce; 1991.

NCRP (National Council on Radiation Protection and Measurements). Measurement of radon and radon daughters in air. Bethesda. Maryland: National Council on Radiation Protection and Measurements; NCRP Report No. 97; 1988.

A det in the

۰,

ز .

ς,

Page J-101

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

- NCRP (National Council on Radiation Protection and Measurements). Control of radon in houses. Bethesda, Maryland: National Council on Radiation Protection and Measurements; NCRP Report No. 103; 1989.
- Negin, C. A.; Worku, G. MicroShield, version 4, user's manual. Rockville, Maryland 20850: Grove Engineering, Inc., 15215 Shady Grove Road, Suite 200; Rep. Grove 92-2; 1992.
- Nelson, M. S. K-65 area survey results and actions. Letter to C. L. Karl, U.S. Atomic Energy Commission. Cincinnati, Ohio: National Lead Company of Ohio; 10 March 1972 (1972a).
- Nelson, M. S. U content of silos. Letter to C. A. Keller, Uranium Enrichment Division, U.S. Atomic Energy Commission. Cincinnati, Ohio: National Lead Company of Ohio; 21 September 1972 (1972b).
- Nielson, K. K.; Rogers, V. C. A mathematical model for radon diffusion in earthen materials. Salt Lake City, Utah: Rogers & Associates Engineering Corporation; NUREG/CR-2765, PNL-4301, RAE-18-2; 1982.
- NLCO (National Lead Company of Ohio). Manual for the K-65 area, including tanks and building (a standby facility) at the U.S. Atomic Energy Commission's Feed Materials Production Center at Fernald, Ohio. National Lead Company of Ohio; August 1962.
- NLCO (National Lead Company of Ohio). K-65 storage, earth embankment at K-65 tanks, plan. Fernald, Ohio: NLCO; drawing number 34-4013; FMPC drawing index code 34X-5500-M-00066. 2 December 1963.
- NLCO (National Lead Company of Ohio). Report of chemical analyses; Lab. Nos. 1-8441 and 1-8442. Cincinnati, Ohio: National Lead Company of Ohio; 7 September 1972.
- NLCO (National Lead Company of Ohio). Monthly project record file for project 34-9, repair of K-65 storage tanks. Handwritten records of project status from October 1963 through May 1984. National Lead Company of Ohio; 1984.
- Noyes, J. H. Letter to C. L. Karl, U.S. Atomic Energy Commission. Cincinnati, Ohio: National Lead Company of Ohio; 25 September 1958.
- Noyes, J. H. Progress photographs on protective work at K-65 tanks. Letter to C. L. Karl, U.S. Atomic Energy Commission. Cincinnati, Ohio: National Lead Company of Ohio; 1 May 1964.
- NRC (U.S. Nuclear Regulatory Commission). Final generic environmental impact statement on uranium milling, project M-25. Washington, D.C.: Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission; NUREG-0706, Volume II. 1980.
- Paine, D. Comments on draft Radiological Assessments Corporation (RAC) report CDC-5 for the Fernald Dosimetry Reconstruction Project. Letter, with attached comments, to J. Till, Radiological Assessments Corporation. Cincinnati, Ohio: Fernald Environmental Management Corporation; letter C:ESH:94-0029; 11 March 1994.
- Preload (Preload Enterprises, Inc.). Two 125,000 c.f. slurry storage tanks type K65, Atomic Energy Commission, Fernald, Ohio, Catalytic Construction Co. Revision 4. New York: Preload; drawing number 51T20-3; FMPC drawing index code 34X-1450-A-00086; 15 September 1951 (1951a).
- Preload (Preload Enterprises, Inc.). Two 125,000 c.f. slurry storage tanks type K65, Atomic Energy Commission, Fernald, Ohio, details. Revision 3. New York: Preload; drawing number 51T20-7; FMPC drawing index code 34X-1450-P-00090; 25 September 1951 (1951b).

<u>م---</u>

÷.,

34

Ę.

2

i.

にないたい

Ş

.

~~~~~

4

- Rogers, V. C.; Nielson, K. K.; Kalkwarf, D. R. Radon attenuation handbook for uranium mill tailings cover design. Salt Lake City, Utah: Rogers & Associates Engineering Corporation; NUREG/CR-3533, PNL-4878, RAE-18-5; 1984.
- Shanks, P. A. Volume of air space of K-65 silos, method 1. Unpublished calculations. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; 14 December 1988.
- Shanks, P. Spreadsheet table of K-65 silo temperature and pressure monitoring data taken March to May, 1987. Personal communication from P. Shanks to D. W. Schmidt. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; 25 April 1991.
- Shanks, P. A.; Vogel, R. A. The K-65 waste storage silos at the Feed Materials Production Center. Paper for presentation at the DOE Model Conference, Oak Ridge, Tennessee, October 3-7, 1988. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; FMPC-2142; September 1988.
  - Shipman, G. R. An aerial radiological survey of the Feed Materials Production Center and surrounding area, Fernald, Ohio: date of survey: April 1985. EG&G Energy Measurements; rep. EGG-10282-1084; October 1985.
  - Shleien, B, ed. The health physics and radiological health handbook, revised edition. Silver Spring, Maryland: Scinta, Inc.; 1992.
  - Shleien, B.; Rope, S. K.; Case, M. J.; Killough, G. G.; Meyer, K. R.; Moore, R. E.; Schmidt, D. W.; Till, J. E.; Voillequé, P. G. The Fernald Dosimetry Reconstruction Project, task 5: review of historic data and assessments for the FMPC. Draft report for comment. Neeses, South Carolina: Radiological Assessments Corporation; Rep. CDC-4; May 1993.
  - Solow, A. J.; Phoenix, D. R. Characterization investigation study, volume 2: chemical and radiological analyses of the waste storage pits. West Chester, Pennsylvania: Roy F. Weston, Inc.; rep. FMPC/SUB 008, vol. 2; November 1987.
  - Starkey, R. H. Aerial radiological measuring survey FMPC area. Internal memorandum to J. H. Noyes. Cincinnati, Ohio: National Lead Company of Ohio; 30 October 1962.
  - Starkey, R. H. IH&R Department monthly report for April, 1964. Internal memorandum to J. A. Quigley. Cincinnati, Ohio: National Lead Company of Ohio; 8 May 1964.
  - Stern, R. J. Aerial radiation survey of the Feed Materials Production Center, Fernald, Ohio. Memorandum to W. A. Vaughn. U.S. Department of Energy [not explicit; determined from contents of memo]; Environment, Safety, and Health; circa 1985.
  - Strattman, W. J. Storage tanks for K-65. Internal memorandum to D. J. Blythe. Cincinnati, Ohio: National Lead Company of Ohio; 12 November 1953.
  - Strattman, W. J. K-65 dumping operation K-65 area. Internal memorandum to C. R. Chapman. Cincinnati, Ohio: National Lead Company of Ohio; 6 April 1955.
  - Tomczak, L. M. Personal communication with D. W. Schmidt, consultant to Radiological Assessments Corporation. Cincinnati, Ohio: Fernald Environmental Restoration Management Corporation; 6 June 1994.
  - Tomczak, L. M.; Gore, J. C.; Lohner, W. G.; Smith, J. E.; Emerich, F. J. Pit 4, radon flux measurement. Cincinnati, Ohio: Fernald Environmental Restoration Management Corporation; December 1992.
  - Voillequé, P. G.; Meyer, K. R.; Schmidt, D. W.; Killough, G. G.; Moore, R. E.; Ichimura, V. I.; Rope, S. K.; Shleien, B.; Till, J. E. The Fernald Dosimetry Reconstruction Project, tasks

.

Page J-103

#### Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

2 and 3: radionuclide source terms and uncertainties — 1960–1962. Draft interim report for comment. Neeses, South Carolina: Radiological Assessments Corporation; Rep. CDC-2; December 1991.

- Walden, C. H. K-65 receipts. Internal memorandum to G. W. Wunder. Cincinnati, Ohio: National Lead Company of Ohio; 31 July 1952.
- Walker, F. W.; Parrington, J. R.; Feiner, F. eds. Nuclides and isotopes: chart of the nuclides. 14th ed. San Jose, California: General Electric Company; 1989.
- WEMCO (Westinghouse Environmental Management Company of Ohio). Annual site environmental report for calendar year 1991. Cincinnati, Ohio: WEMCO; FEMP-2275; December 1992.
- Woolpert Consultants. Fernald facility, Department of Energy, Fernald, Ohio. Set of 17 topographic maps. Dayton, Ohio: Woolpert Consultants; FMPC drawing index codes 75X-5500-G-00112 through 75X-5500-G-00128; circa 1988.

Wunder, G. W. Preload concrete storage tanks. Letter to C. L. Karl, U.S. Atomic Energy Commission. Cincinnati, Ohio: National Lead Company of Ohio; 23 August 1954.

1

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

5.4

٠.

F

0.1111

\$197.14 1

ł,

### ANNEX 1 TO APPENDIX J

## MEASURED RADON CONCENTRATIONS AT K-65 AREA FENCELINE

| Nominal period | Monitoring Dates   | K65 A  | K65 B        | K65 C                              | K65 D | K65 E        | K65 F | K65 G | K65 H |
|----------------|--------------------|--------|--------------|------------------------------------|-------|--------------|-------|-------|-------|
| 2nd qtr 1987   | 03/04/8706/10/87   | 9.6    | 16.2         | 14.9                               | 10.6  | 8.3          | 11.3  | 4.2   | 2.7   |
| 3rd qtr 1987   | 06/11/87-09/05/87  | 5.4    | • 10.8 · C   | 11.2                               | 11.5  | <b>6.7</b> , | .11   | .4.3  | 2.6   |
| 4th qtr 1987 🔅 | 09/06/87-01/07/88  | 3.2 🦯  | 7.2 de       | . 6.1                              | 6.8   | 4.5          | 3.7   | 1.8   | 2.9   |
| 1st gtr 1988   | ~ 01/08/8803/05/88 | 4.55   | 4.75         | ,                                  | 3.1   | 5.2          | 2.1   | 1.9   | 4.25  |
| 2nd qtr 1988   | 03/06/8806/02/88   | 3.3    | 3.2          | ° 3.8 –                            | 5.1   | 3.9          | 3.3   | 2.45  | 3.4   |
| 3rd qtr 1988   | 06/03/8809/03/88   | 9.4    | <b>`9.25</b> | 4.2                                | 13.5  | 4.0          | 3.55  | 2.6   | 4.35  |
| 4th gtr 1988   | 09/04/8802/01/89   | 4.25   | 6.4          | 9.15                               | 16.95 | 17.25        | 12.85 | •     | 5.8   |
| 1st gtr 1989   | 02/02/89-03/05/89  | 3.9    | 3.95         | ···8.3                             | 7.1   | 9.45         | 15.2  | 3.6   | 3.65  |
| 2nd qtr 1989   | 03/06/89-06/11/89  | 2.15   | 2.15         | 3.0                                | 4.6   | 3.9          | 4.35  | 1.85  | 2.25  |
| 3rd atr 1989   | 06/12/8909/11/89   | 3.3    | -2.45        | 4.7 -                              | 6.25  | 5.1          | 5.05  | 3.0   | 7.2   |
| 4th atr 1989   | 09/12/89-01/24/90  | 4.0    | 8.65         | 7.25                               | 6.35  | 3.35         |       | 7.9   | 5.4   |
| 1st gtr 1990   | 01/25/90-03/02/90  | 4.05   | 11.45        | 6.0                                | 4.4   | 1.11         | 2.25  | 3.3   | 1.25  |
| 2nd atr 1990   | 03/03/90-07/04/90  | 2.95   | 4.3 '        |                                    | 3.85  | 2.75         | 2.85  | 2.15  | 2.55  |
| 3rd qtr 1990   | 07/04/90-10/12/90  | 2.05   | 2.5          | 3.1                                | 3.65  | 3.75         | 3.75  | 2.95  | 1.65  |
| 4th qtr 1990   | 10/12/90-01/07/91  | 2.7 `` | 4.55         | 2.75                               | 3.05  | 2.25         | 3.5   | · 2.5 | 1.7   |
| 1st gtr 1991   | 01/08/91-03/08/91  | 2.8    | 4.7          | 4.3                                | 5.4   | 4.7          | 5.1   | 3.9   | 2.6   |
| 2nd qtr 1991   | 03/09/91-07/02/91  | 8.7    | 6.6          | , 12.6                             | 6.8   | 4.7          | 5.5   | 3.5   | 3.3   |
| 3rd qtr 1991   | 07/02/91-10/01/91  | 8.7    | 42.9         | 32                                 | 6.2   | 8.6          | 18    | 1.9   | 2.2   |
| 4th atr 1991   | 10/01/91-01/07/92  | 16.9   | 12.6         | <sup>**</sup> 15.1 <sup>****</sup> | 15.5  | 15.5         | 14.5  | . 8.9 | 3.8   |

Table J1-1. Average <sup>222</sup>Rn Concentrations (pCi L<sup>-1</sup>) at K-65 Area Fenceline Monitoring Stations; Results from FMPC Routine Monitoring<sup>a</sup>

Table J1-1. Average <sup>222</sup>Rn Concentrations (pCi L<sup>-1</sup>) at K-65 Area Fenceline Monitoring Stations; Results from FMPC Routine Monitoring (continued)<sup>a</sup>

| Nominal period | Monitoring Dates  | K65 I | K65 J        | K65 K | K65 L | K65 M           | K65 N | K65 O | K65 P | Mean <sup>b</sup> |
|----------------|-------------------|-------|--------------|-------|-------|-----------------|-------|-------|-------|-------------------|
| 2nd qtr 1987   | 03/04/87-06/10/87 | 3.4   | 4.7          | 5.8   | 12.5  | 12.1            | 10.2  | 7.8   | 6.8   | 8.82              |
| 3rd qtr 1987   | 06/11/87-09/05/87 | 3.7   | 3.1          | 3.7   | 5.0   | 4.2             | 3.9   | 2.9   | 2.2   | 5.76              |
| 4th qtr 1987   | 09/06/87-01/07/88 | 3.6   | <b>4.1</b> · | •     | 5.1   | 4.5             | 6.3   | 6.7   | 5.1   | 4.77              |
| 1st qtr 1988   | 01/08/88-03/05/88 | 4.8   | 5.9          | 3.85  | 6.55  | 4.1             | 4.45  | 3.3   | 2.3   | 4.07              |
| 2nd qtr 1988   | 03/06/8806/02/88  | . 5.0 | 3.6          | 4.6   | 6.75  | 5.4             | 4.0 · | 3.05  | 2.95  | 3.99              |
| 3rd qtr 1988   | 06/03/8809/03/88  | 2.55  | 3.15         | ·4.3  | 8.6   | 5.35            | 3.65  | 4.0   | 2.8   | 5.33              |
| 4th qtr 1988   | 09/04/88-02/01/89 | 5.65  | 4.05         | 3.45  | 26.5  | 19              | 9.55  | 6.75  | 4.7   | 10.15             |
| 1st gtr 1989   | 02/02/89-03/05/89 | 4.7   | 4.95         | 7.3   | 10.65 | 10.95           | 14.2  | 5.85  | 3.75  | 7.34              |
| 2nd qtr 1989   | 03/06/89-06/11/89 | 2.75  | 3.0          | 3.5   | 7.5   | 5.25            | 3.5   | 2.85  | 2.8   | 3.46              |
| 3rd qtr 1989   | 06/12/89-09/11/89 | ·     | 3.0          | 4.95  | 9.5   | 4.35            | 4.6   | 2.9   | 1.45  | 4.52              |
| 4th qtr 1989   | 09/12/89-01/24/90 | 5.7   | 6.55         | 5.5   | 10.85 | 7.5             | 4.4   | 5.15  | 2.05  | 6.04              |
| 1st qtr 1990   | 01/25/9003/02/90  | 1.8   | 1.5          | 2.9   | 2.3   | 2. <del>9</del> | 2.6   | 2.05  | 1.8   | 3.37              |
| 2nd qtr 1990   | 03/03/90-07/04/90 | 2.2   | 1.15         | 1.45  | 2.25  | 2.25            | 2.35  | 1.8   | 1.185 | 2.40              |
| 3rd qtr 1990   | 07/04/90-10/12/90 | 1.7   | 1.15         | 1.25  | 2.1   | 1.95            | 2.2   | 1.65  | 0.63  | 2.25              |
| 4th qtr 1990   | 10/12/90-01/07/91 | 2.1   | 1.85         | 1.6   | 2.35  | 2.9             | 3.7   | 2.05  | 14    | 2.56              |
| 1st gtr 1991   | 01/08/91-03/08/91 | 4.0   | 1.7          | 1.9   | 3.0   | 4.5             | 3.0   | 6.9   | 2.1   | 3.79              |
| 2nd qtr 1991   | 03/09/9107/02/91  | 2.4   | 1.9          | 1.5   | 10.3  | 6.7             | 5.1   | 3.5   | 1.5   | 5.29              |
| 3rd qtr 1991   | 07/02/91-10/01/91 | 2.0   | 1.7          | 2.0   | 2.2   | 2.5             | 4.2   | 4.1   | 1.0   | 8.76              |
| 4th qtr 1991   | 10/01/9101/07/92  | 4.4   | 3.0          | 3.7   | 8.2   | 10.8            | 15.2  | 15.3  | 5.5   | 10.56             |

<sup>a</sup> Ref. Byrne 1992a. Concentrations given here are the average of (typically two) results for Type F detectors.

<sup>b</sup> Mean concentration for all locations for the given quarter.

Page J-105

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

#### ANNEX 2 TO APPENDIX J

#### SUMMARY OF CALCULATIONS OF CURRENT ESTIMATES OF RADON AND RADON DAUGHTER RELEASES FROM K-65 SILOS AND K-65 MATERIAL

#### INTRODUCTION

. مرزد

÷.,

In this Annex we provide brief, summary information about the calculations of our current estimates of Rn and Rn daughter releases from the K-65 Silos and from K-65 material. Calculational approaches are first summarized. Table J2-1 shows, for each separate time period, the available, useful information for performing the release calculations; the information lacking, that would be useful to improve estimates; and the general approach to the calculations of releases. Table J2-2 summarizes the principal release rates that are calculated, page references for the detailed discussions, and lists of the parameters required for each calculation. Information about the parameters used in the calculations is summarized in Table J2-3. This table lists the parameters used, categorizes the primary types of information available for determining the parameters, and describes the distributions chosen to represent the parameters, with the parameters shown generally in the order they are discussed in the text of this Appendix.

The remainder of this Annex provides summaries of the primary equations used in the calculations of the current estimates of Rn and Rn daughter releases.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

5

1.12.623

1.3 1.4

1.200 Mar

Service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the service of the servic

| Period [nominally]                                                                                                                                           | Information available                                                                                                                                                                                                                                                                                                       | Information lacking <sup>a</sup>                                                                                                                                     | General approach to release estimates                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Releases from K-65                                                                                                                                           | Material Stored in Drums o                                                                                                                                                                                                                                                                                                  | n Plant 1 Pad                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| October 1951–June<br>1953                                                                                                                                    | Quantity of drums received<br>through July 1952; <sup>226</sup> Ra<br>concentration in K-65<br>material (indirect);<br>estimated density and<br>moisture content of K-65<br>material.                                                                                                                                       | Radon diffusion<br>coefficient, Rn<br>emanation fraction,<br>and porosity of K-65<br>material; fractional<br>rate of Rn release<br>from the drums.                   | Radon-222, from decay of <sup>226</sup> Ra in<br>K-65 material, diffuses through K-65<br>material into air space in storage<br>drum. A fraction (an assumed value is<br>used) of the Rn in the air space is<br>released, through penetrations in the<br>drum, into the atmosphere.                                                                                                                                                                   |
| Releases from K-65                                                                                                                                           | Material in K-65 Silos                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| [1952-1953] =<br>mid-July 1952-<br>mid-June 1953<br>(operation of Silo 1);<br>[1953-1958] =<br>mid-June 1953-<br>mid-September 1958<br>(operation of Silo 2) | General information about<br>practices for operating the<br>K-65 Silos; estimated<br>average concentrations of<br>radium-226 for Silo 1 and<br>Silo 2.                                                                                                                                                                      | Detailed production<br>information for<br>slurrying and<br>decanting operations;<br>all other <sup>5</sup> .                                                         | Releases based on calculated releases<br>for 1959–1979, with factors (using<br>assumed values) to account for<br>reduced emissions during operations,<br>due to greater moisture content of the<br>K-65 material, and for the differing<br><sup>226</sup> Ra concentrations in the two Silos.                                                                                                                                                        |
| [19591979] =<br>mid-September<br>1958-June 1979                                                                                                              | Exposure rates on silo<br>dome surfaces, prior to and<br>after the dome<br>penetrations were sealed<br>(in June 1979); data to<br>calculate volume of silo air<br>space; estimated rate of<br>release of Rn from K-65<br>material into silo air space,<br>calculated for 1980–1987<br>period.                               | Radon concentration<br>in silo air space;<br>ventilation rate of<br>silos.                                                                                           | Radon concentration is estimated<br>based on value for 1980–1987 and<br>ratio of silo dome exposure rate for<br>1959–1979 to exposure rate for 1980–<br>1987. Radon release rate from K-65<br>material into silo air space is based on<br>value for 1980–1987, with correction<br>for silo air Rn concentration. Total Rn<br>released is then quantity released<br>from K-65 material into silo air minus<br>quantity that decays while in the silo. |
| 1980–1987] =<br>July 1979–<br>December 1987                                                                                                                  | Radon concentration in silo<br>air space; limited data on<br>temperature and pressure<br>changes in silo air; data to<br>calculate volume of silo air<br>space; limited data on<br>thickness of concrete<br>domes of silos; literature<br>values for porosity and Rn<br>diffusion coefficient of<br>concrete of silo domes. | Radon diffusion<br>coefficient, Rn<br>emanation fraction,<br>and porosity of K-65<br>material; ventilation<br>rate of silo air space<br>due to wind across<br>domes. | Air exchange releases: activity of Rn<br>in silo air is based on concentration<br>and volume; fractional ventilation rate<br>of silo air space due to volume<br>expansion and contraction is based on<br>temperature monitoring; release is<br>activity in air space multiplied by<br>fractional ventilation rate.<br>Diffusion releases: Rn in silo air space<br>diffuses through concrete domes of<br>silos into outside air.                      |
| .988                                                                                                                                                         | Measurements of Rn<br>concentrations on the K-65<br>Area fenceline for 1987–<br>1991.                                                                                                                                                                                                                                       | Description of Rn<br>release mechanism;<br>concentration of Rn<br>in silo air.                                                                                       | Total releases are based on releases<br>for 1980–1987 period and ratio of<br>measured Rn concentration for 1988<br>to concentration for 1980–1987.                                                                                                                                                                                                                                                                                                   |

 

 All time periods
 Estimated Rn release rates
 Silo air Rn daughter
 Releases of Rn daughters are based on concentration; Rn

 for all periods.
 concentration; Rn
 Rn releases, with factors to account daughter release

 for Rn equilibrium fraction and factors.
 daughter deposition during release.

<sup>a</sup> There are no direct data on quantities of Rn released, for any period. There also are no data on Rn diffusion coefficient, Rn emanation fraction, and porosity of the K-65 material, for any period.
 <sup>b</sup> For this operational period of the Silce, there are essentially no data of the types found for other wars, that can be

<sup>b</sup> For this operational period of the Silos, there are essentially no data of the types found for other years, that can be used to estimate Rn releases.

ŝ

•

| Emissions of | f Radon, | Radon D | aughters, | and Gamma | Radiation | from th | e K-65 | Silos |
|--------------|----------|---------|-----------|-----------|-----------|---------|--------|-------|
|              |          |         |           |           |           |         |        |       |

| Daughter Releases, for Current Estimates                                             |                                                                                                              |                  |                                                                                                                                                                                                                                                                                                                                                 |  |  |  |  |
|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|--|--|
| To calculate:                                                                        | Description                                                                                                  | Page             | Basic parameters required                                                                                                                                                                                                                                                                                                                       |  |  |  |  |
| Q <sub>exch,post</sub>                                                               | Air exchange Rn release<br>rate from K-65 Silos after<br>sealing of Silos, 1980–1987.                        | J-27             | $C_{a,post}; \Delta T/T_0; \lambda_{v,wind}; V_0.$                                                                                                                                                                                                                                                                                              |  |  |  |  |
| Q <sub>diff,post</sub>                                                               | Diffusion Rn release rate<br>from K-65 Silos after sealing<br>of Silos, 1980–1987.                           | J-34             | $C_{a,post}; \varepsilon_c; \lambda_{Rn}; l_c; L; A_{dome}.$                                                                                                                                                                                                                                                                                    |  |  |  |  |
| Q <sub>pre</sub>                                                                     | Total Rn release rate from<br>K-65 Silos before sealing of<br>Silos, 1959–1979.                              | J–38,<br>J–41    | $C_{a,post}; V_0; \lambda_{Rn}; \Delta T/T_0; \lambda_{v,wind}; Q_{diff,post}; [(e_w l_w + h)/e_w l_w]; X_{bkg}; X_{pre}; X_{post}.$                                                                                                                                                                                                            |  |  |  |  |
| Q <sub>1988</sub>                                                                    | Total Rn release rate from<br>K-65 Silos, 1988.                                                              | J46 <sup>°</sup> | $Q_{\mathrm{exch, post}}; Q_{\mathrm{diff, post}}; R_{\mathrm{mon}}$                                                                                                                                                                                                                                                                            |  |  |  |  |
| Q <sub>52-53</sub>                                                                   | Total Rn release rate from<br>K-65 Silos during operation<br>of Silo 1, 1952–1953.                           | J–53             | $Q_{\rm pre}; f_{\rm Ra,1}; f_{\rm op}.$                                                                                                                                                                                                                                                                                                        |  |  |  |  |
| Q <sub>53-58</sub>                                                                   | Total Rn release rate from<br>K-65 Silos during operation<br>of Silo 1, 1953–1958.                           | J-53             | $Q_{\rm pre}; f_{\rm Ra,1}; f_{\rm Ra,2}; f_{\rm op}.$                                                                                                                                                                                                                                                                                          |  |  |  |  |
| Q <sub>dr</sub> ; R <sub>dr,51</sub> ;<br>R <sub>dr,52</sub> ;<br>R <sub>dr,53</sub> | Radon release rate per drum<br>of stored K-65 material;<br>annual Rn releases from<br>drummed K-65 material. | J–55             | $\begin{split} & [\text{Ra}]_{\text{dr}}; EF_{\text{dr}}; \rho_{\text{dr}}; g_{\text{dr}}; \lambda_{\text{Rn}}; A_{\text{dr}}; \\ & N_{1951}; N_{1952}; N_{1953}; M_{\text{dr}}; U_{\text{D}}; U_{\text{dr}}; \\ & W_{\text{dr}}; [(\lambda_{\text{v}} + \lambda_{\text{d}}) / \lambda_{\text{eff}}]_{\text{post}}; f_{\text{dr}}. \end{split}$ |  |  |  |  |
| Q <sub>daught,i</sub>                                                                | Radon daughter release<br>rates, for the different time<br>periods.                                          | J-64             | Radon release rates (the various $Q$ ,<br>and $R_{dr}$ ); $F_1$ ; $F_{2,dr}$ ; $F_{2,52-58}$ ; $F_{2,pre}$ ;<br>$F_{2,post,exch}$ ; $F_{2,post,diff}$ ; $F_{2,1988}$ .                                                                                                                                                                          |  |  |  |  |

Table J2-2. General Summary of Calculations of Radon and Radon

¢.,

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

<u>:</u>-

1

1

ŝ

1. Sec. 1.

Contract of

1.1.1. A. 1.

Sandy Land

| ·                                                               |                        | Prima                        | ry basis                             |                  | • · · · •           |                                                          |
|-----------------------------------------------------------------|------------------------|------------------------------|--------------------------------------|------------------|---------------------|----------------------------------------------------------|
| Parameter                                                       | Units                  | Site-specific<br>information | Literature<br>Scientific<br>iudzment | Page             | Distribution        | Descriptive statistics <sup>a</sup>                      |
| C <sub>a,post</sub>                                             | pCi L <sup>-1</sup>    | X                            |                                      | J-28             | normal              | mean = $2.62 \times 10^7$ ; stdev = $4.1 \times 10^6$    |
| $\Delta T/T_{o}$                                                | . d−1                  | <b>X</b> .                   |                                      | J-31             | normal <sup>b</sup> | mean = 0.0297; stdev = 0.0138                            |
| J. mind                                                         | · ·                    |                              | х                                    | J-34             | known <sup>e</sup>  | value = 0                                                |
| Vo                                                              | ft <sup>3</sup>        | х                            |                                      | J-29             | uniform             | min = 40,000; max = 62,000                               |
| λ <sub>Rn</sub>                                                 | d-1                    | ·                            | x                                    | J-37             | known <sup>e</sup>  | value = 0.18129                                          |
| E <sub>r</sub>                                                  | · · · · · ·            | •                            | X                                    | J-35             | uniform             | min = 0.16; max = 0.265                                  |
| l, ·                                                            | : cm                   | ¢.Ť                          | x ·                                  | J-36             | uniform             | min = 14.5; max = 23                                     |
| L ···                                                           | cm                     | х                            | • •                                  | J-36             | uniform             | $\min = 3; \max = 4$                                     |
| Adome                                                           | ft <sup>2</sup>        | <b>X</b> - 1                 | •                                    | J-36             | known <sup>e</sup>  | value = 5300 :                                           |
| Xbkg                                                            | - mR h <sup>-1</sup>   | 1 X .                        | • ••                                 | J-42             | uniform             | min = 35.5; max = 76                                     |
| X <sub>pre</sub>                                                | `√` mR h <sup>−1</sup> | X                            | 25 - 1<br>1                          | J-42             | uniform             | min = 65 or $X_{bkg}$ , whichever is<br>larger: max = 90 |
| Y                                                               | - mR h-1               | <b>y</b>                     |                                      | J_42             | uniform             | $m_{10} = 168; m_{10} = 400$                             |
| (c + b)                                                         |                        | · .                          | ď                                    | J-40             | known <sup>c</sup>  | value = 6.35                                             |
| $\frac{(\varepsilon_w \omega + n)}{(\varepsilon_w \omega + n)}$ |                        | •                            | • • • • • •                          |                  |                     |                                                          |
| ε <sub>w</sub> l <sub>w</sub>                                   | · · ·                  | • :-                         |                                      | 1                | •                   |                                                          |
| R <sub>mon</sub>                                                |                        | Χ.                           |                                      | J-52             | normal <sup>b</sup> | mean = 0.612; stdev = 0.282                              |
| f <sub>Ra,1</sub>                                               |                        | Χ                            | 1 1.15                               | ∦ <b>J55</b> -   | normal              | mean = 1.26; stdev = 0.157                               |
| f <sub>Rs,2</sub>                                               | -                      | Х                            | -                                    |                  | normal              | mean = 0.717; stdev = 0.107                              |
| f <sub>op</sub> .                                               |                        |                              | X                                    | J-55             | uniform             | $\min = 0; \max = 1.0$ .                                 |
| [Ra] <sub>dr</sub>                                              | pCi g <sup>-1</sup>    | . X                          |                                      | -J-59            | uniform             | min = 306,800; max = 890,700                             |
| EF <sub>dr</sub>                                                |                        |                              | х.                                   | J-59             | uniform             | min = 0.1; max = 0.4                                     |
| P <sub>dr</sub> and a                                           | , g cm <sup>-3</sup>   | <b>X</b> .                   |                                      | J-59             | uniform             | $\min = 0.8; \max = 1.2$                                 |
| <i>B</i> <sub>dr</sub>                                          |                        | x                            |                                      | J-59             | normal              | mean = 2.98; stdev = 0.24                                |
| $A_{dr}$ ·                                                      | cm <sup>3</sup>        | x                            |                                      | J-61             | known <sup>c</sup>  | value = 2500                                             |
| M <sub>dr</sub>                                                 | dry weight             | <b>X</b> (35)                | 1. A. A.                             | ∵ <b>J</b> –60 - | nd uniform          | min = 0.2; max = 0.6 or $(1/\rho_{dr})$                  |
|                                                                 | Traction               |                              | • •                                  | _                |                     | l/g <sub>dr</sub> ), whichever is smaller                |
| f <sub>dr</sub>                                                 |                        |                              | X                                    | J-61             | uniform             | $\min = 0; \max = 1.0$                                   |
| W <sub>dr</sub>                                                 | lb                     | - <b>X</b> <sub>1 (V</sub>   | 1 they                               | <b>J</b> _61     | uniform             | min = 400; max = 600                                     |
| UD                                                              |                        |                              | X                                    | J61              | lognormal           | GM = 1; GSD = 2                                          |

 Table J2–3. Parameter Distributions for Monte Carlo Calculations of Current Estimates of

 222Rn and Daughter Releases from K-65 Silos and Drummed K-65 Material

-----

<sup>a</sup> Abbreviations: stdev = standard deviation; min = minimum; max = maximum; GM = geometric mean; GSD = geometric standard deviation.

<sup>b</sup> Actually this distribution is truncated on the low side at zero.

<sup>c</sup> "known" indicates that a single value is used in the calculations.

<sup>d</sup> This parameter is based on other parts of our calculations.
Appendix J

3

and the second sec

Se

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

|                                                                       |          | Primary basis                |            |                        |      |                    |                                     |
|-----------------------------------------------------------------------|----------|------------------------------|------------|------------------------|------|--------------------|-------------------------------------|
| Parameter                                                             | Units    | Site-specific<br>information | Literature | Scientific<br>judgment | Page | Distribution       | Descriptive statistics <sup>a</sup> |
| U <sub>4</sub> .                                                      |          |                              |            | Х                      | J62  | lognormal          | GM = 1; GSD = 1.4                   |
| $\left[\frac{\lambda_{v} + \lambda_{d}}{\lambda_{eff}}\right]_{post}$ |          | · .                          | •          | d .                    | J62  | normal             | mean = 0.156; stdev = 0.051         |
| N1051                                                                 | drum-mo. | x                            |            |                        | J62  | known <sup>e</sup> | value = 6500                        |
| N <sub>1952</sub>                                                     | drum-mo. | х                            |            |                        | J-62 | known <sup>e</sup> | value = 110,000                     |
| N <sub>1953</sub>                                                     | drum-mo. | <b>X</b> .                   |            |                        | J-62 | known <sup>e</sup> | value = 17,000                      |
| $F_1$                                                                 |          |                              |            | х                      | J-65 | uniform            | min = 0.8; max = 1.0                |
| F <sub>2 dr</sub>                                                     |          |                              |            | х                      | J65  | uniform            | min = 0; max = 0.5                  |
| $F_{2.52-58}$                                                         |          |                              |            | х                      | J-65 | uniform            | min = 0.8; max = 1.0                |
| E2.pre                                                                |          |                              |            | x                      | J-65 | uniform            | min = 0.8; max = 1.0                |
| F <sub>2.post.exch</sub>                                              |          |                              |            | Х                      | J65  | uniform            | min = 0.5; max = 1.0                |
| F <sub>2.post.diff</sub>                                              |          | •                            |            | X                      | J65  | uniform            | min = 0; max = 0.5                  |
| F. 1068                                                               |          |                              |            | х                      | J65  | uniform            | min = 0; max = 0.5                  |

Table J2-3. Parameter Distributions for Monte Carlo Calculations of Current Estimates of

Abbreviations: stdev = standard deviation; min = minimum; max = maximum; GM = geometric mean; GSD = geometric standard deviation.

"known" indicates that a single value is used in the calculations.

đ This parameter is based on other parts of our calculations.

### **EQUATIONS FOR 1980–1987 AIR EXCHANGE RELEASES**

As was discussed previously, the air exchange releases for the period 1980 to 1987 can be calculated by:

> $Q_{\text{exch,post}} = C_{\text{a,post}} \lambda_{\text{v,post}} V_0$ (J-14)

where

$$\lambda_{v,\text{post}} = \lambda_{v,\Delta T} + \lambda_{v,\text{wind}}$$
 (J-17)

For these calculations,  $\lambda_{v,wind}$  is set equal to zero. From equation J-20, we substitute for  $\lambda_{v,\Delta T}$ , to obtain:

$$\lambda_{\rm y, post} = \Delta T / T_0 \tag{J-84}$$

This last (equation J-84) is the equation used in the spreadsheet calculations, with no units conversion needed.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

بر بر بر بر

1.15

··· 2. 41.

Then, the release rate is calculated in the spreadsheet as:

$$Q_{\text{exch,post}} = C_{\text{a,post}} \lambda_{\text{v,post}} V_0 CF_1 \qquad (J-85)$$

where  $CF_1$  is the units conversion factor. The units of the result,  $Q_{exch,post}$ , are Ci y<sup>-1</sup>. The units used for the parameters are pCi L<sup>-1</sup> for  $C_{a,post}$ ; d<sup>-1</sup> for  $\lambda_{v,post}$ ; and ft<sup>3</sup> (per silo) for  $V_0$ . Thus,

$$CF_{1} = (10^{-12} \text{ Ci pCi}^{-1})(365.25 \text{ d y}^{-1})(28.317 \text{ L ft}^{-3})(2 \text{ silos})$$
  
= 2.0686 × 10<sup>-8</sup> Ci d L pCi<sup>-1</sup> y<sup>-1</sup> ft<sup>-3</sup> (J-86)

### EQUATIONS FOR 1980–1987 DIFFUSION AND TOTAL RELEASES

### As was previously discussed, the diffusion release rates are calculated as:

$$Q_{\rm diff,post} = JA_{\rm dome}$$
 (J-24)

where

$$J = \frac{\varepsilon_{\rm c} \lambda_{\rm Rn} l_{\rm c} C_{\rm a, post}}{\sinh\left(\frac{L}{l_{\rm c}}\right)} \qquad (J-23)$$

These two equations are combined to give:

$$Q_{\text{diff,post}} = \frac{A_{\text{dome}} \varepsilon_c \lambda_{\text{Rn}} l_c C_{a,\text{post}} \text{CF}_2}{\sinh \left(\frac{L(2.54 \text{ cm in}^{-1})}{l_c}\right)}$$
(J-87)

where we have inserted a units conversion factor for L and the units conversion factor,  $CF_2$ , for the result. The units of the result,  $Q_{\text{diff,post}}$ , are Ci y<sup>-1</sup>. The units of the parameters are ft<sup>2</sup> (per silo) for A; fraction for  $\varepsilon_c$ ; d<sup>-1</sup> for  $\lambda_{\text{Rn}}$ ; cm for  $l_c$ ; pCi L<sup>-1</sup> for  $C_a$ ; and inches for L. Thus, the units conversion factor is:

$$CF_{2} = (10^{-12} \text{ Ci pCi}^{-1})(30.48 \text{ cm ft}^{-1})^{2} (10^{-3} \text{ L cm}^{-3})(365.25 \text{ d y}^{-1})(2 \text{ silos})$$
  
= 6.7866 × 10<sup>-10</sup> Ci L d pCi<sup>-1</sup> ft<sup>-2</sup> cm<sup>-1</sup> y<sup>-1</sup> (365.25 \text{ d y}^{-1})(2 \text{ silos})

The total release rate for the period is 'calculated as the sum of the air exchange and diffusion releases:

$$Q_{\text{post}} = Q_{\text{exch,post}} + Q_{\text{diff,post}}$$
 (J-89)

# EQUATIONS FOR TOTAL RELEASE RATE FOR 1959–1979 AND UNCONSTRAINED RELEASE RATE

Preliminary calculations are performed first:

$$C_{\rm a,pre} = C_{\rm a,post} \left( \frac{X_{\rm pre} - X_{\rm bkg}}{X_{\rm post} - X_{\rm bkg}} \right)$$
(J-39)

0

$$\lambda_{\rm d,post} = \frac{Q_{\rm diff,post}}{C_{\rm a,post}V_0} \frac{(10^{12} \ \rm pCi \ Ci^{-1})}{(28.317 \ \rm L \ ft^3)(365.25 \ \rm d \ y^{-1})(2 \ silos)}$$
(J-28)

$$\lambda_{\text{eff,post}} = \lambda_{\text{Rn}} + \lambda_{\text{v,post}} + \lambda_{\text{d,post}}$$
 (J-90)

$$\frac{\Phi}{\lambda_{\rm Rn}} = C_{\rm a,post} \left( \frac{\lambda_{\rm eff,post}}{\lambda_{\rm Rn}} \right) \left( \frac{\varepsilon_{\rm w} l_{\rm w} + h}{\varepsilon_{\rm w} l_{\rm w}} \right)$$
(J-34)

where appropriate conversions factors have been added to equation J-28. These equations are used in the spreadsheet to obtain these intermediate results.

The Rn production rates are then calculated:

.....

•••

÷.,

5

•

$$P_{\text{Rn,post}} = C_{\text{a,post}} V_0 \lambda_{\text{eff,post}} \left( 28.317 \text{ L ft}^{-3} \right)$$
 (J-27)

$$P_{\rm Rn,pre} = P_{\rm Rn,post} \left( \frac{\phi/\lambda_{\rm Rn} - C_{\rm a,pre}}{\phi/\lambda_{\rm Rn} - C_{\rm a,post}} \right)$$
(J-32)

From equation J-36, the Rn releases for the period 1959 to 1979 are then calculated by:

$$Q_{\rm pre} = \left[ P_{\rm Rn, pre} - C_{\rm a, pre} \lambda_{\rm Rn} V_0 (28.317 \,\,{\rm L}\,{\rm ft}^{-3}) \right] CF_3 \tag{J-91}$$

where CF<sub>3</sub> is a units conversion factor. The units of the result,  $Q_{pre}$ , are Ci y<sup>-1</sup>. The units used for the parameters are pCi d<sup>-1</sup> for  $P_{Rn,pre}$ ; pCi L<sup>-1</sup> for  $C_{a,pre}$ ; d<sup>-1</sup> for  $\lambda_{Rn}$ ; and ft<sup>3</sup> (per silo) for  $V_0$ . Thus,

$$CF_3 = (10^{-12} \text{ Ci pCi}^{-1})(365.25 \text{ d y}^{-1})(2 \text{ silos})$$
  
= 7.305 × 10<sup>-10</sup> Ci d pCi<sup>-1</sup> y<sup>-1</sup> (J-92)

From equation J-35, the unconstrained Rn release rate,  $P_{\rm Rn,0}$ , is calculated by:

Page J-112

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

$$P_{\rm Rn,0} = P_{\rm Rn,post} \left( \frac{\phi/\lambda_{\rm Rn}}{\phi/\lambda_{\rm Rn} - C_{\rm a,post}} \right) CF_2 \qquad (J-93)$$

where we have again added a units conversion factor.

### **EQUATION FOR 1988 RELEASES**

The Rn release rate for 1988 is calculated by the following, with no units conversion required:

14

1 A A

10 m

$$Q_{1988} = Q_{\text{post}} R_{\text{mon}} \tag{J-46}$$

4

1000

### EQUATIONS FOR 1952–1958 RELEASES FROM K-65 SILOS

- f

The release rates of Rn from the K-65 Silos for the operational periods of the Silos are calculated by the following, with no units conversion required:

$$Q_{52-53} = (0.5)Q_{\text{pre}}f_{\text{Ra},1}f_{\text{op}}$$
(J-48)  
$$Q_{53-58} = (0.5)Q_{\text{pre}}(f_{\text{Ra},1} + f_{\text{Ra},2}f_{\text{op}})$$
(J-49)

# EQUATIONS FOR 1951-1953 RELEASES FROM DRUMMED K-65 MATERIAL

A number of preliminary calculations are first performed, to calculate  $\varepsilon_{dr}$ ;  $m_{dr}$ ;  $D_{dr}$ ;  $D_{e,dr}$ ;  $l_{dr}$ ;  $L_{dr}$ ; and  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{dr}$ . The equations for these calculations are not repeated here (see pages J-59 through J-61).

The pore space Rn production rate is first calculated by:

$$\phi_{dr} = \frac{[Ra]_{dr} EF_{dr} \rho_{dr} \lambda_{Rn}}{\varepsilon_{dr}}$$
(J-51)

The unconstrained Rn flux from the K-65 material in the drums is next calculated:

$$j_{\rm D,dr} = \sqrt{\frac{D_{\rm e,dr} \varepsilon_{\rm dr}}{\lambda_{\rm Rn}}} (\phi_{\rm dr}) \tanh\left(\frac{L_{\rm dr}}{l_{\rm dr}}\right) \tag{J-50}$$

The Rn release rate from a single drum is then calculated as:

$$Q_{\rm dr} = j_{\rm D,dr} A_{\rm dr} \left( \frac{\lambda_{\rm v} + \lambda_{\rm d}}{\lambda_{\rm eff}} \right)_{\rm dr} U_{\rm dr} CF_4 \qquad (J-52)$$

Appendix J

÷.

::

Emissions of Radon, Radon Daughters, and Gamma Radiation from the K-65 Silos

where  $CF_4$  is a units conversion factor. Here, the units desired for the result,  $Q_{dr}$ , are Ci month<sup>-1</sup>. The units of the parameters are pCi cm<sup>-2</sup> s<sup>-1</sup> for  $j_{dr}$ ; cm<sup>2</sup> for  $A_{dr}$ ; and fraction for the ratio  $[(\lambda_v + \lambda_d)/\lambda_{eff}]_{dr}$ . Thus, the units conversion factor is:

$$CF_4 = (2.63 \times 10^6 \text{ s month}^{-1})(10^{-12} \text{ Ci pCi}^{-1})$$
  
= 2.63 × 10<sup>-6</sup> s Ci month<sup>-1</sup> pCi<sup>-1</sup> (J-94)

Finally, the total yearly Rn releases from the stored, drummed K-65 material is calculated by:

 $R_{\rm dr,i} = Q_{\rm dr} N_i \tag{J-53}$ 

### EQUATION FOR RADON DAUGHTER RELEASES

It was shown earlier that the releases of short-lived <sup>222</sup>Rn daughters are calculated by:

$$Q_{\text{daught}} = QF_1F_2 \tag{J-64}$$

This equation is applied in the spreadsheet to  $Q_{52-53}$ ;  $Q_{53-58}$ ;  $Q_{pre}$ ;  $Q_{exch,post}$ ;  $Q_{diff,post}$ ; and  $Q_{1988}$ ; to obtain  $Q_{daught,52-53}$ ;  $Q_{daught,53-58}$ ;  $Q_{daught,pre}$ ;  $Q_{daught,exch,post}$ ;  $Q_{daught,diff,post}$ ; and  $Q_{daught,1988}$ ; respectively. For releases from the drummed K-65 material, daughter releases are calculated by:

$$R_{daughtdr} = R_{dr}F_1F_2$$

# EQUATIONS FOR TOTAL RADON AND RADON DAUGHTER RELEASES FOR THE OPERATING PERIOD 1951–1988

The total release quantities of Rn from the FMPC for the site operating period, 1951– 1988, are calculated by the following, with no units conversion required:

 $R_{\text{Silos},52-88} = \sum_{i} Q_i T_i \tag{J-65}$ 

$$R_{dr,51-53} = \sum_{j} R_{dr,j}$$
 (J-66)

$$R_{\rm FMPC,51-88} = R_{\rm Silos,52-88} + R_{\rm dr,51-53} \tag{J-67}$$

The same equations are used to calculate total releases of Rn daughters, with the following substitutions:  $R_{\text{daught,Silos,52-88}}$  for  $R_{\text{Silos,52-88}}$ ;  $Q_{\text{daught,i}}$  for  $Q_i$ ;  $R_{\text{daught,dr,51-53}}$  for  $R_{\text{dr,51-53}}$ ;  $R_{\text{daught,dr,j}}$  for  $R_{\text{dr,j}}$ ; and  $R_{\text{daught,FMPC,51-88}}$  for  $R_{\text{FMPC,51-88}}$ .

Radiological Assessments Corporation "Setting the standard in environmental health"

(J-95)

### APPENDIX K

### OTHER SOURCES AND EPISODIC RELEASES TO THE ATMOSPHERE

# INTRODUCTION

5

. . .

.

A comprehensive review of the History of FMPC Radionuclide Discharges (Boback et al. 1987) was undertaken in the fall of 1988 to assure that all potential sources (current and historical) of airborne uranium and thorium emissions from the Feed Materials Production Center (FMPC) had been adequately assessed (Hill and Dolan 1988; Clark et al. 1989). The study identified six areas where emissions from FMPC to the atmosphere had been potentially underestimated. These included:

- uranium trioxide gulping process in Plant 2/3
- other unmonitored uranium processes
- thorium processes, both monitored and unmonitored
- fugitive emissions from building ventilation
- laboratory hood exhausts
- fugitive emissions from the waste storage area.

Unmonitored uranium emissions from the  $UO_3$  gulping process are addressed in Appendix H. Appendix K of the interim source term report (Voillequé et al. 1991) reviewed and summarized uranium release estimates from the other unmonitored sources for the years 1960-1962. The total uranium release estimates for these sources, which included unmonitored process emissions, building ventilation, laboratory hoods, incinerators, and fugitive emissions from waste pits, were minor compared with other sources such as the Plant 8 and Plant 2/3 scrubbers and the dust collectors from the various FMPC production facilities. Although these sources were believed to be relatively insignificant, the bases for most of the previous estimates were not well documented, and there were no uncertainties associated with them. These shortcomings have been overcome by a thorough review of original sources of information, literature reviews, implementation of alternate models/methods, and reconstruction of releases with uncertainties.

This appendix also includes an assessment of uranium releases from accidents. We separate these into two categories, "non-routine events" and "episodic releases." Clark et al. (1989) estimated hypothetical historic releases of uranium from a variety of non-routine events, such as fires and spills, which did occur rather frequently during the operation of FMPC production facilities. These were not release estimates for actual events, but rather estimated amounts released to the environment based on the frequency of such events and the observed or calculated release quantities for a typical event of that type. Previous estimates of uranium releases for non-routine events during the 1960-1962 period were included in Appendix K of Voillequé et al. (1991), and were comparable to the other

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

12

. . . . .

1. N. 1.

۲. مەزەر يې

さいたた

unmonitored releases from waste incineration and from fugitive emissions from the FMPC waste pits.

In contrast to the hypothetical non-routine events, "episodic releases" are defined as actual historic releases of large enough magnitude and short enough duration to warrant special dose assessment procedures. Several approaches were taken to identifying episodic releases, which include the review of historic documents describing accidental conditions and the examination of environmental monitoring data, particularly air monitoring and gummedfilm data. Monitored as well as unmonitored releases may be episodic. Our assessments identified some potential episodic releases not monitored at the source. Identification of episodic releases and estimates of the quantities released are included in this appendix.

The estimates of uranium releases from incinerators and other unmonitored processes will be addressed first, followed by an assessment of fugitive emissions from the waste pits. The last sections of this appendix deal with episodic releases and non-routine events, including a release of radon from the K-65 silos in April 1986.

# URANIUM RELEASES FROM WASTE INCINERATION OPERATIONS AT THE FMPC

Boback et al. (1987) list estimated releases of uranium to the atmosphere from five waste incineration systems which have been used at the FMPC. A review of the historic operations of these facilities (as well as an open burn pit) and reconstruction of past releases is presented in the following sections. In addition to estimates of release quantities, other important characteristics of the source terms from incineration, such as the flow rates and temperatures of stack gases and particle sizes, are also addressed here. These parameters were not characterized previously in the interim Task 2/3 report (Voillequé et al. 1991). Releases and release parameters for the earlier incinerators were typically not measured or were measured very infrequently; therefore releases must be estimated indirectly. These indirect methods used included combustion engineering principles, examination of uranium content of incinerator residues and mass balance considerations, published literature on similar processes, and environmental measurements of air, soil, and gummed film in the vicinity of the incinerators.

### WASTE INCINERATION IN THE OPEN BURN PIT

The burn pit was located between Pits 3 and 4, west of the production area (Figure K-1). It was constructed in 1957 as a site to excavate clay to line Pits 1 and 2. The burn pit was subsequently used to dispose of laboratory chemicals and to burn combustible materials, including pyrophoric and reactive chemicals, oil, and other low-level contaminated combustible materials (Solow and Phoenix 1987). The boundaries of the burn pit can no longer be distinguished from the covered Pit 4.

Although the solid waste sent to the burn pit was supposed to be uncontaminated or decontaminated, correspondence during 1964–1965 indicates that unexpectedly large amounts of uranium ended up in burn pit residues (Davis and Davies 1964; Audia 1964; Noyes 1965; Starkey 1965a; Klein 1965; Davis 1965a; Davis 1965b).

后来这些人来说**是我**的"数学的"是一个问题。



ала С

**Figure K-1.** Location of waste pits, burn pit, and old solid waste incinerator relative to the production area and other landmarks. Incinerators within the production area are shown in a subsequent figure. The fly ash pile shown as "inactive" was used until the mid-1960s.

.

Audia (1964) indicated a burn pit capacity of about 280,000 cubic feet, with about 240,000 cubic feet present at that time. He argued that a previous estimate (reference not cited) of 104,000 pounds of uranium in the pit was too high but stated that "there is no question that there is a substantial amount." Plans at that time were to move material more toward one

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

2

「おんていい

end, cover with a layer of clay, and discard trash in the cleared end. Much of the burnable trash then going to the pit was to be routed in the future to the incinerator, where uranium recovery was possible (Noyes 1965). The success of this waste segregation may have been somewhat limited, as evidenced by large scale analyses of ash from burn pit dumpsters and incinerator dumpsters (Davis and Palmer 1968). The uranium content of ash from waste placed in incinerator dumpsters averaged only 2.5 times that of ash from waste placed in burn pit dumpsters.

There has been no previous estimate of uranium releases to air from open burning at the burn pit. This pathway was evaluated by the Fernald Dosimetry Reconstruction Project in conjunction with evaluation of waste burned in the solid waste incinerator.

# **OLD SOLID WASTE INCINERATOR (1954-1979)**

The old solid waste incinerator, which operated from November 16, 1954 to December 31, 1979, was used to dispose of combustible general plant refuse, some of which was likely to contain recoverable uranium, including such items as scrap wood pallets, fuel core shipping containers damaged beyond repair, oily sludges and sanitary sewage sludges. The major portion of these materials was delivered to the incinerator through the use of a "Dempster Dumpster" collection system (Anonymous 1970). Some items, such as broken pallets, shipping boxes, and drums of sludge, were delivered to the incinerator by truck. The incinerator was located east of the production area near the site sewage treatment plant (Figure K-1).

History and Operation of the Old Solid Waste Incinerator

This section gives an overview of the history and operation of the Old Solid Waste Incinerator (OSWI). However, a more detailed chronological history of notes and information, gathered mainly from historic reports of the Industrial Hygiene and Radiation (IH&R) Department, is included as Annex 1 to this appendix.

Grossly contaminated combustibles such as dust collector bags, contaminated gloves, and other items showing high levels of contamination were separated from the general refuse stream at the point of generation (Anonymous 1970). Some attempts were made to burn these grossly contaminated items at the incinerator, but "the activity level of the stack discharge was above an acceptable limit" (Anonymous 1970). In 1962, the types of wastes burned at the incinerator included wood (railroad bracing, broken skids), rags, paper, gloves, clothing, shoes, sanitary sewage sludge, and filter bags and cartridges (Noyes 1962). The ash was processed through the Recovery Plant and the uranium was returned to the production stream.

The following information on the early old solid waste incinerator was obtained from Engineering Drawing 39X-X-00002, "Preliminary Drawing — Incinerator, October 2, 1953," and from NLO memoranda. The old solid waste incinerator was a variation on the Plibrico No. 222 design. In Engineering Drawing 39X-S-00004, "Foundation Plan, Details — Incinerator, February 18, 1954," the incinerator is shown surrounded by chain link fencing on the N, W, and E sides and topped by a slanted, corrugated asbestos roof which was about 20 feet above grade. This roof is visible in an aerial photograph from 1965 (Figure K-2), in

# Appendix K Other Sources and Episodic Releases to the Atmosphere

2

7

Page K-5

which the roof is roughly half as tall as the stack. The physical stack height was 36 feet above grade plus an additional 5 feet of 16 gauge, 4x4 mesh wire cloth, which acted as a spark arrester. Flue gases from the combustion chamber passed through four 90° angles (created by interior baffles) before exiting the stack. These angles served to enhance settling and impingement of entrained ash. There were no secondary burners at this time nor was there filtration of stack gases. A 15 x 24" draft door allowed control of air to the primary combustion chamber. Ashes fell below a grate and were shoveled out into drums via five clean-out doors.



Figure K-2. Photograph of the FMPC sewage treatment plant area in 1965. The old solid waste incinerator is in the NW corner of this area. The dark plume from the stack is blowing approximately W towards the production area. Surrounding land use is grazing and farming.

The OSWI was significantly modified in early 1970 "to improve the performance of the unit in regard to smoke density and particulate discharge" (Anonymous 1970). Noyes (1969) discussed the need to modify the incinerator to comply with Executive Order 11282, "Control of Air Pollution Originating From Federal Installations," because both the visibility standard and the particulate quantity criteria for refuse disposal incinerators were not being met. Plibrico, the manufacturer of the incinerator, proposed the installation of added baffling, additional settling chambers, and secondary combustion as the most economical method of improving the performance of this unit, although 100% compliance with the emission standards in the Executive Order was not guaranteed. They indicated that such a guarantee would be available only with the addition of flue gas scrubbers and/or an assurance that oily wastes would not be charged into the unit.

# The Fernald Dosimetry Reconstruction Project

È

The construction proposal CP-69-17 (Anonymous 1969), as well as the engineering drawing 39X-G-00009 "Modifications to Plant Incinerator, April 24, 1969," describe the modifications to the plant incinerator. These included:

- movement and replacement of existing stack with one of equal height (36 feet)
- addition of after-burners (one each side @ approximately 2,000,000 BTU h<sup>-1</sup> each) in a new secondary combustion chamber (max)
- addition of air jets in new secondary combustion chamber

addition of burn-off compartment for liquid wastes

Nelson (1969) indicated that these modifications to the plant incinerator would necessitate a shutdown of the facility for approximately four weeks (which he estimated would occur in February 1970). During this period, NLO planned to open-burn their refuse at the old burn pit, which was approved by Karl (1969).

After the modifications to the incinerator, it could be described as a multiple chamber in-line incinerator (National Air Pollution Control Administration 1969). The as-built stack height after these modifications was apparently not 36 feet, as the preliminary drawing had indicated. Drawing 39X-M-00012 (September 1972), as well as other sources, shows the incinerator after the modifications had been completed, with a stack height of 45 feet.

In order to evaluate the dispersion of effluents from the OSWI, the stack effluent temperature and flow rate must be estimated. We could locate no original measurements of these parameters in historic documer. Solon, although there apparently were measurements made in the early years (see Annex 1). In the application for a permit to operate an air contaminant source, Riestenberg (1978) gave a temperature range of 600-1500 °F for the exit gas from the OSWI. The flow rate is not given on this permit application, but handwritten notes by Grant (1986) give an estimate of 1181 feet per minute for the OSWI. No supporting calculations are shown, although Grant (1993) recalled that his notes were obtained from files which included the measurement data.

We checked the reasonableness of these temperature and flow rate values using standard combustion analysis calculations (National Air Pollution Control Administration 1969). We assumed an incineration rate of 750 lbs  $h^{-1}$  (the quoted average for the FMPC incinerator) of a 50%/50% mixture of wood and paper (moisture content 15%) at 200-300% excess air. Radiative heat losses were assumed to be 15% (National Air Pollution Control Administration 1969). The temperature of the exit gas from the OSWI under these conditions was computed to be 1000-1400 °F, which is within the temperature range given on the NLO permit application. The exit velocity of flue gases was estimated to be 780-850 feet per minute, based only on the volume of combustion product gases. Additional excess air would enter the primary combustion chamber by natural draft. Thus the exit velocity in Grant's notes may be considered reasonable. Table K-1 summarizes the physical and operating parameters for the OSWI. Particle size considerations for effluents from all incinerators are discussed later in this appendix.

Page K-6

| Appendix K                 |                            |
|----------------------------|----------------------------|
| Other Sources and Episodic | Releases to the Atmosphere |

.....

1

| Parameter                  | Value                                       | Reference                               | Notes                                                                        |
|----------------------------|---------------------------------------------|-----------------------------------------|------------------------------------------------------------------------------|
| Physical<br>stack height   | Through 1969:36 ft                          | Engineering Drawings<br>39X-M-00012 and | See discussion in text.                                                      |
|                            | After 1970: 45 ft                           | 39X-X-00002<br>Grant (1986)             | •                                                                            |
| Building                   | Through 1969:                               | Engineering Drawings                    | Before 1970 the incinerator                                                  |
| dimensions                 | 15.4 x 8.2 x 9 feet tall.                   | 39X-M-00012 and                         | · building was covered by a                                                  |
|                            | After 1970:<br>39.1 x 8.2 x 9 ft tall       | 39X-X-00002                             | sloping, corrugated asbestos roof<br>which was about 20 feet above<br>grade. |
| Stack inner                | Before 1970: 24 x 70                        | Engineering Drawings .                  | This lining of the newer stack                                               |
| dimensions                 | in., rectangular<br>(11.7 ft <sup>2</sup> ) | 39X-M-00012 and<br>39X-X-00002          | was oval shaped, with short and<br>long axis dimensions as shown.            |
|                            | 40 1070-                                    | . •                                     | A 3" width refractory stack is                                               |
|                            | After 1970:<br>27 = 71 in                   |                                         | assumed (AEC 1971) for                                                       |
| `                          | oval                                        | · · · · ·                               | of this stack.                                                               |
| Exhaust gas<br>velocity    | 780-850 ft min <sup>-1</sup>                | This study                              | Based on combustion analysis<br>and stack geometry before 1970.              |
|                            | 1181 ft min <sup>-1</sup>                   | Grant (1986)                            |                                                                              |
| Exhaust gas<br>temperature | 1000–1400 °F                                | This study                              | Based on combustion analysis<br>(see text). No supporting                    |
|                            | 600–1500 °F                                 | Riestenburg (1978)                      | calculations given for other                                                 |
|                            | 1048 °F                                     | Grant (1986)                            | recalled the value was based on<br>measurements.                             |
| Operating<br>schedule      | Until 1969:                                 | (Karl 1967)                             | The plant-wide waste generation                                              |
| Sentedune                  | $49-50 \text{ wk v}^{-1}$                   |                                         | $d-1/See Table K_4)$ This                                                    |
|                            | $(1960-2400 \text{ h y}^{-1})$              |                                         | corresponds to an operating                                                  |
|                            | 1970-1979:                                  | (Riestenberg 1978)                      | d-1 at an average fring rate of                                              |
|                            | $6 h d^{-1}$ , $3 d w k^{-1}$ .             | (medicinere 1010)                       | $750 \text{ lb } \text{h}^{-1}$ , which is in good.                          |
|                            | 49 wk y <sup>-1</sup>                       | · ·· • <sup>· ·</sup> •                 | agreement with the schedule                                                  |
|                            | (882 h y <sup>-1</sup> )                    |                                         | indicated. When the burning of                                               |
|                            |                                             | •                                       | (sometime between 1967 and                                                   |
|                            |                                             |                                         | 1969), the operating schedule                                                |
|                            |                                             |                                         | was reduced                                                                  |

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

2

ŝ

ĝ

-----

### Previous Uranium Release Estimates for the Old Solid Waste Incinerator

The previous release estimates (Boback et al. 1987) for the old solid waste incinerator, were 15 kg in 1954, 118 kg y<sup>-1</sup> for 1955 through 1968, 94 kg y<sup>-1</sup> for 1969, and 71 kg y<sup>-1</sup> for 1970 through 1979. The total estimated release for 1954–1979 would thus be  $\approx 2500$  kg. The source term estimates were supposedly based on data from several stack emission tests. Investigators from IT Corporation concluded that documentation for estimates of historical releases from non-production sources (including the oil burner and old solid waste incinerator) was limited and included information which conflicted with release estimates reported by Boback et al. (IT 1989).

### **Reconstruction of Uranium Source Term for the Old Solid Waste Incinerator**

A number of original sources of documentation were located and carefully reviewed to permit a reconstruction of the source term for the old solid waste incinerator. During this process, a chronological history of important events and other notes was compiled, which is included as Annex 1 to this appendix. This annex provides a detailed record of relevant changes and correspondence which was used to aid interpretion of the original data. The types of quantitative information we evaluated to estimate the source term from the OSWI fall into the following categories:

- Category 1. Stack measurements of uranium and gross alpha activity in stack gases.
- Category 2. Uranium content of incinerator residues and mass balance

considerations.

• Category 3. Environmental measurements of uranium and gross alpha activity in air and deposited on gumpaper around the incinerator.

Although Category 1, effluent monitoring of the stack gases, provides the most relevant data for source term reconstruction, there were very few measurements made. The second category of data was particularly plentiful in the 1960s, when a large emphasis was placed on documenting the uranium content of various plant wastes and residues. The third category (environmental measurements) was most important for evaluating operations in the 1950s, in which a number of tests of burning contaminated materials were undertaken, and measurements of associated environmental contamination were made (see time line in Annex 1). Although a source term is difficult to reconstruct using environmental measurements, they do provide a direct indication of the effect of those early tests on contamination levels in the surrounding environment.

Category 1 information — Stack measurements of uranium and gross alpha in stack gases from the OSWI. Five tests were made of particulate emissions from the incinerator stack in May 1977 (Ross 1977). In all five tests, the measured releases were greater than the Ohio EPA limit of 0.1 lb particulates per 100 lb burned. The uranium content of the waste burned was not documented, but there is no reason to conclude that it was not typical plant waste. The measured loss of uranium during the five tests was 0.06, 0.10, 0.13, 0.15, and 0.17 pounds per hour. Using the Crystal Ball<sup>™</sup> uncertainty analysis

3 1 - <sup>1</sup>

Appendix K

. .

### Other Sources and Episodic Releases to the Atmosphere

Page K-9

program (Decisioneering 1992), we defined a custom parameter distribution which described the hourly uranium release rate, using the measured values. This hourly release rate was multiplied by the operating schedule estimate of 882 hours per year for the post-1969 period (Table K-1), which was assumed to be normally distributed with a standard deviation of 10% of the mean. The annual source term forecast based on these stack tests is illustrated in Figure K-3. The median estimate is 52 kg per year with a 5th to 95th percentile range of 20 to 78 kg per year.





Earlier stack testing at the OSWI tended to be part of operational testing as opposed to compliance testing (see Annex 1). For example, particulate samples were collected from the trash incinerator flue gas in April 1964 to check the air contamination resulting from disposing of various uranium contaminated organic materaials at the incinerator (IH&R monthly report, April 1964; Starkey 1964b). The original analytical data sheets for these tests were located and are presented in Table K-2 below. The average of 18 measurements of uranium in flue gases was 1.7 mg U m<sup>-3</sup> (range 0.27-5.9).

We computed a source term estimate from the stack testing data in Table K-2 using the Crystal Ball<sup>TM</sup> uncertainty analysis software (Decisioneering 1992). The concentrations of uranium in the stack gas were defined using a custom distribution which described the actual measurements. In addition to the uranium concentrations in flue gas, the volumetric flow of stack gases and the operating schedule must be estimated. The stack gas velocity was defined by a triangular distribution in which the most probable value (1200 fpm) was documented by Grant (1986), the minimum value (800 fpm) was established by combustion analysis (Table K-1), and the maximum value (1440 fpm) was 20% higher than Grant's estimate. The operating schedule used was 1960-2400 hours per year (Table K-1), with a most probable value at the midpoint of this interval (2180 hours per year).

The estimated uranium source term based on the 1964 stack tests is shown in Table K-3. The median annual source term estimate is 67 kg per year, with a 5th-95th percentile range of 6-250 kg per year.

| The Fernald Dosimetry Reconstruction Proj  | ect |
|--------------------------------------------|-----|
| Tasks 2 and 3, Source Terms and Uncertaint | ies |

The second

でしたい

モントッシン

"Straty

|             |                                                 |          | . µg              | <u>U m<sup>-3</sup> flue g</u>        | as           |
|-------------|-------------------------------------------------|----------|-------------------|---------------------------------------|--------------|
|             | • • • • • • • • • • • • • • • • • • • •         | TBP or   |                   | •                                     |              |
| Date        | Description of                                  | sludge   | 1st               | 2nd                                   |              |
| <u> </u>    | Material Burned <sup>a</sup>                    | present? | impinger          | impinger                              | Tota         |
| 4/8         | Background; Ad. Blg. trash                      | No er    | 370               | 2270                                  | 2640         |
| 4/9         | Background trash                                | No       | 1140              | 590                                   | . 1730       |
| 4/9         | Background sample – Shipping<br>and Receiving   | No       | 1060              | 4850                                  | 5910         |
| <b>4/10</b> | Background. N-6 Insp. &                         | No       | 830               | 140                                   | <u>ີ</u> 970 |
| <b>.</b> .  | WINLO filters                                   |          |                   |                                       |              |
| 4/10 🧠      | Background. Plt. 9 trash                        | No los   | 1640              | 230                                   | 1870         |
| 4/10        | Plant 9                                         | Yes      | 1910              | <b>360</b>                            | 2270         |
| 4/10        | Plant 2/3 Maint., Boiler Plt                    | Yes      | 730               | 140                                   | 870          |
| 4/10        | Plant 2/3 Maint., Boiler Plt                    | Yes      | <b>360</b>        | 360                                   | 720          |
| 4/13        | Dumpster E-6                                    | Yes      | 300               | 35                                    | 335          |
| 4/13        | Dumpster E-6                                    | Yes      | 250               | 20                                    | ົ 270        |
| 4/13        | Dumpster S-9                                    | Yes      | 325               | 165                                   | 490          |
| 4/15 ··· E  | (illegible)                                     | Yes -    | 1200 <sup>b</sup> | • • • • •                             | 1200         |
| 4/15        | (Same as previous sample)                       | Yes      | 390 <sup>ь</sup>  | . 4: <i>1</i>                         | 390          |
| 4/15        | Same as previous two samples, .<br>fire stirred | Yes      | 1500 <sup>b</sup> | •                                     | 1500         |
| 4/21        | Background. Dumpster – Comb.<br>Raff.           | No       | 1320 <sup>b</sup> | 640°                                  | 1960         |
| 4/21        | Background. Dumpster NW4                        | No       | 1920 <sup>b</sup> | 131°                                  | 2051         |
| 4/21        | Background                                      | No No    | 4850 <sup>b</sup> | 11 - 11 - 11 - 11 - 11 - 11 - 11 - 11 | 4850         |
| 4/28        | None given                                      | Unknown  | 1500 <sup>b</sup> | 160°                                  | 1660         |

# Table K-2. Stack Sampling of the OSWI in April 1964 to Evaluate the Air

<sup>a</sup> As recorded on analytical data sheets. "Background" is interpreted to mean typical plant trash, as opposed to the uranium-contaminated organic materials being tested. <sup>b</sup>Sampled with pleated filter instead of impinger.

<sup>c</sup>Millipore backup filter.

. 31

Page K-10

Table K-3. Estimated Uranium Source Term from the OSWI, Based . 9 on Stack Testing in 1964

| Release .     |    | Percentile of Estim | nated Sourc | e Term Distribution | 1   |
|---------------|----|---------------------|-------------|---------------------|-----|
| Rate          | 5% | 25%                 | .50%        | 75%                 | 95% |
| g U per hour  | 3  | 16                  | 31          |                     | 120 |
| kg U per year | 6  | 34                  | 67          | 110                 | 250 |

OSWI before 1964, and most were analyzed only for gross alpha, not uranium. Ten samples collected on May 25, 1962 ranged from 61 to 1100 dpm alpha per cubic meter of flue gas. Four samples obtained from the top of the stack on May 11, 1962 ranged from 89 to 240 dpm alpha per cubic meter. If this activity were all due to natural uranium, these samples ·...

i.

represent a range of  $40-730 \ \mu g$  U per cubic meter of flue gas, which is well within the distribution defined by the 1964 measurements.

Category 2 information — Evaluation of uranium content of incinerator residues and mass balance considerations. In our draft source term report (Voillequé et al. 1991, we used a mass balance approach to provide a basis for the incinerator source term in the 1960s. We chose to use this method in order to take advantage of the large amount of data on uranium in incinerator and burn pit ash residues. The data were obtained by the FMPC to estimate the amount of recoverable uranium in the solid waste streams. The most complete evaluation located was by Stevenson (1968), who tabulated results of a comprehensive program to evaluate the uranium content and production of various plant wastes between October 21, 1967 and April 9, 1968. Production rates of the various types of wastes and the uranium content of the resulting residues after incineration were obtained from Stevenson (1968) and are listed in Table K-4.

In order to apply a mass balance calculation to the residue data, a release fraction (fraction released to air during incineration) is needed. One estimate of the release fraction was reported by Bostick et al. (1991) from emissions testing of uranium-contaminated wastes at the K-1435 Mixed Waste Incinerator in Oak Ridge, TN. These tests indicated that 2.9% of the uranium fed to the incinerator was discharged to stack gases (prior to air cleaning equipment). In addition, Glauberman and Loysen (1964) conducted a survey of AEC contractors to determine the extent of the use of incinerators and their effectiveness for uranium contaminated waste reduction. Two contractors operating incinerators without air cleaning equipment for uranium-contaminated wastes provided estimates of the percent retention of uranium in the ash. One estimate was 99% retention and the other was 95–100% (0–5% release). Four contractors operating incinerators with air cleaning equipment estimated 99% retention of uranium in the ash. For our assessment, we described the release fraction to flue gas as a triangular distribution with a most probable value of 3% and minimum and maximum values of 1 and 5%.

Based on the measured uranium content of incineration residues, plant-wide waste generation rates, and mass balance considerations, an airborne source term estimate for incineration was derived (See Table K-4 for explicit explanation of the calculation.) In addition to the uncertainty in the release fraction, the plant-wide waste generation rate, the %residue, and the %U in residue were also defined as uncertain parameters which were normally distributed with standard deviations of 10% of the mean.

The annual airborne source term calculated using this method is 100 kg U y<sup>-1</sup>. The distribution of the estimate is roughly normal, with a mean of 102 kg per year. The 5th-95th percentile range is 54-150 kg per year. This source term includes a 7 kg per year atmospheric source term from wastes routed to the burn pit (Table K-4).

Although the late 1960s provided the most data on uranium content of incinerator residues, earlier measurements were compiled from original data sheets and NLO memoranda. Because a number of "special burnings" were known to have occurred, the possible releases of uranium from those tests needed investigation. Figure K-4 illustrates the need for this analysis. The uranium content of incinerator residues from the special burning tests were considerably higher than those obtained for routine burning in the late 1960s and beyond.

Page K-12

1.1

٠:

### Table K-4. Mass Balance Approach to Estimate Uranium Releases to Air from Incineration of Solid Wastes at the FMPC During 1967–1968<sup>a</sup>

.5

| •                                                                                                             | ·                       |          |                                                              | Wast               | е Туре                   |                       |                   |
|---------------------------------------------------------------------------------------------------------------|-------------------------|----------|--------------------------------------------------------------|--------------------|--------------------------|-----------------------|-------------------|
|                                                                                                               | Oil<br>Burner<br>Sludge | Skids    | Shipping<br>Containers                                       | Sewage<br>Sludge   | Incinerator<br>Dumpsters | Burn Pit<br>Dumpsters | Total             |
| Average plant-<br>wide waste<br>generation rate (lb<br>waste d <sup>-1</sup> ) <sup>b</sup>                   | 233                     | 2500     | • 44.5 • 44.6 • 44.<br>• • • • • • • • • • • • • • • • • • • | 132                | 2238                     | 1194                  | 6500 <sub>.</sub> |
| % Residue <sup>b</sup>                                                                                        | . 35.4                  | 2.7      | • . <b>2.2</b> • . • •                                       | 35.2               | 11.6                     | 9.9                   |                   |
| Residue<br>generation rate (lb<br>residue y <sup>-1</sup> ),<br>based on 240<br>operating d y <sup>-1 b</sup> | <b>19,800</b>           | 16,200   | • <b>1100</b>                                                | 11,200             | 62,310                   | 28,370                | 139,000           |
| % U in<br>residue <sup>b</sup>                                                                                | 9.0                     | 12.21    | 6.0                                                          | "Nil" <sup>C</sup> | 4.48                     | 1.66                  | 5.1 <sup>.</sup>  |
| U in residue<br>(lb U y <sup>-1</sup> )                                                                       | 1780                    | 1978     | <b>66</b>                                                    | 112                | 2791                     | 471                   | 7200              |
| U in original<br>waste (lb y <sup>-1</sup> ) <sup>d</sup>                                                     | 1835                    | 2039     | ο το <b>68</b> το ματρ<br>το δ <u>α</u>                      | 115                | 2877                     | 486                   | 7420              |
| Airborne source<br>term <sup>e</sup> (lb U y <sup>-1</sup> )<br>(kg U y <sup>-1</sup> )                       | 55<br>25                | 61<br>28 | 1 - 1994 (1997)<br>1 - 1997 - <b>2</b> - <sup>793</sup><br>1 | 3<br>2             | 86<br>39                 | 15<br>7               | 220<br>100        |

<sup>a</sup> Significant figures shown to illustrate calculation, but do not imply this degree of precision.

<sup>b</sup> Based on evaluation of solid waste streams at the FMPC, conducted between October 21, 1967 and April 9, 1968 (Stevenson 1968).

and April 9, 1968 (Stevenson 1968). <sup>c</sup> Observed result of "nil" was believed by Stevenson (1968) not to be typical of FMPC sewage sludge, which historically had shown some uranium content. For the calculations in this table, an estimated value of 1% U in sewage sludge residue is used.

<sup>d</sup> From mass balance considerations, *i.e.*, U in original waste = U in residue +  $(1-f_a)$ , where  $f_a$  is the airborne release fraction, with a most probable value of 0.03 (see text).

<sup>e</sup> Airborne source term = U in original waste – U in residue.

an an teore in the foreigned of the foreigned sectors in the foreigned sectors. In the foreigned sectors in the Sectors are a sectors in the sectors in the foreigned sectors in the sectors in the foreigned sectors in the sec



Figure K-4. Uranium content of residues from incineration of solid wastes at the FMPC. With the exception of the Nov 3, 1956 burn, which occured at the burn pit, all residues were collected from the old solid waste incinerator. Data were obtained from analytical data sheets, IH&R department reports, Vath (1967), Audia (1969), Harmon (1973), and Kruezmann and Neblett (1976).

2

.

There were 18 days in 1956 when known special burning tests of contaminated solid waste took place at the FMPC. For 16 of those days, data were located on the uranium content of the residue. Using the mass balance approach described above, a source term for each burn was estimated (Table K-5). The footnotes to Table K-5 explain the methodology more explicitly. It was assumed that each special burn lasted for eight hours at the average feed rate of 750 pounds of waste burned per hour (Riestenberg 1978). In addition, the % residue was assumed to be 9%, which is the overall average including all waste types (Table K-4). The total source term for these 18 days of special burning is estimated to be 41 kg (median), which is about 40% of the annual source term from solid waste incineration in the 1960s. Because of the uncertainty in the airborne release fraction, the 5th-95th percentile interval is 22-61 kg.

Category 3 information — Environmental measurements of uranium and gross alpha activity in air and deposited on gumpaper around the incinerator. A number of environmental measurements around the OSWI were made in the 1950s, apparently to evaluate the possibility of incinerating various types of materials as well as to document the uranium losses. The reader is referred to Annex 1 of this Appendix for a chronological history of events relevant to incinerator testing in the 1950s. As mentioned previously, it is difficult to back-calculate a source term from environmental measurements, but they provide an important direct indication of contamination levels during particular events. For example, there were no residue data for two of the 18 known special burns in 1956 (Table K-5), but environmental measurements were made. These environmental data can also

indicate the rate of decrease of contamination with distance from the release point. The data presented in this section were obtained from original analytical data sheets, unless noted otherwise, and are discussed in chronological order.

|                      | FMPC                     | in 1956ª           |                      |                     |
|----------------------|--------------------------|--------------------|----------------------|---------------------|
|                      |                          |                    | kg U in              | Airborne            |
| Date of Special      | %U in                    | kg U in            | Original             | Release             |
| Burning Test         | <u>Residue</u>           | Residueb           | Waste <sup>c</sup>   | (kg U) <sup>d</sup> |
| 26 May               | NDe                      | •                  |                      |                     |
| 7 June               | ND <sup>e</sup>          | •••••              | •                    |                     |
| 23 June              | 18.1                     | 44.42              | 45.79                | 1.37                |
| 30-June              | 0.6                      | 1.59               | 1.63                 | 0.05                |
| 5-July               | 2.3                      | 5.58               | 5.76                 | 0.17                |
| 18-August            | 28.9                     | 70.86              | 73.05                | 2.19                |
| 26-August            | 35.4                     | 86.89 <sup>.</sup> | 89.57                | 2,69                |
| 9-September          | 51.6                     | 126.5              | 130.4                | 3.91                |
| 17-September         | 60.78 -                  | 149.1              | - 153.7              | 4.61                |
| 22-September         | 36                       | 88.34              | <sup>(**</sup> 91.08 | 2.73                |
| 29-September         | <b>30</b>                | 73.62              | 75.9                 | 2.28                |
| 6-October            | 46.5                     | 114.1              | 117.6                | 3.53                |
| 13-October           |                          | 58.9               | 60.72                | 1.82                |
| 20-October           | 12.8                     | 31.41              | 32.38                | 0.97                |
| 28-October           | 22.4                     | -54.97             | 56.67                | 1.70                |
| 3-November           | <b>76.8</b> <sup>-</sup> | 188.5              | 194.3                | 5.83                |
| 11-November          | . 76                     | 186.5              | 192.3                | 5.77                |
| 17-November          | 19                       | 46.63              | 48.07                | 1.44                |
| an an Arran an Arran | 07 801.91 G              | TOTAL              |                      | 41                  |

### Table K-5. Estimate of Airborne Uranium Source Terms From Known Special Burns of Contaminated Solid Waste at the EMPC in 1956<sup>a</sup>

<sup>a</sup> Significant figures shown to illustrate calculation, but do not imply this degree of precision.

<sup>b</sup> kg U in residue = 750 lb waste h<sup>-1</sup> × 8 h d<sup>-1</sup> × 0.4545 kg lb<sup>-1</sup> ×
0.09 kg residue (kg waste)<sup>-1</sup> × kg U (kg residue)<sup>-1</sup> (column 2).
<sup>c</sup> From mass balance considerations, *i.e.*, U in original waste = U in residue + (1-f<sub>a</sub>), where f<sub>a</sub> is the airborne release fraction, with a most probable value of 0.03 and a range from 0.01 to 0.05.
<sup>d</sup> Airborne source term = U in original waste - U in residue.
<sup>e</sup> No data. However, see environmental measurements in next section.

On May 26, 1956, there was a special burning of contaminated gloves in the OSWI. The wind was from the SW at about 6–8 mph, and there was a drizzle to light rain throughout the day. The measured alpha deposition to gumpaper as a result of this test is illustrated in Figure K–5, and measurements of gross alpha activity in air are tabulated in Table K–6. The gumpaper data suggest a rapid decrease in uranium contamination within 100 m of the incinerator.

1



::**:** 

1

 $\sim$ 



From Table K-6 and other similar tables to follow, it can be seen that the incineration operation was dusty, with relatively high airborne contamination levels present on the platform where waste was dumped and fired. For some of these special burning tests, the analytical data sheets note that the incinerator operator was wearing respiratory protection. The concentrations in air downwind of the incinerator during the test were quite low, but sampling times were short, and the uncertainties in the measurements would be high. As discussed in Shleien et al. (1993), the conversion of gross alpha concentration measurements in air to uranium concentration is subject to large uncertainty for these short count rates and times. We view the gross alpha activity measurements as a qualitative indication of uranium contamination around the OSWI, and have not used them to reconstruct release estimates.

t :

1.000

· • ......

| Gioves in the Old Solid Waste Incinerator on May 20, 1950 |                                          |               |                                        |  |  |  |
|-----------------------------------------------------------|------------------------------------------|---------------|----------------------------------------|--|--|--|
|                                                           | Approximate                              | •             | dpm alpha                              |  |  |  |
| Location                                                  | Distance from                            | Number of     | m <sup>∽3</sup> (range                 |  |  |  |
| · · · · · · · · · · · · · · · · · · ·                     | Stack (m)                                | Samples       | of values)                             |  |  |  |
|                                                           | 1 42 2 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | ······        | ······································ |  |  |  |
| General area sample on incinerator                        | Not                                      |               | 624 <sup>b</sup>                       |  |  |  |
| platform                                                  | Applicable                               | 9             | nd <sup>c</sup> – 1267                 |  |  |  |
| Breathing zone sample on incinerator                      | . Not                                    |               | 653 <sup>b</sup>                       |  |  |  |
| platform                                                  | Applicable                               | .: 9          | nd – 1226                              |  |  |  |
| 5 Stack Lengths in the E, N, and W                        |                                          |               | ••                                     |  |  |  |
| directions                                                | 55                                       | 6             | 4-7                                    |  |  |  |
| 10 Stack lengths in the E, N, and W                       | ••• •• •                                 |               | • •                                    |  |  |  |
| directions                                                | 110                                      | 6             | nd – 3                                 |  |  |  |
| 15 Stack lengths in the E, N, and W                       |                                          |               | * .                                    |  |  |  |
| directions                                                | - 165                                    | <b>6</b>      | nd – 5                                 |  |  |  |
| 25 Stack lengths in the E. N. and W                       | ~                                        | ·· · ·        | '                                      |  |  |  |
| directions                                                | 274                                      | 3             | nd-1                                   |  |  |  |
| 100 Stack lengths in the E, N, and W                      | - ·                                      |               |                                        |  |  |  |
| directions                                                | 1100                                     | 3             | nd _ 2                                 |  |  |  |
| a In addition to these general air                        | and breathing zone s                     | amples, one 2 | 230-min stack                          |  |  |  |

ತ ಪ್ರತಿಗಳನ್ನು ಸಾಧ Table K-6. Air Dust Samples Taken During a Special Burning of Contaminated

sample collected during the test was 118 dpm alpha per cubic meter air. aa filay **`**.

141.

<sup>b</sup> Average

• -

c "nd" = Not detectable

. NEED A REP. On June 7, 1956, a second special burning of contaminated gloves took place at the OSWI. Air dust samples taken during the test are tabulated in Table K-7. The wind was from the west, was very light and somewhat variable. The time of the test burn was 5:00 PM to 10:00 PM. In addition to the environmental measurements shown, one stack sample collected during the duration of the test contained 1080 dpm alpha per cubic meter air.

> - <u>5 5</u> 6 • - • • з.

| Contaminated Gloves in the<br>Location                                             | Old Solid Waste Incir<br>Approximate<br>Distance from<br>Stack (m) | Number of<br>Samples | une 7, 1956<br>dpm alpha<br>m <sup>-3</sup> (range<br>of values) |
|------------------------------------------------------------------------------------|--------------------------------------------------------------------|----------------------|------------------------------------------------------------------|
| General area sample on incinerator<br>platform                                     | Not                                                                | 24                   | 131ª<br>8 – 662                                                  |
| directions                                                                         | 88                                                                 | 9                    | $nd^b - 10$                                                      |
| 10 Stack lengths in the NE, E, and SH                                              | C                                                                  |                      |                                                                  |
| directions                                                                         | 110                                                                | 18                   | nd – 5                                                           |
| <sup>a</sup> Average. Samples taken while dr<br><sup>b</sup> "nd" = Not detectable | ums were dumped, glov                                              | es spread out        | and burned.                                                      |

| Appendix K        |                         |               |
|-------------------|-------------------------|---------------|
| Other Sources and | Episodic Releases to th | ie Atmosphere |

On June 27, 1956, 10 air dust samples were taken on the incinerator platform, while dumping and burning of papers was occurring. There was no notation of the type of waste being burned (i.e. contaminated or not). The samples ranged from 3 to 78 dpm alpha per cubic meter.

On June 29, 1956 another set of air dust samples downwind of the incinerator were taken between 8:45 AM and 2:30 PM (Table K-8). There is no notation of the type of waste being burned.

| Location                              | Approximate<br>Distance from<br>Stack (m) | Number of<br>Samples | dpm alpha<br>m <sup>-3</sup> (range<br>of values) |
|---------------------------------------|-------------------------------------------|----------------------|---------------------------------------------------|
| 5 Stack lengths to the NE (downwind)  | 55 ·                                      | 6                    | nd <sup>a</sup> –15                               |
| 20 Stack lengths to the NE (downwind) | 220                                       | 6                    | 1-17                                              |
| 25 Stack lengths to the S (downwind)  | 270                                       | 2                    | 2 - 7                                             |
| a "nd" = Not detectable               | · ·                                       |                      |                                                   |

### Table K–8. Air Dust Samples Taken During a Burning at the Old Solid Waste Incinerator on June 29, 1956

A load of contaminated shoes was burned at the incinerator on June 30, 1956. The wind during the test was light (4-6 mph) and variable in direction. There were several types of samples taken during that run. The ash which resulted from this test burn was only 0.6% U (Table K-5), indicating that the shoes were not highly contaminated. A 135-min stack sample contained 573 dpm alpha per cubic meter of sampled air. A 154-min high-volume air sample from the base of the incinerator stack (assumed to be outside) measured a concentration of 0.79 dpm alpha per cubic meter air. Twelve air dust samples collected on the incinerator platform, while shoes were burning and were being dumped out of drums and put into the incinerator, ranged from <1 to 224 (average: 54) dpm alpha per cubic meter. A gumpaper sample about 10 stack lengths (110 m) to the E contained roughly twice as much uranium (1 mg per sample) as three other samples placed 10 stack lengths to the N, 25 stack lengths to the NE, and 30 stack lengths to the SW (about 0.4 mg U per sample).

On two separate days in March 1957, air dust samples were taken at varying distances from the incinerator in the downwind direction. The location of the samples was noted on the analytical data sheets as a certain number of paces from the fence. On March 4, the wind was from the NE from 5 to 15 mph and gusty. The first sample was taken at the fence SW of the incinerator. From a recent scale map of the sewage treatment plant area (DOE 1992), we determined that this distance is about 30 feet. The March 4 and March 20 data are plotted together in Figure K-6, assuming a "pace" is equal to 2.5 feet.

> Radiological Assessments Corporation "Setting the standard in environmental health"

.





.

1

ġ,

۶.

.

10.00

À

1000000

5

÷

ş

Figure K-6. Measurements of gross alpha in air with distance downwind from the incinerator on March 4 and March 20, 1957. Values plotted for March 20 are the averages of two 10-min replicate samples at each distance.

On May 4, 1957, 110 drums of contaminated clothing and 15 drums of dust collector filter bags were burned in the incinerator. The IH&R monthly report indicated that the air dust and fallout samples were higher than normal. We located the original analytical data sheets for samples taken during this test. Table K-9 shows the results of air dust samples. The results could indicate that greater deposition occurred at farther distances from the incinerator than the March 1957 tests would indicate. However, the uranium content of the waste being burned was very inhomogeneous, and the samples shown in Table K-9 were taken sequentially throughout the day. The close-in sampling began at 9:30 AM and the farthest sampling was finished around 2:00 PM. The general air samples on the incinerator platform show great variability, depending on whether or not filters bags were being dumped and fired. Therefore, we suspect that the effluent from the stack was similarly variable. The magnitude of the contamination measured in air does indicate that this burn was likely to be one of the more important test burns which have lead to local contamination from the old solid waste incinerator. and a set of the top the the 1.1

and a first state of the

There in the second

the stander the term

States a self of the

1121

the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of

•

.

· · ·

: -1

·... ·.

54. 14

1.1.1

# Appendix K Other Sources and Episodic Releases to the Atmosphere

, iz Ç

. ا

1

|                                                               |                         | dpm alpha per cubic meter |                    |
|---------------------------------------------------------------|-------------------------|---------------------------|--------------------|
| Location                                                      | Number of Samples       | average                   | range              |
| General area sample on<br>incinerator platform <sup>a</sup>   | 5                       | 685 <sup>b</sup>          | 3 – 2692           |
| Breathing zone sample on<br>incinerator platform <sup>a</sup> | 7                       | 2201                      | 13 - 7426          |
| 11 m downwind                                                 | <b>2</b> ·              | 4                         | 2-6                |
| 28 m downwind                                                 | 2                       | 3                         | 2-4                |
| 33 m downwind                                                 | 2                       | NA                        | nd <sup>b</sup> –2 |
| 55 m downwind                                                 | 4                       | 6                         | 5-8                |
| 88 m downwind                                                 | 4                       | - 38                      | 26-50              |
| 110 m downwind                                                | 4                       | 26                        | 3-43               |
| 132 m downwind                                                | 4                       | 10                        | 4–19               |
| <sup>a</sup> Operation was very dus                           | sty. Operators wore res | spirators. The            | highest values     |

| Table K–9. Air Dust Samples Taken During a Special Burning of        |
|----------------------------------------------------------------------|
| Contaminated Clothes and Dust Collector Filter Bags in the Old Solid |
| Waste Incinerator on May 4, 1957                                     |

<sup>a</sup> Operation was very dusty. Operators wore respirators. The highest values were measured during dumping and firing filter bags. <sup>b</sup> "nd" = Not detectable

The important conclusions which can be drawn from the air and gumpaper sampling data from the 1950s are that operations at the OSWI were dusty, with airborne contamination on the platform requiring respiratory protection, at least during burning of some types of wastes. The contamination levels appear to drop off rapidly within the first few

contamination on the platform requiring respiratory protection, at least during burning of some types of wastes. The contamination levels appear to drop off rapidly within the first few hundred meters of the source. Because of the short sampling times and the fact that gross alpha activity rather than uranium measurements were made, these data were used for qualitative purposes only.

One other set of environmental measurements from the 1960s was examined to see if it would shed light on reconstruction of airborne source terms from the OSWI. Klein (1963, 1964) briefly described the results of a 19-month study of fallout around the OSWI and the oil burner (discussed in the next section of this appendix). During the study, special gumpaper stands were placed downwind (adjacent and NE) from the two incinerators. Uranium deposition at these stations was compared to that measured on gumpaper at other nearby permanent stations in order to determine the extent of fallout due to the incinerators. We determined the locations of the special gumpaper fallout stations from an undated map which indicated their positions. The special station near the OSWI is about 40 m to the NNE. These data are compared to those collected at the permanent station E-2, which is about 200 m to the NNE of the OSWI and directly east of the center of the production area. Klein (1964) concluded that fallout in the area of the OSWI was 2.7 times greater than that at the nearby permanent station.

We located the original analytical data sheets for these measurements to examine the results more closely. First, the original data were corrected for the collection efficiency of gumpaper for particulates, which is 15% for a weekly exposure period and 14% for the monthly exposure period (Shleien et al. 1993). The corrected cumulative deposition to gumpaper for the 19-month period February 1963 through September 1964 was 19.1 g m<sup>-2</sup> at

the OSWI gumpaper station and 6.0 g m<sup>-2</sup> at the E-2 station. Thus, the net deposition, due to the OSWI airborne source term, would be 690 mg m<sup>-2</sup> mo<sup>-1</sup>, or 23 mg m<sup>-2</sup> d<sup>-1</sup>.

### Evaluation of Airborne Source Term From Ash Handling at the OSWI

As early as 1958, Ross writes: "A ground survey of the area where ashes are shoveled out of the furnace and into drums shows some surprisingly high results. These are caused by spillage from the shovels. It is probable that a wind break or some type of enclosure around this area would lessen the ground contamination by preventing ashes from being blown about while they are being drummed." As late as 1972, a request was made to black top the area around the incinerator, because this crushed stone area had become contaminated due to spills (Farr 1972).

Current soil sampling confirms that the OSWI was a significant source of local environmental contamination. The soil sampling results from the Remedial Investigation and Feasibility Study (RI/FS) indicate that concentrations of radionuclides in the soils adjacent to the solid waste incinerator are well above background levels. The two highest samples, closest to the incinerator showed 25,670 pCi g<sup>-1</sup> and 2376 pCi g<sup>-1</sup> of <sup>238</sup>U (Anonymous 1990). For perspective with residue values presented earlier in this appendix, ash containing 8% U is equivalent to about 53,000 pCi g<sup>-1</sup> total U (27,000 pCi g<sup>-1</sup> <sup>238</sup>U). The soil contamination extends toward the ENE from the OSWI (Figure K-7).

Evaluation of airborne releases from non-routine events at the FMPC, including solid spills, is discussed later in this appendix. There were no emission factors located which would apply to this particular situation (hand-shoveling of ash into drums). The amount of ash handled per year is fairly well known (Table K-4), but the fraction which could have been spilled is unknown. In addition, not all of the spilled material becomes airborne; in fact only about 0.5% becomes airborne, according to EPA emission equations (discussed in the non-routine events section). The parameters used in our evaluation of this source term are listed in Table K-10. Spillage of 5% of the total ash handled in a year is equivalent to about 7000 lbs of ash, or 160 kg U. However, the estimated median amount becoming airborne is 2 kg U per year (5-95% interval of 0.4 to 6 kg). This estimated airborne release due to ash handling is <3% of the uranium estimated to be released via the stack during the 1960s.

| Resus                                                              | pension of S  | pilled Incinerator         | Ash in the       | 1960s                                                      |
|--------------------------------------------------------------------|---------------|----------------------------|------------------|------------------------------------------------------------|
| Parameter                                                          | Minimum       | Most Probable <sup>a</sup> | Maximum          | Basis                                                      |
| Ash residues handled<br>y <sup>-1</sup> (metric tons) <sup>b</sup> | 62.5          | 69.5                       | 76.4             | Stevenson (1968)                                           |
| Percent of residue<br>spilled                                      | 1%            | 5%                         | 10%              | Assumption                                                 |
| Percent of spilled<br>residue becoming<br>airborne                 | 0.03%         | 0.5%                       | . 3%             | See discussion under<br>"Non-routine<br>Releases" section. |
| % U in residue                                                     | .1%           | 5.1%                       | 12.2%            | See Table K-4.                                             |
| <sup>a</sup> Triangular distributio                                | n assumed for | uncertainty analysis       | 3.<br>s estimate | ·                                                          |

| Table K-10. Assumptions Used in Uncertainty Analysis of Source Term | from |
|---------------------------------------------------------------------|------|
| <b>Resuspension of Spilled Incinerator Ash in the 1960s</b>         |      |

......



1

.

•••

29

Figure K-7. Regions of higher radioactivity of uranium in the soil at the FMPC, based on plots from RI/FS measurements (Frazier 1990). The regions at the far right of the figure are associated with the old solid waste incinerator.

Radiological Assessments Corporation "Setting the standard in environmental health" 11

12.11.21

194 - A. A.

# Summary of Revised Source Term Estimates for the Old Solid Waste Incinerator

۰, and an and the Table K-11 summarizes our revised source term estimates for the OSWI and the basis for those estimates. A number of original analytical data sheets, letters, memos, and engineering drawings were studied in developing these estimates, but the primary bases are highlighted here. The estimate for the 1970–1979 period was based on 1977 stack testing and a reduced operating schedule as compared to the previous time periods. The estimate for the 1960s was based on 1964 stack testing as well as a mass balance calculation. The source term estimate for the 1950s was increased over the 1960s by 40 kg per year, based on our analysis of the special burn tests in 1956 (Table K-5). Also, the waste generation rate and the general contamination level of the waste were likely higher in the 1950s than the 1960s, which supports a higher source term for the 1950s, even if special burning did not occur every year. The total estimated release of uranium from the OSWI from 1954–1979 is 2200 kg, with a 5th-95th percentile range of 1600-2900 kg. Over 75% of the total release occurred before 1970. Although handling of incinerator ash resulted in localized contamination, our estimate of airborne release due to these activities is only 2–3 kg per year throughout the 1950s and 1960s. handstenders in sta .

States and the second

· · · ·

|                                                                                                                   | g U released<br>per hour of<br>operation                                | kg U per year<br>released via<br>stack                           | Basis                                                                                                                                                   |
|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1954                                                                                                              | NA                                                                      | 20<br>101111                                                     | Based on 1 1/2 months at the 1955 release rate.                                                                                                         |
| 1955–1959                                                                                                         | NA                                                                      | 140 <sup>a</sup><br>(94–190) <sup>b</sup>                        | 1960s mass balance evaluation + 40 kg y <sup>-1</sup><br>additional release for more highly<br>contaminated waste and greater waste<br>generation rate. |
| 1960–1969                                                                                                         | 31<br>(3–120) <sup>b</sup>                                              | 67 <sup>a</sup><br>(6–250) <sup>b</sup>                          | 1964 stack tests.                                                                                                                                       |
| •••                                                                                                               | · · ·                                                                   | 100 <sup>a</sup><br>(54–150) <sup>b</sup>                        | Mass balance calculations. <sup>d</sup>                                                                                                                 |
| 1970–1979 .                                                                                                       | 27–77°                                                                  | 52ª<br>(20–78) <sup>b</sup>                                      | 1977 stack tests.                                                                                                                                       |
| <sup>a</sup> Estimated me<br><sup>b</sup> 5th–95th perc<br><sup>c</sup> Measured ran<br><sup>d</sup> Used in comp | edian. Distributi<br>centile range<br>age of values<br>utation of total | ion shape throu<br>State State<br>State State<br>releases from O | gh 1969 is roughly normal.<br>SWI.                                                                                                                      |
| 1                                                                                                                 |                                                                         | 5 12 .20 21 vi 2 -                                               |                                                                                                                                                         |

Appendix K 👘

ġ.

70

### Other Sources and Episodic Releases to the Atmosphere

#### OIL BURNER (1962–1979)

Two other incinerators, the oil burner and the graphite burner, were located within the production area north of the boiler plant (Figure K-8). Waste oil generated at FMPC was primarily mineral oils and coolant or cutting oils. Some extraction solvents were also mixed in with these liquids. The mineral oils came from garage operations and the changeover of oils in equipment such as gear boxes and hydraulic systems. Most of these oils were described as only slightly contaminated (Boback 1972). Oil was also used to cover the chips packaged in steel drums during shipment from Mallinckrodt Chemical Works (MCW) to FMPC (Mead 1972). At FMPC the oil was drained from the chips and then decanted to remove sludge. The decanted oil was shipped to MCW for reuse, although some excess oil was processed at the FMPC oil burner facility.

In the early years of FMPC operations, waste oil was burned outdoors in the open, in shallow pans which each burned 100-150 gallons per day. Also, oil was dumped over burnable solid trash for combustion in an on-site burn pit (see discussion above). Both techniques were halted because of the heavy smoke produced (Boback 1972). There also were several attempts to adapt the Scrap Recovery Plant to burn contaminated oils with conventional burners or existing equipment (Brandner et al. 1963); however, there were process difficulties and high air dust levels.

Brandner et al. (1963) describe the incineration of waste contaminated oil at the FMPC. They divided the over 100 classes of waste liquid organic material stored at the FMPC into four principal types:

- 1. Mineral Oils. Typically containing 2-4 g  $L^{-1}$  uranium, and accompanied by a water phase which is usually lower in uranium content. Sludges which had settled to the bottom of some of these drums ranged from 5-10% uranium.
- 2. Emulsions. Uranium levels of 5-10 g  $L^{-1}$  were typical for emulsions and for any accompanying water phase below the emulsion.
- 3. Waste Extraction Solvent. Uranium levels of 2-4 g L<sup>-1</sup> in the TBP-kerosene solvents were typical.
- 4. Wastes Rich in Chlorinated Hydrocarbon Solvents. Not amenable to incineration since they would require careful blending and decomposition products would be highly toxic.

Only the first two types of liquid organic waste material were being incinerated in 1963 (Brandner et al. 1963).

#### History and Operation of the Oil Burner

This section gives an overview of the history and operation of the oil burner. In addition, a more detailed chronological history of notes and information, gathered mainly from historic reports of the Industrial Hygiene and Radiation (IH&R) Department, is included as Annex 2 to this appendix.

The oil burner was constructed in early 1962. Boback et al. (1987) give the start-up date as March 31, 1962. Brandner et al. (1963) indicate that other refinements and modifications

were made that year, including procedures and equipment for preparing feed and regulating burning conditions. Eventually, the oil burner system consisted of a series of five treatment tanks, an oil pre-heat tank, and a five-foot-square refractory brick enclosure with a 3 x 3 ft square stack which housed the stainless steel burner pot (Boback 1972).



and the set of the set of a different to

. . . . . . . . .

.. ..

Figure K-8. Map of FMPC production area, showing location of the oil burner (operated 1962-1979), the graphite burner (operated 1965-1984), and the new incinerator building, which housed the new solid and liquid waste incinerators in the 1980s. The circles represent the locations of selected gumpaper fallout stations used to measure deposition of uranium (discussed in text). The location of the "SP" station is very approximate.

#### Appendix K

.

### Other Sources and Episodic Releases to the Atmosphere

The four main operational steps' for the oil burning operation, (1) cold or warm feed preparation, (2) oil heating, (3) pot feeding, and (4) oil burning are described in some detail in Brandner et al. (1963). In addition, the standard operating procedure for the burner was located and reviewed (Baer 1966a). The water fraction was routed to an open evaporator where the water was boiled away by a high temperature steam coil. The oily sludge generated during preparation of the oil burner feed was drummed and sent to the solid waste incinerator, where the resulting incinerator ash was routed to the Recovery Plant. Feed rate to the burner was controlled by a valve above the feed pan to about 20–30 gal  $h^{-1}$ (Brandner et al. 1963).

The oil burner was operated with a forced draft of excess air, in order to limit smoking. Brandner et al. (1963) indicate that this high pressure draft system was supplied by compressed air and a low pressure draft system was supplied by a fan. Both systems were adjustable both in location and direction of air input to keep the off-gas clean. Boback (1972) indicates that the 1/2" high pressure line delivered 100 psi air to a point about 12" above the burner pot. Low pressure air was supplied by a fan located near the burner enclosure, providing air at six locations in the enclosure, through ducts which had blast gates for air control at each entry point.

Stack testing for particulate emissions from the oil burner were conducted on May 13, 1976 (Ross 1976). These data were the only measurements located which provide data on the velocity and temperature of stack gases (shown in Table K-12), although the values were confirmed by later handwritten notes (Grant 1986). The resulting calculated particulate emission rate from the oil burner (1.8 lb h<sup>-1</sup>) did not meet the Ohio EPA standard of 0.2 lb per 100 lb of material burned in an incinerator having a capacity less than 100 lb h<sup>-1</sup> (Ross 1976). However, the old oil burner was not shut down until June 15, 1979. A new liquid organic waste incinerator began operating in the incinerator building (Figure K-8) in the spring of 1983 (Boback et al. 1987).

Table K-12 summarizes the physical and operating parameters for the oil burner. Particle size considerations for effluents from all incinerators are discussed later in this appendix.

### **Previous Uranium Release Estimates for Oil Burner**

Previous uranium release estimates for the oil burner presented by Boback et al. (1987) were supplied by Neblett (1985), based on "knowledge gained from supervising these operations and from waste management's project assignments in the past". Neblett believed that data to substantiate these estimates were not available, and that the records for these operations had long since been discarded. A flow diagram showing his estimate is shown as Figure K-9. In 1962, the annual release was estimated to be 20 kg y<sup>-1</sup>, rather than 27, because the burner started operation after the first three months of the year. The total estimated release over the entire operating history would be ~470 kg U.

| Page | K–26 |
|------|------|
|------|------|

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

~

いいうかい

12.23

والإندار

3 5

| Table K-3 | 12. Summary | of Physical and Op | erating Parameter | rs for the Oil Burner |
|-----------|-------------|--------------------|-------------------|-----------------------|
|           |             | (Operated 3/31/    | '62 to 6/15/79)   | -                     |

| Parameter                                                       | Value                                     | * Reference                           | Notes                                                                                                         |
|-----------------------------------------------------------------|-------------------------------------------|---------------------------------------|---------------------------------------------------------------------------------------------------------------|
| Physical stack<br>height                                        | 15 ft                                     | Engineering<br>drawing<br>10X-M-00322 |                                                                                                               |
| Building<br>dimensions                                          | 5 x 5 x 5 ft                              | Engineering<br>drawing<br>10X-M-00322 | Cubic shaped outer structure tapers to<br>3-foot x 3-foot stack with total height of<br>15 feet above ground. |
| Stack inner<br>dimensions <sup>a</sup>                          | 20 x 20 inches<br>(2.78 ft <sup>2</sup> ) | Engineering<br>drawing<br>10X-M-00322 | Outer dimensions of stack were $3 \times 3$ ft.<br>Stack composed of 8" thick firebrick.                      |
| Exhaust gas<br>velocity<br>(ft min <sup>-1</sup> ) <sup>a</sup> | 350400                                    | Ross 1976<br>Grant 1986               | Measured with rotating vane<br>anemometer during particulate<br>emission test.                                |
| Exhaust gas<br>temperature                                      | 120–200 °F                                | Ross 1976                             | Estimated temperature of stack gases<br>at particulate sampling point and at<br>metering orifice.             |

<sup>a</sup> The cross sectional area at the point where velocity was measured was about 12 ft<sup>2</sup>, for a volumetric flow rate of 350 fpm  $\times$  12 ft<sup>2</sup> = 4200 actual cfm (3373 standard cfm) according to Ross (1976). The velocity in the upper part of the stack would have been 4200 cfm + 2.78 ft<sup>2</sup> = 1500 fpm (disregarding cooling of gases) or 1200 scfm.



÷i 19922.1 Figure K-9. Basis for previous estimates of releases of uranium from oil burner (from Neblett 1985).

### Appendix K

### Other Sources and Episodic Releases to the Atmosphere

Neblett's exhaust emission rate of 40 lbs of particulate material per day (Figure K-9) is reasonable based on measurements during the emissions test (Ross 1976), which resulted in an estimate of 1.8 lb  $h^{-1}$  (43 lb per 24-h day). An evaluation of the other parameters in his estimate requires a more in-depth look at historic records. Our review of historic documentation and revised source term estimates are presented in the following sections.

Evaluation of Historic Documentation to Reconstruct Uranium Source Terms from the Oil Burner

A number of original sources of documentation were located and carefully reviewed to permit a reconstruction of the source terms for the oil burner. During this process, a chronological history of important events and other notes was compiled, which is included as Annex 2 to this appendix. This annex provides a detailed record of relevant changes and correspondence which was used to aid interpretion of the original data. It also includes information on burning of oils before the final oil burner was constructed in 1962. The types of quantitative information which were evaluated to estimate the source term from the Oil Burner fall into the following categories:

- Category 1. Processing rate information (operating schedule).
- Category 2. Materials balance information.
- Category 3. Measurements of uranium and gross alpha activity in stack gases.
- Category 4. Environmental measurements of uranium and gross alpha activity in air and deposited on gumpaper around the incinerator.

There were very few category 3 stack measurements which would permit a credible reconstruction of the source term from those data alone. Therefore, we searched for processing rate and materials balance information (categories 1 and 2) to derive source term estimates. In doing so, it was apparent that the operating schedule of the oil burner was heavy in the year or two immediately after construction, and then tapered off. Thus, while it may be a reasonable long-term average, the previous constant source term estimate by Neblett did not reflect these variations. Category 3 and 4 information was collected and reviewed for verification of the source term estimates.

Category 1. Processing rate information. The processing rate was important to examine for source term reconstruction, because in later years the oil burner was only operated whenever the oil inventory levels reached sufficient size to permit a production campaign (Mead 1972). However, there was a large backlog of contaminated liquids accumulated by 1962. Coates (1962) estimated a total inventory of contaminated burnables at 2812 drums (112,480 gal) of burnable oil (includes 237 drums of emulsions), 3599 drums (143,960 gal) of other organic solvents (trichlor, perchlor, TBP-kerosene), and 700 drums (21,000 gal) of "enriched" organics in August 1962. (The non-metric unit of "gallons" is used throughout this section because that is the unit typically used in the original sources.) Coates noted that operation of the oil burner would begin on a 3-shift-per-day basis as soon as lights and other required changes could be installed. The oil burner was started as a production unit operating 24 hours per day, five days per week in January, 1963 (Brandner

> Radiological Assessments Corporation "Setting the standard in environmental health"

نې د د

Sec. . .

i 1.

10 A 10

いうちょう

et al. 1963). Boback (1972) indicated that the oil burner, which consumed about 500 gallons per day on a 3-shift schedule, eliminated the backlog of contaminated liquids by August 1964.

We located handwritten ledgers (Anonymous, 1964–1968) titled "Oil Burner and Incinerator Operations" for January 1964 through December 1968, as well as a number of monthly memoranda titled "Resume of Oil Burner and Incinerator Operations During the Month of [Month, Year]," which confirmed the data on the ledgers. In addition, the total waste processing rate for 1969 was given as 32,500 gallons in Anonymous (1970). Figure K-10 illustrates the waste processing and oil burning trends at the FMPC. Because the earliest ledgers were for 1964, values for 1962 and 1963 were estimated based on the following premises:

- 1. Processing at one shift per day in 1962 and three shifts per day in 1963 (Coates 1962, Brandner et al. 1963);
- 2. Consumption of the entire backlog of liquids given by Coates (1962) between September 1962 and August 1964 (as indicated by Boback 1972);
- 3. Continuous receipt of waste at a baseline rate of 7200 gallons per month (based on 1965 monthly average waste processing rate, after backlog was consumed).

, ·

The estimated peak processing rate of 271,000 gallons of waste in 1963 is well within the capabilities of the oil burner system, which was stated by Brandner et al. (1963) to be capable of consuming 400-700 55-gal drums of waste per month, which would translate to 264,000-462,000 gallons per year, under continuous processing conditions.

On average, 0.5 gallon of oil was burned per gallon of waste processed (determined from data in Anonymous 1964–68). The majority of the remainder of the waste volume was void space in the drums, water, or sludge, which was processed separately.





# Appendix K Other Sources and Episodic Releases to the Atmosphere

- 1

Neblett's estimate of 290,400 pounds of oil burned per year would correspond to about 39,100 gallons of oil burned per year, assuming a specific gravity of 0.89 (ranged from 0.88–0.90 on analytical data sheets). This value is a factor of three less than that actually burned in 1964 (Anonymous 1964-1968), but agrees very well with the six-year average for 1964-1969 (38,900 gallons oil burned per year). In 1975, Stevenson estimated the waste processing rate at the oil burner at 7500 gallons per year of waste lubricating oils and 1200 gallons per year of spent TBP-kerosene solvents. This total of 8700 gallons per year shows a further decrease in the processing rate to 22% of the six-year average for 1964–1969. Perkins (1976) indicated a current operating schedule of 4–6 weeks per year with a throughput of  $\approx$ 45 kg per hour, which translates to 9000–13,000 gallons per year.

Category 2. Materials balance information. The most relevant original data located from FMPC records was from a materials balance test in October 1961. This test was performed in a prototype oil burner. Approximately 570 gallons of various types of oil were burned, resulting in recovery of about 16.4 pounds of uranium from the waste (DeFazio 1962). A rough draft of DeFazio's letter (dated 2/23/62) gives more information on the results of the mass balance tests than the final letter:

"On October 9, 1961, a materials balance test was started which lasted for six days. The results are as follows:

Oil burned 569 gallons - 4270 pounds Average U concentration 3.7 g U/l Specific gravity of oil 0.90 Total U in 569 gallons 17.6 pounds Total ash after burning 45 pounds Weight of dry ash 44 pounds Heavy sludge from bottom of tank 17.5 pounds U concentrations in ash 35.7% U concentrations in sludge 3.9% U recovered from burning

> (44 lbs. ash at 35.7% U) = 15.7 lbs. (17.5 lbs. sludge at 3.9% U) = .7 lbs.

A total of 16.4 pounds of U recovered from 569 gallons of oil, or 16.4 pounds from a total of 17.6 pounds, equals approximately 90% recovery."

We located the original analytical data sheets for this materials balance test, which according to the sheets, began October 13th, rather than October 9th. We were able to verify the data summarized by DeFazio, with the exception of the concentration of uranium in the oil burned. No analytical data sheet was located for this measurement; however, this concentration (3.7 g U per liter) is within the typical range for waste oil and solvents at the FMPC (Brandner et al. 1963). In addition to the data summarized above, there were also measurements of gross alpha activity in air at short distances from the burner during the test. However, these data were were not analyzed further, because they are not as relevant as similar measurements taken in and around the final oil burner, which was constructed the following year.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

にもわれる

.

ĥ

The 1961 materials balance test provides an estimate of 90% recovery of uranium in the ash and sludge. The release to air, presuming any other losses are negligible, would be 10% of the uranium in the original feed material. Because there was no replication of the test or the measurements, no uncertainty can be assigned to that release fraction estimate. However, other estimates of the release fraction from burning U-contaminated waste, including oil, were located in the scientific literature. Bostick et al. (1991) measured a release fraction of 2.9% to off-gas (prior to air-cleaning equipment) for uranium in contaminated oil fed to the Oak Ridge mixed waste incinerator. AEC contractors operating incinerators for uranium-contaminated materials in the 1960s reported release fractions of 0-5% (Glauberman and Loysen 1964).

A source term estimate can be developed from the materials balance information, using the uranium content of oils and solvents burned, annual processing rates, and an estimate of the airborne release fraction. For our uncertainty analysis, we used a uniform distribution for the airborne release fraction, ranging from 1 to 10%. The uranium concentration of the liquid wastes is shown in Table K-13, along with estimates of the fraction of the FMPC liquid wastes which fall into those categories. For our source term reconstructions, it was reasonable to assume 97% of the liquid wastes processed were mineral oils and extraction solvents, which both contain uranium at an estimated concentration of 2-4 g U L<sup>-1</sup>. The other 3% of waste was assumed to contain concentrations ranging from 5-10 g U L<sup>-1</sup> which are more typical of the emulsions. The distribution shape of uranium concentrations in the waste was assumed to be uniform within the values given.

| Concentr                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | ations                                                                                   |                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                               | _                                                                                                                                                                                                                                                                                                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| concentration in<br>(g U L <sup>-1</sup> ) <sup>a</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Fraction of w<br>ventory back<br>1962 <sup>b</sup>                                       | vaste<br>klog in                                                                                                                                                                                                                         | Fraction of annual<br>volume processed in<br>1970s <sup>c</sup>                                                                                                                                                                                                               | _                                                                                                                                                                                                                                                                                                     |
| 2-4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 0.36                                                                                     |                                                                                                                                                                                                                                          | 0.86                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                       |
| * <b>2-4</b> **************                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                          |                                                                                                                                                                                                                                          | .0.14                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                       |
| 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | •                                                                                        |                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                       |
| 5–10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | • • • 0.03                                                                               | •                                                                                                                                                                                                                                        | 1. A.L. 199                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                       |
| unknown                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 0.10                                                                                     |                                                                                                                                                                                                                                          | • . • • • 4                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                       |
| the state of the s | f                                                                                        | n an star<br>Anna Chi                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                               | _                                                                                                                                                                                                                                                                                                     |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | concentration in<br>(g U L <sup>-1</sup> ) <sup>a</sup><br>2-4<br>2-4<br>5-10<br>unknown | Concentrations         Fraction of w         Fraction of w         (g U L <sup>-1</sup> ) <sup>a</sup> 1962 <sup>b</sup> 2-4       0.36         2-4       0.36         2-4       0.51         5-10       0.03         unknown       0.10 | Concentrations         Fraction of waste         concentrations         fraction of waste         concentration         (g U L <sup>-1</sup> ) <sup>a</sup> 2-4         0.36         2-4       0.36         2-4       0.51         5-10       0.03         unknown       0.10 | Concentrations         Fraction of waste       Fraction of annual         concentration inventory backlog in volume processed in (g U L <sup>-1</sup> ) <sup>a</sup> 2-4       0.36       0.86         2-4       0.36       0.86         2-4       0.03       0.14         5-10       0.03       0.10 |

1.222.000

· `, `

÷7.

 Table K-13. Fraction of Liquid Waste of Different Types and Uranium

 Concentrations

The airborne source term estimates for the oil burner, derived using this materials balance/processing rate approach, are tabulated in Table K-14 for 1962 through 1979. We did not have the detailed processing record to estimate the source term each year separately for the 1970s. The distribution of each annual source term estimate is approximately normal. Neblett's previous estimate of 60 lbs (27 kg) uranium per year from the oil burner is an underestimate, according to our method, for the years 1962 through 1964. However, our median estimate for the entire operating period (370 kg) is in good agreement with the previous estimate (470 kg).

# Appendix K Other Sources and Episodic Releases to the Atmosphere

.

10

| Year                 | Median | 5th percentile | 95th percentile |
|----------------------|--------|----------------|-----------------|
| 1962                 | 37     | 18             | 63              |
| 1963                 | 104    | 50             | 177             |
| 1964                 | 91     | 44             | 156             |
| 1965                 | 24     | 12             | 42              |
| 1966                 | 12     | 6              | 20              |
| 1967                 | 13     | . 7            | 23              |
| 1968                 | 20     | · 10           | 36              |
| 1969                 | 12     | <b>6</b> ·     | 21              |
| 1970-1978            | . 6    | 3              | 11              |
| 1979                 | . 3    | 2              | 6               |
| TOTAL<br>(1962-1979) | 370    | 270            | . 470           |

Table K-14. Revised Source Term Estimates for the Oil Burner (kg U y<sup>-1</sup>), Derived Using a Materials Balance/Processing Rate Approach

Category 3 Information. Stack measurements of uranium and gross alpha in stack gases from the oil burner. There were no historic memoranda or reports located which indicated that any direct measurements were made of uranium releases from the oil burner stack. However, a few analytical data sheets were located with this type of information. The analytical data sheet for the 1976 particulate testing (Ross 1976) provided a uranium analysis result as well as the particulate analysis result which had been presented in the memo. This stack air sample was taken on May 13, 1976 on a pleated filter for six hours. The concentration of uranium in this off-gas sample was 45.4  $\mu$ g m<sup>-3</sup>. Using the measured volumetric flow rate of stack gases (Table K-12), the emission rate would be 0.3 g U per hour. The paraffin used in the particulate emissions test was apparently an uncontaminated material, as this uranium emission rate would correspond to a release of only 2 kg U per year under continuous processing conditions.

Another analytical data sheet from November 4-5, 1976 contained measurements of particulates, uranium, and water content for air over the oil burner stack, while burning under air pressure and while using steam. The concentration of uranium was 4.3  $\mu$ g m<sup>-3</sup> while burning under air pressure and 164  $\mu$ g m<sup>-3</sup> while using steam. Again, these concentrations correspond to release rates which are quite low compared to those developed using the materials balance/processing rate approach described above.

Category 4 Information. Environmental measurements of uranium and gross alpha activity in air and deposited on gumpaper around the incinerator. There are two types of environmental measurements which could be used to verify our source term estimates for the oil burner:

- short-term measurements of radioactivity in air a short distance from the stack
- monthly deposition measurements of uranium onto gumpaper near the oil burner

Brandner et al. (1963) and Anonymous (1970) refer to measurements of uranium concentrations in the plume at 5 to 10 feet downwind from the top of the stack (Table K-15).
When burning was properly controlled to prevent smoking, the uranium concentration in air averaged approximately 0.05 mg m<sup>-3</sup>.

| Table | e K-18 | 5. Avera   | ge Airbo | rne Urä  | nium Co  | ncentr  | ations M | leasured | 5–10 feet fr | om |
|-------|--------|------------|----------|----------|----------|---------|----------|----------|--------------|----|
|       | T      | op of Oi   | l Burner | Stack    | nder a V | Variety | of Burni | ng Condi | itions       |    |
|       |        | - <u>-</u> |          | ovacii a |          | anicy   |          |          |              |    |

| (Dian                                | uner et al. 1900/ |                    |
|--------------------------------------|-------------------|--------------------|
| Burning Condition                    | * 43              | mg m <sup>-3</sup> |
| Properly controlled burning          |                   | 0.05               |
| Light smoke being emitted from stack |                   | 0.2                |
| Entrained ash visible above pot      | - 1944<br>        | 0.4                |
| Flame coming out of stack            | ▶. <u>-</u>       | 0.8                |
| Heavy smoke being emitted from stack |                   | 1.9                |
|                                      |                   |                    |

Because of the potential importance of these measurements to verification of source terms from the oil burner, we located the original analytical data sheets for these measurements. In reality, the measurements made near the oil burner were of gross alpha activity, not uranium. We were able to locate data for a total of 54 measurements on nine separate days (Table K-16).

From other FMPC memoranda, we determined that a ratio of 1.5 dpm alpha per microgram U was used by the FMPC in the 1960s to convert gross alpha measurements in air to uranium in air, which was probably what Brandner et al. (1963) had used. In practice, this ratio is subject to some measurement uncertainty. In our conversion of the gross alpha measurements to estimates of uranium concentration, we used an uncertainty distribution for the alpha-to-uranium ratio which was determined from 149 ambient air measurements or uranium and gross alpha during 1957–1959 at the FMPC (see Figure B2-2 of Shleien et al. 1993). The median ratio obtained from this dataset was indeed 1.5, and the 25th– 75% tiles were 1.17 to 2.29. The distribution of this ratio as well as the measured distribution of gross alpha in air were used to develop an estimate of the uranium distribution in air close to the oil burner stack (Figure K-11).



**Figure K-11.** Distribution of estimated uranium concentrations in air close to the oil burner stack during operation. Data obtained from original analytical sheets from 1962 and 1963.<sup>744</sup>

#### Appendix K Other Sources and Episodic Releases to the Atmosphere

....

.

. .

|                             | Distance from            | dom aleb        | ······································                                                          |
|-----------------------------|--------------------------|-----------------|-------------------------------------------------------------------------------------------------|
| Date                        | Burner (ft)              | m <sup>-3</sup> | Notes from original data sheet                                                                  |
| June 4, 1962                | 7                        | 159             | Puffing black smoke occasionally                                                                |
| June 4, 1962                | 8                        | 54              | Burning rate 13.32 gal in 23 min                                                                |
| June 4, 1962                | 6-7                      | 61              |                                                                                                 |
| June 4, 1962                | 6–7                      | 1043            | Sample considered most representative of those taken so far.                                    |
| June 8, 1962                | 5                        | 506             | Burning rate 13.3 gal in 22 min.                                                                |
| •                           | 5                        | 345             | Little heavier smoke than previous sample.                                                      |
| June 8, 1962                | · 5                      | 514             | Light smoke.                                                                                    |
| June 8, 1962                | 5                        | 555             | Same as above.                                                                                  |
| June 24, 1962               | 4                        | 6               | Burning very good. No smoke.<br>Burning rate 13.3 gal in 28 min.                                |
| June 24, 1962               | 2                        | 260             | No smoke. Burning rate 13.3 gal in 27 min.                                                      |
| June 24, 1962               | 3                        | 88              | Same as previous.                                                                               |
| June 24, 1962               | 2                        | 980             | Burning rate 13.3 gal in 18 min. Filter<br>burned slightly. Low pressure air on.                |
| June 24, 1962               | 3                        | 82              | Burning rate 13.3 gal in 25 min. No low pressure air on.                                        |
| June 24, 1962               | 2                        | 570             | Burning rate 13.3 gal in 18 min. Filter<br>burned.                                              |
| lune 24, 1962               | 2                        | 95              | Burning rate 13.3 gal in 18 min. Smoking slightly.                                              |
| July 18, 1962               | Not given. <sup>a</sup>  | 320             | No baffle over burner pot (applies to all samples this day). Light smoke.                       |
| July 18, 1962               | Not given. <sup>a</sup>  | 200             | Black smoke.                                                                                    |
| uly 18, 1962                | Not given. <sup>a</sup>  | 460             | Heavy smoke.                                                                                    |
| uly 18, 1962                | Not given. <sup>a.</sup> | 220             | Smoke clearing up.                                                                              |
| uly 18, 1962                | Not given. <sup>a</sup>  | 65              | No smoke visible.                                                                               |
| uly 18, 1962                | Not given. <sup>a.</sup> | 790             | Smoking a little.                                                                               |
| July 18, 1962               | Not given. <sup>a</sup>  | 360             | Burner had been operating for over 30 min<br>with no visible smoke. Rate 13.3 gal in<br>22 min. |
| uly 18, 1962                | Not given. <sup>a</sup>  | 670             | Same as previous.                                                                               |
| lugust 9, 1962              | 4                        | 160             | New burning pot and cross vane installed<br>(applies to all samples this day). Light<br>smoke.  |
| lugust 9 <u>, 1962</u>      | 4 <sup>b</sup>           | 560             | Slightly heavier smoke. Filter started to burn.                                                 |
| lugust 9, 1962 <sup>.</sup> | 4 <sup>b</sup>           | 140             | No smoke visible.                                                                               |
| lugust 9, 1962              | 4 <sup>b</sup>           | 68              | Light smoke. Wind shifting.                                                                     |
| lugust 9, 1962              | 4 <sup>b</sup>           | 53              | Heavy smoke.                                                                                    |
| lugust 9, 1962              | 4 <sup>b</sup>           | 35              | No smoke visible. Burning rate 38 gal per hour.                                                 |
| ugust 9, 1962 👘             | 4 <sup>b</sup>           | 61              | Same as previous, light smoke.                                                                  |
| ept. 6, 1962                | 3                        | 210             | Burning heavy emulsion with large door<br>partially open (applies to all samples<br>this dow)   |

(continued next page)

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

marter Conne

ë

10.10

|                                        | ••                       | 1962–1963 (cont.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|----------------------------------------|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                        |                          | dpm <sup></sup> the second se                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Date                                   | Distance from            | alpha (25) Notes from original data sheet.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                        | Burner (ft)              | m_3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Sept. 6, 1962 🖉                        | 3                        | 130 No smoke.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Sept. 6, 1962                          | 3                        | 1400 No smoke.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Sept. 6, 1962                          | 3                        | 1900 , Heavy smoke.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| October 4, 1962                        | 5                        | 310 No smoke.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| October 4, 1962                        | 5                        | 240 Occassional smoke.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| October 4, 1962                        | 5                        | 2 No smoke. Flame lowered by increasing air                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| La tradition in the                    | the second second second | at ring in stack.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| October 4, 1962                        | 5 J. 5 March 1999        | 390 Light smoke.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| October 4, 1962                        | 5                        | 110 Same as above.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| August 21, 1963                        | 5 ft W, 3-4 ft           | 34 Wind blowing from east. Normal burning                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| - · ·                                  | abovec                   | approx. 20–30 gal per hour (applies to                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                        |                          | all samples this day).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| August 21, 1963                        | 5 ft W, 4-5 ft           | the 21 south the second s                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                        | abovec                   | an a the state of the second                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| August 21, 1963                        | 5 ft W. 3-4 ft           | • <b>2</b> • • • • • • • • • • • • • • • • • • •                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| ······································ | above <sup>c</sup>       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| August 21, 1963                        | 5 ft W. 4-5 ft           | 6800                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                                        | above <sup>C</sup>       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| August 21, 1963                        | 5 ft SW 3-4 ft           | 15 110 1 1 10 1 1 10 1 1 1 1 1 1 1 1 1 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 1105000                                | ahove                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| August 21 1963                         | 5 A SW 4-5 A             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 110600011, 1000                        | showe <sup>C</sup>       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| August 21 1963                         | 5 A NW 3_4 A             | 720                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 114643621, 1000                        | ohoro <sup>C</sup>       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| August 91 1063                         | 5 ANW A SA               | 740                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 110guar 21, 1900                       | ahaac                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| August 01 1062                         | 10 A W .4 E A            | and the second                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| August 21, 1903                        | 10 IL W, 4-0 IL          | ▲ℓ                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Aumat 01 1000                          |                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| August 21, 1903                        | 10 IL W, 4-0 IL          | (4) Z. Charles and A. Santa and A<br>Santa and A. Santa br>And A. Santa and A. Santa a |
| August 01 1000                         | BDOVe                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Mugust 21, 1903                        | o it downwind            | 2000 riames emanating from furnace and light                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| August 01, 1000                        | <b>FAJ</b> . 11          | Smoke.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| August 21, 1963                        | D IL downwind            | <b>DOUV</b> Flames emanating from furnace and light                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|                                        | F 0 117 4 7 0            | smoke.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| August 26, 1963                        |                          | 6300 Normal burning conditions. Rate 20 gal pe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                        | above                    | ere province in the second state of the second    |
| August 26, 1963                        | 5 ft NW, 3-4 ft          | 1400 As above.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                        | abovec                   | and the state of the                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|                                        |                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

M AL CO

<sup>a</sup> Location of samples not given on analytical data sheet, but IH&R July 1962 monthly reports says samples were taken in off-gas from the oil burner.

<sup>b</sup> Location not given, but assumed to be the same as first sample taken that day. <u>CAbove furnace height.</u>

n 1977 - New York, and a start and the start of the second start of the start of the start of the start of the A start of the start

#### Appendix K Other Sources and Episodic Releases to the Atmosphere

.

Page K-35

The distribution of uranium concentrations in air close to the burner (Figure K-11) is highly skewed to the lower concentrations. The median concentration is 0.24 mg per cubic meter; the 5th to 95th percentile interval is 0.02 to 2.9, which is in good agreement with the values presented by Brandner et al. (Table K-15). From the data it appears that sometimes the sampling missed the flue gases altogether (concentrations are barely detectable) and other times the concentrations were quite high, indicating that the flue gases were probably captured in that sample.

It might be possible to back-calculate an emission rate (g U h<sup>-1</sup>) from these air concentrations, but assumptions must be made about the amount of dilution of stack gases between the release point and the measured location (typically 2 to 10 feet downwind). If it is assumed that the dilution is a factor of 10, the median source term based on the air concentration measurements is 17 g U released per hour, or 100 kg per year, assuming continuous processing for 5 d wk<sup>-1</sup>, 50 wk y<sup>-1</sup>. This is in reasonable agreement with our source term estimates for the higher processing-rate years (Table K-14).

Fallout measurements. One other set of environmental measurements from the 1960s were examined to see if they would shed light on reconstruction of airborne source terms from the oil burner. Klein (1963, 1964) briefly described the results of a 19-month study of fallout around the OSWI and the oil burner. During the study, special gumpaper stands were placed downwind (adjacent and NE) from the two incinerators to measure local fallout. Uranium deposition at these stations was compared to that measured on gumpaper at other nearby permanent stations. We determined the approximate locations of the special gumpaper fallout stations from an undated map which indicated their positions. The special station near the oil burner was about 400 feet to the ESE, according to this map, as shown in Figure K-8. However, Klein's memos indicate that the special gumpaper stand was to the NE. The data from the special gumpaper stations were compared to those collected at the permanent stations N-1, which is less than 200 feet to the NW and station NE-1 which is about 1000 feet to the NE of the oil burner. Klein (1964) concluded that fallout in the area of the oil burner was 3.6 times greater than at N-1 and 6.8 times greater than at NE-1.

We located the original analytical data sheets for these measurements so they could be examined more closely. We also included the permanent station "D" in our comparisons (location shown on Figure K-8). First, the measured depositions in  $\mu g U ft^{-2}$  were corrected for the collection efficiency of gumpaper for particulates, which had been determined to be 15% for a weekly exposure period and 14% for the monthly exposure period (Shleien et al. 1993). They were then normalized to a daily deposition rate (mg m<sup>-2</sup> d<sup>-1</sup>). The data are illustrated in Figure K-12. The higher deposition at the oil burner gumpaper station is readily apparent. Station D, which is closer to major production area sources, is next highest, followed by N-1 and NE-1. The cumulative deposition over the 19-month period February 1963 through September 1964 was 45500 mg U m<sup>-2</sup> for the oil burner, 20700 for station D, 10500 at station N-1, and 6000 at station NE-1. The graphite burner was not yet operating at this location (see next section), and there is no other known important source of uranium in this area of the production plant. The net deposition, due to the oil burner airborne source term, would be 1960 mg m<sup>-2</sup> mo<sup>-1</sup>, or 65 mg m<sup>-2</sup> d<sup>-1</sup>, if it is assumed that the average of N-1 and NE-1 is a baseline deposition rate due to other sources. As demonstrated in the previous sections, 1963 was a peak processing year for the oil burner.





Figure K-12. Deposition to gumpaper (corrected for weathering) at a station near the oil burner compared to stations within the production area but further away (see Figure K-8 for locations). The oil burner was processing at a high rate during this period.

a contraction of

#### GRAPHITE BURNER (1965-1984)

1. N. W. C.

A substantial quantity of waste graphite was generated at the FMPC. Most of this generation was a result of the uranium metal recast step, and consisted primarily of scrap furnace crucibles and molds (Anonymous 1970). The process application of these graphite materials caused them to be quite contaminated with uranium and daughter products. The uranium content of the crucibles could reach 3% after several uses (Boback 1972); the quantity of uranium contained in this waste stream was sufficient to make recovery of this material economically attractive (Anonymous 1970). In the early years of operation, graphite was burned in a furnace in the Recovery Plant and the residue was leached to recover the uranium. This process was discontinued in 1960 because the carbon content of the product was too high (Mead 1972).

#### History and Operation of Graphite Burner

In October 1965, an experimental graphite furnace was built, and it was established that graphite could be successfully incinerated with essentially all of the uranium contained in the total feed being recovered in the ash (Anonymous 1970). This substantially reduced the quantity of material that had to be chemically processed for final uranium recovery.

The only pre-treatment given to the graphite waste was to break it into pieces small enough to be fed into the burner. A minimal amount of sorting was done: (1) some types of scrap known, by previous chemical analysis, to contain minimal uranium were discarded

. . .

#### Appendix K Other Sources and Episodic Releases to the Atmosphere

directly into the dry residue waste pit, and (2) visible pieces of uranium metal were removed. The removal of this massive uranium from the graphite feed was necessary to "permit the burner to operate without causing a problem from radioactivity in the stack discharge" (Anonymous 1970).

The following description of the graphite burner operation is provided in Anonymous (1970): The graphite burner was a simple apparatus, consisting of a refractory lined cylinder with a steel shell. The cylinder had an inside diameter of 27" and is 60" high. Ports are spaced around the circumference of the cylinder to introduce air. Graphite scrap was fed into a charge port above the furnace, and ashes were raked out of seven ports at the bottom (see example port in Figure K-13). No auxiliary fuel was necessary except to start the fire. This was normally accomplished by using coal or wood and kerosene. After the fire was started and the graphite near the bottom was ignited, the fire was self-sustaining. Fresh scrap was periodically fed into the top of the furnace.

Boback (1972) describes graphite burner operation as follows:

.....

. .

"The graphite burner is a simple outdoor incinerator. The combustion chamber is a refractory-lined, 1/4"-thick, carbon steel cylinder mounted on four legs and topped with an eight-foot-tall steel stack. An elevated platform permits graphite to be charged into a port near the stack bottom.

For operation, a 3-inch layer of sand is placed in the bottom of the burner shell. A wood fire is started and oil-soaked nugget coal is added until a two-foot-thick bed of red hot coals is obtained. A layer of graphite is placed on the coals and an air lance is inserted through a bottom port. When the graphite becomes orange-red, more graphite is added and the air supply is reduced.

Additional graphite is added only if the previous charge is orange-red. The air lance is removed when the combustion is proceeding at an acceptable rate.

A four-foot-thick bed of burning graphite is maintained. As the charge burns down, ashes are raked out through seven ports into 3-1/2 gallon buckets. Cooled ashes are transferred to 55-gallon drums for storage and later processing to recover the uranium. Ash from this burner is about 60% uranium.

After startup, the burning usually proceeds smoothly, producing only a slightly visible stack discharge. Uranium in the stack effluent has ranged from 0.15 to 8.3 mg/m<sup>3</sup>. The average discharge of airborne uranium is estimated at less than 0.5 pounds per 24 hours of operation."

1



No.

ξ,

٤.

Figure K-13. Schematic of graphite burner; showing example rake-out port (one of seven), charge port, etc. Burner stood on concrete pad northeast of boiler plant; release height is 14.5 ft. above ground level.

Previous Uranium Release Estimates for Graphite Burner

March 193 (1984) In Street, Constraint (1984)
 March 1984 (1984) In Street A. Statement (1984)
 March 1984 (1984) In Street A. Statement (1984)

アムシーウイトない方

.....

The release estimates presented by Boback et al. (1987) for the graphite burner were provided by Neblett (1985), based on "knowledge gained from supervising these operations and from waste management's project assignments in the past." Neblett believed that data to substantiate these estimates were not available, and that the records for these operations had long since been discarded. A flow diagram showing his estimate is shown as Figure K-14. The total release estimate over the operating history of the graphite burner would be = 130 kg uranium. Appendix K Other Sources and Episodic Releases to the Atmosphere

<.;

, ,

.....

Page K-39



Figure K-14. Neblett (1985) estimate for historic releases of uranium from graphite burner.

#### Additional Historic Documentation Located to Support Reconstruction of Uranium Source Term from Graphite Burner

All of the original measurements and memoranda which were located for reconstruction of the source term for the graphite burner were generated during 1965, 1966, and 1967. The types of measurements included stack samples taken inside the burner, as well as air samples taken directly downwind of the burner during operation. Table K-17 shows a summary of measurements of uranium in air while burning uranium contaminated graphite.

Measurements of the loss of uranium in the graphite burner stack are summarized in an internal NLO memorandum (Ross 1966). We were able to locate and verify all of these measurements from original analytical data sheets. For this reason, we consider this source particularly reliable and definitive for dose reconstruction purposes. There were no data errors, however, the memo incorrectly identified three stack samples taken on 11/12/65 as "downwind samples."

One set of stack samples from the graphite burner were obtained on Millipore filters through a 1/4" stainless steel tube (Ross 1966). The velocity in the tube was about 2900 ft min<sup>-1</sup> as opposed to the stack velocity of about 500-600 ft min<sup>-1</sup>, thus the samples were obtained with higher than isokinetic flows. A total of 22 stack measurements were taken on three days (one each in December 1965, January 1966, and February 1966). The other set

| K-40 | The Fernald Dosimetry Reconstruction Project  |
|------|-----------------------------------------------|
|      | Tasks 2 and 3, Source Terms and Uncertainties |

Page

were apparently taken inside the burner "at open top of crucible." The method for these samples is unclear; however, in his memo, Ross used the former to estimate the uranium releases to air. The data from the two sets of measurements are shown in Table K-18.

| Table K-17. Uranium Measurements in Air While Burning Uranium Contaminated |
|----------------------------------------------------------------------------|
| Graphite in the Graphite Burner (Starkey 1965b)                            |

|                                                                             | •    | Uranium |      | Alpha <sup>a</sup>     |
|-----------------------------------------------------------------------------|------|---------|------|------------------------|
| · · ·                                                                       |      | (µg m~) |      | <u>(dpm m~) (dpm m</u> |
|                                                                             | High | Low     | Avg. | Avg.                   |
| Process sample at top of burner or inside                                   | 8300 | 160     | 2100 | 3150                   |
| Downstream samples 3 ft to 5 ft downwind<br>from burner in burner airstream | 930  | 8       | 300  | 450 <sup>b</sup>       |
| Downstream samples, 12 ft from burner                                       | 13   | 13      | 13   | 20                     |
| Downstream samples, 80 ft from burner                                       | 3.   | 2       | 3    | 5                      |
| Downstream samples, 150 ft from burner                                      | 12   | 10      | 11   | 15                     |

<sup>a</sup> Calculated value given in Starkey (1965b). Apparently based on a ratio of 1.5 dpm alpha per microgram U.

<sup>b</sup> Additional data for this distance from the burner were located in an analytical data sheet for samples collected October 28, 1965. Four 15-minute samples of gross alpha in air, 4 ft downwind of the graphite burner stack and 18 inches above the horizontal top level of the burner, were: 590, 610, 490, and 185 dpm alpha per cubic meter air (average 470 dpm m<sup>-3</sup>). The airborne contamination level at the same location when the operator was raking and charging the furnace was about three times higher (1400 dpm m<sup>-3</sup>).

The burner was operated continuously, being shut down only for an emergency or lack of feed (Baer 1966b). During calendar year 1969, approximately 150,000 pounds of graphite scrap were burned in this facility (Anon 1970). It was not necessary to operate the burner all year; an average production rate was estimated by Anonymous (1970) as 1,000 to 1200 pounds of graphite scrap per 24-hour operating day. This corresponds to about 150 operating days per year, compared to Neblett's nominal estimate of 30 days per year. Perkins (1976) states the normal operation schedule as 4 weeks per year at a graphite throughput rate of 150-175 pounds per hour.

We used the stack measurements, the estimated stack flow rate and the estimated days per year of operation to determine an estimate of the annual airborne source term from operation of the graphite burner. Because the parameters involved in the estimate are all subject to some uncertainty, we used Monte Carlo sampling implemented by the Crystal Ball<sup>TM</sup> software system (Decisioneering 1992), using the parameter assumptions defined in Table K-19. The mean annual source term estimate was 15 kg per year with a 5th-95th percentile range of 3.1 to 37 kg per year. A summary of the source term characteristics for the graphite burner is compiled in Table K-20.

.

#### Appendix K Other Sources and Episodic Releases to the Atmosphere

|         | Uranium C       | Uranium Concentration $(ugm^{-3})$              |  |  |  |
|---------|-----------------|-------------------------------------------------|--|--|--|
|         | Sampled at Open | Sampled Through .<br>Hole in Stack <sup>c</sup> |  |  |  |
| • -     | <u>160</u>      | 240                                             |  |  |  |
|         | 260             | 180                                             |  |  |  |
|         | 290             | 190                                             |  |  |  |
|         | 230             | 1500                                            |  |  |  |
|         | 3510            | 1500                                            |  |  |  |
| • .     | . 600           | 1600                                            |  |  |  |
|         | 480             | · 430                                           |  |  |  |
|         | 700             | 350                                             |  |  |  |
|         | 4000            | 350                                             |  |  |  |
|         | 6000            | 425                                             |  |  |  |
|         | 1100            | 375                                             |  |  |  |
|         | 150             | 300                                             |  |  |  |
|         | 330             | 350                                             |  |  |  |
|         | 8300            | 560                                             |  |  |  |
|         | 3500            | 720                                             |  |  |  |
|         | 190             | 1700                                            |  |  |  |
|         | 800             | 270                                             |  |  |  |
|         | .700            | 130                                             |  |  |  |
| • .     | 470             | <b>280</b> .                                    |  |  |  |
|         | 630             | 300                                             |  |  |  |
|         | 870             | 270                                             |  |  |  |
|         | :               | 160                                             |  |  |  |
| Number  | 21              | 22                                              |  |  |  |
| Minimum | 150             | 130                                             |  |  |  |
| Maximum | 8300            | 1700                                            |  |  |  |
| Average | 1584            | 554                                             |  |  |  |
| Modian  | 630             | 350                                             |  |  |  |

# Table K-18. Uranium Concentration in Air Samples fromGraphite Burner Stack During Operation (Ross 1966)<sup>a</sup>.

<sup>a</sup> Data verified by examination of original analytical data sheets.

<sup>b</sup> Location of samples within burner is not clear. Samples taken on six separate days in October and November 1965.

<sup>c</sup> Samples taken on three separate days in December 1965 and January and February 1966.

| Page | K-42 |
|------|------|
|------|------|

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

**Graphite Burner Source Term** Most Probable<sup>a</sup> Maximum o de Minimum Uranium concentration in stack gases 1.14  $(ug U_m^{-3})$  . 554 1700 130 Exit flow rate. 1.1  $(m^3 min^{-1})^b$ 168 118 218 • • • <u>30</u>° Days per year of operation 10 200 <sup>a</sup>Triangular distribution. <sup>b</sup> Assumed ± 30% of measured flow rate in Ross 1966. c Neblett (1985) estimate. Confirmed in Perkins (1976).

## Table K-19. Assumptions Used in Uncertainty Analysis of Graphite Burner Source Term

In addition to an airborne source term through the stack, some uranium could have become airborne when ash was spilled during the rake-out process. The burner sat on a 55ft by 85-ft concrete pad (Baer 1966b; DOE 1992), so gross contamination could have been easily cleaned up. Our assessment of this pathway for the old solid waste incinerator indicated that resuspension of spilled ash was relatively insignificant compared with stack emissions. Airborne resuspension of spills is handled in a general way under "non-routine events," later in this appendix.

Table K-20. Summary of Source Term Characteristics for the Graphite Burner (operated 11/1/65 to 9/14/84)

|                                              | (upe                                         | rated 11/1/05 (0 5/14/04)                                              |                                                                         |
|----------------------------------------------|----------------------------------------------|------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Parameter                                    | Value                                        | Reference/Basis                                                        | Notes                                                                   |
| Uranium Source<br>Term (kg y <sup>-1</sup> ) | 15                                           | Uncertainty analysis<br>based on assumptions<br>defined in Table K–19. | 5th–95th percentile<br>range is 3.1–37 kg y <sup>–1</sup> .             |
| Physical Release<br>Height                   | 14.5 (ft)                                    | Engineering Drawing<br>10X-M-00324                                     | Eight-ft stack above 5-ft<br>furnace, mounted 1.5<br>feet above grade.  |
| Building outer<br>dimensions                 | 37"<br>diameter<br>cylinder,<br>14.5 ft tall | Engineering Drawing<br>10X-M-00324                                     | •                                                                       |
| Stack inside<br>diameter                     | 36.5 in.                                     | Engineering Drawing<br>10X-M-00324;<br>Anon 1970                       | Inside diameter of<br>furnace area is 27", due<br>to refractory lining. |
| Exhaust gas<br>velocity                      | 500–600<br>fpm<br>168 m <sup>3</sup>         | Ross 1966                                                              | · · · · · · · ·                                                         |

ه این معرد ایر د

111111111

677

1

#### KELLEY SOLID WASTE INCINERATOR (OPERATED 11/1/79 TO 4/28/86)

In 1978, it was proposed to move the old solid waste incinerator to the Calciner Building, Plant 3, inside the production area, in part to reduce the ground contamination which was known to be occuring in the area of the sewage treatment plant (Anonymous 1978). On June 18, 1979, the new solid waste incinerator, manufactured by the Kelley Company, Model No. 780/31, was delivered to NLO, and installation into the incinerator building (39A), in the Plant 2/3 area (Figure K-8) was complete by October 31, 1979 (Anonymous 1982).

The incinerator was a controlled air, pyrolytic chamber with a thermal reactor mounted above the main chamber that burned particulate matter which would otherwise escape the stack (Baer 1981). The Standard Operating Procedure (Baer 1981) describes the proper operation of the incinerator. There was no gas cleaning equipment for the effluent air. For proper combustion and efficient operation, the main chamber temperature was kept below 1500 °F. A water spray, regulated by a flowmeter, cooled the incinerator internally to minimize the emission of particulate matter. The rated capacity of the incinerator is 700 lbs  $h^{-1}$ . Physical and operating parameters needed to assess dispersion from this release point are given in Table K-21.

| Parameter                                       | Value                      | Reference                             | Notes                                                                                                                                                                                                                |
|-------------------------------------------------|----------------------------|---------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical stack height                           | 53 ft                      | Engineering Drawing<br>39A-M-00025ª   |                                                                                                                                                                                                                      |
| Building dimensions                             | 52 × 54 ft ×<br>37 ft high | DOE 1992                              |                                                                                                                                                                                                                      |
| Stack cross sectional<br>area                   | 2.292 ft <sup>2</sup>      | Anonymous (1982)<br>Heatherton (1981) | Engineering Drawing 39A-<br>M-00025 gives a stack<br>diameter of 21", which is<br>equivalent to 2.4 ft <sup>2</sup> .<br>However, the 2.292 ft <sup>2</sup> value<br>is presented with stack<br>testing information. |
| Exhaust gas velocity<br>(ft min <sup>-1</sup> ) | 2250 ± 450<br>1462–2908    | Anonymous (1982)                      | Mean, S.D. and range<br>during stack testing on 10<br>separate days in 1980–1982                                                                                                                                     |
| Exhaust gas<br>temperature (°F)                 | 1330 ± 340<br>726–1669     | Anonymous (1982)                      | Mean, S.D. and range<br>during stack testing on 10<br>separate days in 1980–1982                                                                                                                                     |

#### Table K-21. Summary of Physical and Operating Parameters for the New Solid Waste Incinerator

<sup>a</sup>Incinerator Bldg. Solid Waste Incinerator. General Arrangement Plan and Elevation. November 13, 1979.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

ÿ.

÷

: . !

The incinerator was not designed for the disposal of radioactively contamined materials. Contaminated articles to be burned were to be inspected, emptied of all metal chips, turnings, and oxides, and vacuumed or wiped clean of obvious contamination. Contaminated production or process wastes, dust collector bags, contaminated gloves and rags, and other obviously contaminated materials were not to be burned in the incinerator (Baer 1981). However, operations in the new solid waste incinerator were suspended on April 28, 1986 after a series of investigations in the spring of that year (e.g. Huey et al. 1986), which showed that too much contaminated material was being sent to the incinerator, resulting in ash content of 2.5% U by weight. The solid waste incinerator did not resume operation after that time. 7:112 . 1'

#### Uranium Release Estimates for the Kelley Solid Waste Incinerator

Previous release estimates for the Kelley Solid Waste Incinerator presented by Boback et al. (1987) are tabulated in Table K–22. Handwritten notes (Anonymous 1985) suggest that the value for 1984 is actually a total for the solid waste incinerator and the liquid waste incinerator, which are in the same building (39A). The source term for the solid waste incinerator alone was 2.4 kg and the liquid waste incinerator was 4 kg per year. The basis for the solid waste incinerator estimate appeared to be:

Average charge rate: 337 lbs per hour

. . . .

Uranium in effluent: 0.36 gram U per 100 lb charged

Operating schedule: 40 hours per week; 50 weeks per year.

In an informational letter to the Ohio EPA, Wing (1980) estimated emissions of 1.5 lb U per year (0.7 kg per year) from the Kelley Solid Waste Incinerator. 1. 1. State 1. 1997

5 19 N

| Cal | endar | Annual Release   |         |   |  |
|-----|-------|------------------|---------|---|--|
| · Y | ear   | _(kg)            | · · · · |   |  |
| 1   | 984   | 6.4 <sup>a</sup> | · ·     |   |  |
| • 1 | 983   | 2.4              | •       |   |  |
| . 1 | 982   | 1.8              |         |   |  |
| 1   | 981   | 1.2              |         | • |  |
| •   | 980   | 0.68             | •       |   |  |

### Table K-22. Previous Uranium Release Estimates for the

We used this same basic approach to estimating a source term for the solid waste incinerator, but examined the uncertainty in the input parameters more carefully. It appears that the contractor estimate (at least for 1984) was supposed to be an upper bound, because the incinerator typically did not operate 2000 hours per year. A typical operating schedule for the FMPC incinerator was estimated to be 400 to 600 lbs waste burned per

#### Appendix K Other Sources and Episodic Releases to the Atmosphere

· · · ·

1

hour for 6 h d<sup>-1</sup>, 2 d wk<sup>-1</sup>, 98 d y<sup>-1</sup>, or 1176 hours per year, equally distributed throughout the year (Ostendorf 1979). Wing (1980) estimated a maximum burn rate of 340,000 pounds per year of solid waste, which is equivalent to about 630 hour per year, at the average refuse charge rate (see below). For our analyses, the operating schedule is defined as a triangular distribution with a most likely value of 1176 hours per year, and minimum and maximum values of 600 and 2000 hours per year.

A number of stack tests were conducted at the new solid waste incinerator. The results for 10 separate days of testing in 1980–1982 are summarized in Anonymous (1982). From this summary, the amount of particulate material released was obtained. The actual values ranged from 0.09 to 0.71 pounds particulate per 100 pounds of refuse charged. For our uncertainty analysis, this parameter was described by a custom distribution based on the original measurements. Another parameter obtained from the stack testing summary was the refuse charging rate, which ranged from 172 to 758 pounds per hour and averaged 536 pounds per hour.

The stack testing summary (Anonymous 1982) does not contain any information on uranium emissions, only total particulates. However, we located original analytical data sheets for seven of those ten tests, and two others, which provided data on the uranium content of particulates collected from the effluent air from the incinerator. The measured values ranged from 0.32 to 15.4 mg U per g particulate. For our uncertainty analysis, this parameter was described by a custom distribution based on the original measurements.

The annual uranium release rate for the Kelley Solid Waste Incinerator, based on the operating data and measurements just described, is illustrated by the distribution in Figure K-15. The median estimate of the total release over the 5.5-y operating period is 8 kg.



Figure K-15. Source term estimate for the Kelley Solid Waste Incinerator. The median source term estimate is 1.3 kg per year, and the 5th and 95th percentile values are 0.1 kg and 17 kg, respectively.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

45

Real Sector

Res in

1.1.1.1.1.1

#### TRANE THERMAL LIQUID WASTE INCINERATOR (OPERATED 3/28/83 TO 5/7/86)

Within a month after the old oil burner was closed down, a project proposal for a new liquid waste incinerator had been prepared (Anonymous 1979). The proposal indicated that stack gases from the new unit would be cooled with dilution air and passed through a new bag filter collector to ensure compliance with Ohio EPA requirements for particulate emissions from incinerators. The facility was to be capable of processing 20 55-gal drums of waste oil per month when operating on one shift per day.

The incinerator began operating in late March 1983. Physical and operating parameters for the incinerator are given in Table K-23. Operations at the liquid waste incinerator were suspended on May 7, 1986 due to uncertainties associated with the characteristics of the waste oil feed stream as well as the status of permit action on the incinerator. Operations were never resumed.

| Parameter             | Value               | Reference                             | Notes                                    |
|-----------------------|---------------------|---------------------------------------|------------------------------------------|
|                       |                     | and the strate of the                 |                                          |
| Physical stack height | 53 ft               | Audia (1980)                          | an a |
|                       | 4                   | States and the second second          |                                          |
| Building dimensions   | $52 \times 54$ ft × |                                       | •                                        |
|                       | 37 ft high          | DOE 1992                              |                                          |
| Stack inside diameter |                     |                                       |                                          |
| •                     | 14"                 | Audia (1980)                          | •                                        |
|                       | •                   | · · · · · · · · · · · · · · · · · · · |                                          |
| Exhaust gas flow rate | 4500 acfm           |                                       |                                          |
| · · ·                 | 4200 fpm            | Audia (1980)                          |                                          |
| Exhaust gas           |                     |                                       |                                          |
| temperature (°F)      | 400                 | Audia (1980)                          |                                          |
| Waste processing rate | max: 56 lb          | Andia (1980)                          | Typical value was 7 gal per              |
| maste processing late | (7.5 gal) per       | r (1900)                              | hour.                                    |

Table K-23. Summary of Physical and Operating Parameters for theTrane Thermal Liquid Waste Incinerator

Boback et al. (1987) estimated releases of 3 and 4 kg from the liquid waste incinerator for 1983 and 1984, respectively. They state that the release estimates for the liquid organic waste incinerator were based on performance criteria and the concentration of uranium in the incinerator feed. Handwriten notes (Anonymous 1985) state that the liquid waste incinerator would emit 4 kg yr<sup>-1</sup> under the maximum permitted rate. These calculations (partly illegible) appear to use a uranium concentration of 8.7 g per L in the waste. This is the concentration given by Wing (1980), who indicated that there was a large backlog of liquid wastes containing about 8.7 g U per L. According to our previous assessments of FMPC liquid wastes, typical oils and solvents would contain U concentrations of 2-4 g U L<sup>-1</sup> (see Oil Burner section above). For our source term estimates for the new liquid waste

| Appendix K                                            | Page K-47 |
|-------------------------------------------------------|-----------|
| Other Sources and Episodic Releases to the Atmosphere |           |

incinerator, we used a uniform distribution between 2 and 9 g U  $L^{-1}$  to describe the uranium concentration in liquid waste being processed.

The quantity of liquid waste generated at this time was approximately 1000 gal per month. The Ohio EPA permit application for the liquid waste incinerator (Audia 1980) provides the following additional information relevant to estimating releases (see also Table K-23). The operating schedule was to be 8 hours per day, 5 days per week, 49 weeks per year (1960 hours per year). At an average processing rate of 7 gallons per hour, this operating schedule is equivalent to 14,000 gal per year. Additional information in Wing (1982) specifically indicates an intended processing rate of 12,000 gal per year of lubricating and cooling oils and 400 gal per year of kerosene/TBP mixtures, both of which would contain low-level U contamination. Wing (1980) stated that the maximum amount of oil expected to be burned was 145,000 liters (38,300 gal) per year and that a typical year would be about 1/4of this amount (9600 gal per year). He estimated a first year emissions rate of 8.6 lb U (3.9 kg), based on 1.36 g U released per 100 lb. charged. No reference was given for the basis of this emissions ratio. For our analyses, we used a processing rate of 12,000 gal per year with a standard deviation of 1,000.

As was determined for the old oil burner, we used a uniform airborne release fraction of 1-10% for the amount of uranium released from the waste to the off-gas from the incinerator. The basis for this distribution is discussed in the previous oil burner section. A collection efficiency of 90% for the bag collector was used (CIV 1980). The distribution describing the estimated annual release from the Trane Thermal Liquid Waste Incinerator is shown in Figure K-16. The median estimate of the total release over the 3.1-y operating period is  $\approx 4$  kg.

 $\sim$ 

Ş



Figure K-16. Source term estimate for the Trane Thermal Liquid Waste Incinerator. The median source term estimate is 1.2 kg per year, and the 5th and 95th percentile values are 0.3 kg and 3 kg, respectively.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

226.222.14

19-14-12

サントン・シンド

#### PARTICLE SIZE AND DEPOSITION CHARACTERISTICS FOR URANIUM EMISSIONS FROM FMPC INCINERATORS

The solid waste incinerators, the graphite burner, and the oil burner all operated without any emissions control equipment. Thus, any uranium-contaminated particles which were entrained in the exiting air stream were emitted directly to the atmosphere. Although there were some fallout studies of uranium deposition around the oil burner and graphite burner (Klein 1963; 1964), these were not of the quality necessary to quantify the particle size and deposition characteristics. The most applicable experimental data located were generated by scientists from the Health and Safety Laboratory (HASL) in New York (Weinstein and Breslin, unpublished manuscript titled "Environmental Contamination from Burning Uranium Metal, circa 1959). These experiments involved the open burning of uranium metal, in the form of turnings, shavings and chips, in quantities ranging from 20 grams to 900 pounds. Experiments were conducted both in the laboratory and in the field.

Mass median diameters of uranium oxide in stack effluents were 3.2 to 6.5 microns compared to 1.34 to 1.76 microns for oxide in the smoke plume 25 feet downwind at ground level. A value of 0.51 microns was determined in a laboratory experiment.

Weinstein and Breslin present curves of uranium deposition in µg ft<sup>-2</sup> with distance from a natural draft field incinerator with a 12-foot stack. Following burning of 160 lbs of uranium, average total deposition decreased by about a factor of 7 (from 10 to 1.5 µg ft<sup>-2</sup>) between 100 feet and 300 feet from the source. For a 160 lb source, total deposition decreased from about 40 µg ft<sup>-2</sup> at 100 feet to about 15 at 300 feet (about a factor of 3). Their computed average deposition velocity to gummed paper was 0.66 m s<sup>-1</sup> for a 100 pound uranium fire, 0.47 m s<sup>-1</sup> for a 160 pound fire and 0.57 m s<sup>-1</sup> for a 900 pound uranium fire. These data support other evidence presented in this report which indicates a rapid drop-off of contamination with distance from the FMPC incinerators.

#### UNMONITORED RELEASES OF URANIUM FROM FMPC BUILDINGS

This section on unmonitored emissions from FMPC buildings is divided into three categories: unmonitored process emissions, building ventilation, and laboratory hoods. No revised estimates are provided for emissions from unmonitored processes and lab hoods. Some new information uncovered since our interim source term report (Voillequé et al. 1991) did permit a thorough reevaluation and reconstruction of releases from building ventilation.

#### **Unmonitored Process Emissions**

An addendum to the estimates of radionuclides released from FMPC during 1951-1984 (Boback et al. 1987) was prepared by Clark et al. (1989) following the determination in June 1988 of higher than expected airborne concentrations of uranium at air monitoring stations in the NE quadrant of the plant. These air concentrations were traced to the operation of the Plant 2/3 denitration gulping system which was a previously unmonitored source of uranium emissions. Uranium releases from the gulping process are presented in Appendix H. Because this system was previously thought to be an insignificant source of airborne

#### Appendix K

<u>.</u>

5

#### Other Sources and Episodic Releases to the Atmosphere

emissions, concern was raised about other unmonitored and potentially unreported air emission sources that had or still existed.

All unmonitored radionuclide emission sources were investigated during the plant-wide vacation shutdown in July 1988. Processes associated with monitored stacks were well characterized in terms of emissions and were allowed to restart after the vacation shutdown was completed. However, the investigation found 35 unmonitored process stacks (associated with 26 separate production processes) that were potential sources of significant radionuclide emissions. The majority of sources associated with unmonitored stacks are generally described as wet exhausts. These are scrubbed exhausts, such as Plant  $2/3 UO_3$  gulping, and exhausts from processes involving acid dissolution of uranium. Previous testing had quantified emissions from the Plant 8 furnace discharges in 1988.

The method used by Clark et al. (1989) to estimate emissions from the current unmonitored uranium processes at FMPC was either engineering calculations or actual stack emission measurements. Processes were not sampled if sufficient data existed to approximate emissions (Hill 1989a). Calculations considered the uranium concentration in each process, the capacity of the stack blower, and other operating parameters. Information from equipment manufacturers and process experience were used in the calculations. Where data were not sufficient to estimate emissions, personnel from Westinghouse Materials Company of Ohio and two environmental emissions testing firms sampled the process exhausts, using EPA Method V for stack sampling.

In the cases of historic processes which were no longer in use, extensive literature searches and interviews were used to re-create the production processes. Based on this process information, emissions were determined based on comparison to current operations or by calculation based on estimated equipment efficiencies and throughput for processes where no current operation was available for comparison (Hill and Dolan 1988).

An emission factor per ton of uranium processed or per hour of operation was developed for each unmonitored process (Hill 1989a). These emission factors per ton (or per hour) were then used together with the plant-by-plant production data to estimate the emissions from the unmonitored processes in each year. Table K-24 summarizes their estimates of unmonitored process emissions for 1953-1988. The year-by-year estimates are presented in Table 3 of Hill (1989a). The total of 324 kg was only <1% of the total atmospheric releases of approximately 135,000 kg U reported by Boback et al. (1987) for 1951-1984.

An unmonitored source that was not included in Hill and Dolan (1988) is a box furnace, which was installed in the pilot plant in 1956 to process  $U_3O_8$ , enriched uranium turnings, sawdust and other residues generated in the production of enriched cores (Mead 1972). Hill and Dolan did not estimate the annual emission for this source because no production data were available. However, they state that the exhaust air from the furnace is "a probable source of radionuclide emissions." Starkey (1964a) estimated emissions from the oxidation furnace dust collector at 6 pounds of uranium per month, when the furnace was in use. At that time, it must have been used about two months per year because his average monthly emission estimate is 1 lb mo<sup>-1</sup> (5 kg y<sup>-1</sup>). This was 12% of his estimated total of unmonitored emissions from the Pilot Plant.

We have not derived any new source terms for these miscellaneous unmonitored process emissions. From our review of the documentation, the methods used to derive the estimates in Table K-24 appear reasonable. A subjective uncertainty of a factor of three is applied to

(37.,2

Page K-50

the previous estimate, resulting in an uncertainty band of 110-970 kg U over the 1953-1988

| period.                                 | of and an e                                                                        |                     |
|-----------------------------------------|------------------------------------------------------------------------------------|---------------------|
| Table K-24                              | . Estimates of Miscellaneous Un<br>Process Emissions for 1953–1988                 | imonitored          |
| Process                                 | Uranium<br>Release (kg) <sup>a</sup>                                               | Percent<br>of Total |
| Plant 6 Briquetting<br>Plant 6 Pickling | 121.0<br>12.2                                                                      | 37.3<br>3.8         |
| Plant 9 Briquetting<br>Plant 9 Pickling | a na shi wa shi ƙata ƙasar <b>19.1</b><br>Shi sa sa sang sasar na 19 <b>.3.7</b> n |                     |
| Nitric Acid Recovery<br>Cooling Towers  | 33.4<br>105.1                                                                      | 10.3<br>32.4        |
|                                         | Total 324                                                                          | 100                 |
| <sup>a</sup> Values from Table 3 of     | Hill (1989a).                                                                      | and a setter sold   |

#### **Building Ventilation**

For building ventilation, data collected by continuous air monitors (CAMs) located in each plant in 1987 were used with engineering information concerning the building exhaust fans (Hill and Dolan 1988, Hill 1989c). All radiation measured by the CAMs was assumed to be normal uranium; an assumption that Hill and Dolan felt was reasonable because the plants process large quantities of depleted uranium and lesser amounts of low-level enriched uranium. The average concentrations reported as monthly results from the individual CAM units were averaged to provide a typical building concentration for each plant.

The building exhaust fans, which were the principal source of fugitive emissions, were not used all year in most of the plants; they were used primarily in the summer to lower the temperature in the buildings. Estimates of the actual operating hours for each fan were obtained from Operations personnel, and the assumption was made that exhaust fan use has not varied appreciably during the history of operations (Hill 1989c). Because the CAMs were usually placed on the floor in areas of highest suspected concentrations, the exhaust fans are in the ceiling or high on the walls, and make-up air enters the plant through open doors and windows, the measured concentration was multiplied by a factor of 0.1 to account for dilution (Hill 1989c).

Hill assumed that emissions from building ventilation would be proportional to production rates (Hill 1989c). Historical release estimates were estimated by multiplying the 1987 release estimate for each plant by the ratio of production for that plant in the year in question to production in 1987. Explicit calculations for each plant are provided as an attachment to Hill (1989c). +0.0 £j ₹

The resulting uranium release estimates from building ventilation are given in Table 1 of Clark et al. (1989). The total release estimate for 1953-1988 was 389 kg from building ventilation as compared to about 179,000 kg from all sources. The highest annual release estimate was 33 kg in 1960. The most significant contributors to the building ventilation emissions were Plant 6 (39% of total) followed by Plants 2/3 (20% of total) and Plant 4 (29% of total) (Hill and Dolan 1988).

#### Appendix K

ें ।

#### Other Sources and Episodic Releases to the Atmosphere

In our view, one of the main weaknesses of Hill's assessment of historic releases in FMPC building ventilation is the assumption that past air dust levels could be scaled from the 1987. measurements according to the ratio of production in an earlier year to that in 1987. This approach may not reflect the increasing emphasis which was placed on contamination control equipment and procedures through the years.

An evaluation of air dust levels in uranium feed materials production facilities for 1948– 1956 was located (Breslin 1958), which permitted a forward projection of ventilation releases from historic air measurements. These measurements by the Health and Safety Laboratory for 1954–1956 should be quite typical of the Fernald operations, because in fact the FMPC was one of the two consolidated uranium production facilities in which the measurements were taken during those three years. The surveys were designed to obtain time-weighted average daily exposures to workers. Representative replicate air samples were collected at all the jobs and in all areas to which each employee was assigned during the working day. Breslin (1958) presents the data in a series of plots illustrating the percentage of workers exposed to a certain concentration range in different types of plants in the uranium production facility. Our readings of Breslin's plots (estimated to be accurate within  $\pm 2\%$ , or a fraction of 0.02) are tabulated in Table K-25. One data set, measurements in scrap recovery operations in 1955, did not add up to a total frequency of 1.0, presumably due to an error in the drafting of that figure.

Table K-25. Fraction of Workers Exposed to Various Airborne Contamination Levels in Feed Materials Production Facilities in 1954–1956 (from Breslin 1958)

| Type of     | •                 | •    | dpm per cubic meter air |          |         |                                       |          |       |
|-------------|-------------------|------|-------------------------|----------|---------|---------------------------------------|----------|-------|
| _Plant      |                   | 0-55 | 55-110                  | 110-220  | 220-440 | 440880                                | 880-1800 | >1800 |
| •           | 1954              | 0.78 | 0.08                    | 0.06     | 0.03    | 0.03                                  | 0.00     | 0.02  |
| All         | 1955              | 0.57 | 0.19                    | 0.11     | 0.05    | 0.02                                  | 0.03     | 0.03  |
|             | 1956              | 0.83 | 0.09                    | 0.03     | 0.04    | 0.01                                  | 0.00     | 0.00  |
|             | 1954              |      |                         |          |         |                                       |          |       |
| Rolling     | <sup>.</sup> 1955 | 0.28 | 0.25                    | 0.24     | 0.11    | 0.02                                  | 0.10     | 0.00  |
|             | 1956              |      |                         |          |         | · · · · · · · · · · · · · · · · · · · | ·        |       |
| Reduction & | 1954              | 0.78 | 0.10                    | · 0.08 · | 0.00    | 0.04                                  | 0.00     | 0.00  |
| Recasting   | 1955              | 0.72 | 0.15 ·                  | 0.04     | 0.07    | 0.00                                  | 0.00     | 0.02  |
|             | 1956              | 0.78 | 0.19                    | 0.01     | 0.01    | 0.01                                  | 0.00     | 0.00  |
|             | 1954              | 0.78 | 0.08                    | 0.09     | 0.03    | 0.00                                  | 0.00     | 0.02  |
| Refining    | 1955              | 0.89 | 0.09                    | 0.02     | 0.00    | 0.00                                  | 0.00     | 0.00  |
|             | 1956              | 0.82 | 0.03                    | 0.06     | 0.09    | 0.00                                  | 0.00     | 0.00  |
| Scrap       | 1954              | 0.46 | 0.18                    | 0.00     | 0.00    | 0.00                                  | 0.00     | 0.36  |
| Recovery    | 1955              | 0.35 | 0.12                    | 0.00     | 0.00    | 0.00_                                 | 0.00     | 0.34  |
|             | 1955              | 0.29 | 0.71                    | 0.00     | 0.00    | 0.00                                  | 0.00     | 0.00  |
| Sampling    | 1956              | 0.14 | 0.56                    | 0.14     | 0.08    | 0.00                                  | 0.08     | 0.00  |
| Fuel        | 1954              | 0.81 | 0.04                    | 0.03     | 0.07    | 0.04                                  | 0.01     | 0.00  |
| Fabrication | 1955              | 1.00 | 0.00                    | 0.00     | 0.00    | 0.00                                  | 0.00     | 0.00  |
|             | 1956              | 0.97 | 0.03                    | 0.00     | 0.00    | 0.00                                  | 0.00     | 0.00  |

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

2

.....

たけいごと

We used the measurements of Breslin and the ventilation characteristics of the Plants as defined by Hill (1989c) to estimate the release of uranium by building ventilation in 1954–1956. See Annex 3 to this appendix for ventilation capacities and fan operating factors. The distributions of airborne contamination levels shown in Table K-25 above were entered as custom distributions in the Crystal Ball<sup>1M</sup> uncertainty analysis software (see Annex 3). When Breslin's data were not available for a particular year and type of plant, we used the adjacent year's data for the same type of plant. Plant 9 was not operating at this time, but we included Plants 1, 2/3, 4, 5, 6, and 8 in our assessment. Breslin's operating categories were correlated with the FMPC plants as follows: Plant 1: Sampling; Plant 2/3: Refining; Plants 4 and 5: Reduction and Recasting; Plant 6: Rolling; and Plant 8: Scrap Recovery. Because the mid-1950s was a peak operating period, we assumed that operations were underway virtually full-time (3 shifts per day). Because of the 2-week vacation shutdown and other maintenance operations, we used an overall operating fraction of 0.95 for all active plants in 1954–1956.

The measurements of uranium in air in active working areas may not be representative of building exhaust air, although it should be roughly proportional. This issue relates to the dilution factor parameter that Hill used for make-up air. This dilution factor is intended to describe the ratio of the concentration of radioactivity in air measured by the constant air monitors in the working areas to the concentration in air leaving by the exhaust fans. If inlet air entered the building above the working areas, then the exhaust fans would be removing air which was relatively less contaminated than that measured in the working areas. This factor was treated as an uncertain parameter in our analysis which could range from 1.0 (no dilution) to 10, with a most likely value of 3. As discussed previously, Hill had used a factor of 10 dilution, which in our judgement would be a more reasonable upper bound than a central estimate.

The release estimates from building ventilation in 1954, 1955, and 1956 are presented in Table K-26 below. They are considerably higher (medians ranging from 150-220 kg per year) than Hill's previous estimates for these years. We feel they are a better estimate because they are linked to direct measurements of airborne contamination made at the time. However, they are still quite uncertain, for the reasons discussed above.

|   |                           | kg U per year  | . t |
|---|---------------------------|----------------|-----|
| • | Percentile<br>of Estimate | 1954 1955 1956 |     |
|   | 5%                        | 35 37 37       |     |
| • | 25%                       | 68 73 76       |     |
| , | 50%                       | 150 190        | • . |
|   | 75%                       | 400 420 390    | ••  |
|   | 95%                       | 730 760 650    |     |

Table K-26. Median Release Estimates for Uranium in FMPC Building Exhaust Ventilation in 1954–1956, Based on Air Dust Data from Breslin (1958) and Building Ventilation Characteristics Described by Hill (1989c)

In the mid-1960s, Starkey (1964a) provided an estimate of unmeasured dust losses to the atmosphere in building exhaust air, which is shown in Table K–27. He indicated that none of

#### Appendix K

#### Other Sources and Episodic Releases to the Atmosphere

#### his estimates for the exhaust systems were based on direct measurements. The estimates of releases from building ventilation were minor compared to other process sources which Starkey examined at the same time, so there may have been little incentive to refine his initial estimates for building ventilation. His estimate does lend credence to our considerably higher release estimates.

| Table K-27. Histori | ic Estimates of Unmonitored Dust Losses to the Atmosphere via |
|---------------------|---------------------------------------------------------------|
| • •                 | Roof and Wall Exhaust Fans (Starkey 1964a)                    |

| Plant       | Operating Fraction <sup>a</sup> | Average Monthly<br>Release (lb U mo <sup>-1</sup> ) | Annual Release<br>(kg U y <sup>-1</sup> ) |
|-------------|---------------------------------|-----------------------------------------------------|-------------------------------------------|
|             |                                 | · · ·                                               |                                           |
| 1           | 1                               | 3                                                   | 16                                        |
| 4           | 5/13                            | 30                                                  | 163                                       |
| ··· 5       | 3/50                            | 3                                                   | 16                                        |
| 6           | 1                               | . 3                                                 | . 16                                      |
| 8 '         | 5/9                             | 5                                                   | . 27                                      |
| 9           | 1                               | . 5                                                 | 27                                        |
| Pilot Plant | 1                               | 4                                                   | 22                                        |
| Total       | · · ·                           | 53                                                  | 287                                       |

average monthly release.

. .

<u>ينان</u>

An estimated source term for uranium in building ventilation was projected forward in time from the 1956 release estimate. The projection to future years (through 1970) was made by scaling the 1956 estimated release (by plant) according to plant-specific production rates. The production data used for this assessment are included in Table K3-1 in Annex 3 to this appendix. For some plants, which contained different types of production activities, the key production processes, which were associated with high airborne contamination levels were used for the projection. For example, major activities in Plant 9 included both production of uranium ingots and machining of metal products (Appendix C). Because the casting operation appeared to be the more significant one in terms of airborne radioactivity levels, we based our projection for Plant 9 only on the uranium ingot production rates (Table K3-1), and we used Breslin's measurements of uranium in air in reduction and recasting operations areas. In addition, we used the production data for rolling operations in Plant 6, since the fabrication operations in that plant are much less significant in terms of contamination levels.

With the exception of the magnitude of the dilution factor, we felt that the method of Hill was reasonable for projecting as far back as 1970. Hill's estimates, adjusted to a dilution factor of 3 rather than 10, are presented in Figure K-17 along with the other estimates. Uncertainty was propagated through the projections. The detailed distributions for the annual estimates are included in Table K3-2 of Annex 3 to this appendix. Roughly 80% of the total releases from building ventilation occurred between 1957 and 1970, inclusive. The other 20% occurred in 1954-1956 ( $\approx 14\%$ ) and during 1971-1987 ( $\approx 6\%$ ).

The increase in the estimated release between 1957 and 1960 is primarily due to the increase in scrap recovery operations in Plant 8. These operations produced high airborne activity levels inside the plant (Table K-25), which are reflected in emissions in building

Page K-53

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

ž

.

4

1.

ventilation. Plant 8 production was a factor of 2 higher in 1960 as compared to 1956. In our final dose report, the entire building ventilation source term will be modeled as if it had been released from Plant 8. This simplification is warranted by the relatively small releases and the fact that over half of the total uranium released in building ventilation through 1970 is believed to have come from Plant 8.

It is encouraging that Starkey's estimate for 1964 is in very good agreement with our forward projection (Figure K-17). The forward and backward projections were overlapped for three years (1970-1972) to see how they compare (Figure K-17). The forward projection results in median source term estimates which are a factor of 2-3 higher than those obtained using the backward projection for these three years; however, the uncertainty distributions overlap. Considering the range of estimates over the history of plant operations, we consider this agreement good. In addition, both methods produce estimates of releases which are minor relative to other sources after 1970 (see concluding section of this appendix). No further investigation into the differences in the two projection methods was made.

The total estimated release of uranium in FMPC building ventilation during 1954 through 1987 is 4100 kg (median estimate) with a 5th-95th percentile range of 970-15,000 kg. This is about a factor of ten higher than Hill's previous estimate (390 kg). The two main reasons for the large difference are: (1) the use of a lower dilution factor for building make-up air and (2) the use of higher in-plant airborne contamination levels, measured in the 1950s, to make a forward projection through 1970.



100 50 0 955 50 1957 1958 828 8 2 20 200 8 5 898 20 8 3

Figure K-17. Summary of release estimates for uranium in building exhaust ventilation.

Laboratory Hoods Uranium emissions from laboratory hoods were based upon the average number of

------

samples processed per year in each hood, the probable loss per sample and the estimated

#### Appendix K

.....

:

Ž

#### Other Sources and Episodic Releases to the Atmosphere

Page K-55

uranium concentration of the samples (Hill and Dolan 1988). Existing hoods and known former laboratory exhausts were evaluated. The resulting emission estimate was a constant at 1.9 kg y<sup>-1</sup>, or 66.5 kg over the period 1953-1987. Hill and Dolan (1988) indicate that the estimate for emissions from laboratory hoods is probably high; however, a more accurate value would have required long-duration stack tests for each vent, which were not warranted due to the low emission estimate. From review of the relevant documentation, we agreed that no further assessment was warranted.

#### **EPISODIC RELEASES**

Accidental releases are frequently characterized as increases in the effluent discharge rates due to unplanned and non-routine events. Typical events can include spills, fires, and cleanup system failures. However, when the frequency of unusual events is high, one questions whether the adjective "non-routine" is correct. Similarly, when a large release is the result of a conscious operational decision, it hardly qualifies as unplanned. Such situations complicate the definition of the term accidental releases, so the term episodic releases will be defined below for a specific purpose.

Semantics aside, the important concerns about such releases for dose reconstruction are whether they were detected and/or sampled and whether their magnitudes are sufficient to warrant special treatment in the dose estimation process. Radionuclide releases that occurred via unsampled discharge points have been estimated in this appendix, Appendix H, and Appendix I. This was necessary to achieve the goal of completeness for the radionuclide source term. The second question is whether the event caused an effluent discharge that was substantially above that normally expected and observed at the FMPC. If so, then special dose assessment procedures should be employed to document the doses to individuals living in areas that were downwind, or downriver, at the time of the release.

#### Criteria for Implementation of Special Dose Assessment Procedures

Criteria are needed to determine when special dose assessment procedures should be applied. These procedures will be used to estimate the movement of particular discharges in the local environment and to perform special assessments of radiation doses to individuals in areas that were affected by the discharge. Development of such criteria is not a simple task in the context of historic FMPC operations.

Presentations of release estimates in this report have illustrated both the magnitudes and the variability of effluent discharges from the FMPC. In the early years of operation, large amounts of uranium were frequently discharged to the atmosphere and to the river. As many as ten facilities contributed to the total discharges from the FMPC. The largest discharges were not always from the same facilities, although some facilities were clearly more important sources of effluents than others. This means that a large increase in the effluent from a facility that was a minor contributor to the total discharge could have a negligible effect on the total release rate. Also, the magnitudes of the total discharges have decreased substantially over the years. This has the effect of lowering the threshold above which a particular release of radioactivity would deserve special attention in dose assessment.

days.

10

121414.6

The second second

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

la se la composi-nomeno en entre These factors require that the criteria for special dose assessment procedures must consider the magnitude of the release in the context of the releases from all of the facilities at the FMPC and the relative importance of the release to the total discharge at the time it occurred. Releases in recent years that were large enough to be significant perturbations to the overall plant effluent and the cause of an inquiry (Investigation Board 1988) would have had a relatively minor effect on the total monthly discharge during early years of operation.

In consideration of these historical facts, the following are criteria that can be used to determine whether special evaluation of a release from a particular event is warranted:

1923 - 19**1** - 19 the event under consideration caused the composite release rate of the FMPC to increase by a factor of ten or more above the value that would otherwise have been observed, and . : }

the duration of the high release rate caused by the particular event was less than 10

٠. 1. 16 204 213 - 小道の経過の かいたい . .... 

The second criterion takes into consideration the fact that natural dispersion phenomena also play a significant role in the dosimetric analysis. For releases of long duration, the variability in dispersion conditions, including wind direction, will spread the effect over a wider area and reduce the magnitude of the increased dose to individuals in อกอเมช any particular area.

#### **Episodic Releases Identified from Document Review**

1. 1. 1. 1

A review of available incident reports was conducted to identify those which involved potential releases of uranium to the atmosphere (Table K-28). Further study reveals that three short-term releases from the Pilot Plant, two which involved breached  $UF_6$  cylinders and one which resulted from dust collector failure, satisfy the criteria for special environmental dose evaluations. It should be noted that the failure of dust collectors was fairly common and resulted in relatively large quantities of uranium being released from the FMPC. However, these episodes generally occurred over periods of time that resulted in release rates within a factor of ten of that normally observed. A compilation of major dust loss incidents is documented in Adams (1985) and, with the exception of the one described below, are included in the annual source terms presented in Appendix E. Finally, many of the incidents shown in the table were described in the incident reports without estimates of emissions. It was assumed in such cases that the releases were minor because little effort was expended in determining the magnitude of the releases. This assumption is justified in light of calculations made in the section entitled "Non-routine releases," which appears later in this report.

The first episodic release occurred in the Pilot Plant on November 7, 1953, when a cylinder containing uranium hexafluoride (UF $_{6}$ ) was breached releasing approximately 100 pounds (45 kg) of the gas. The cylinder had been heated up, and UF<sub>6</sub> was flowing via a feed line to the reactor (which converts  $UF_6$  to  $UF_4$ ) when a plug developed in the reactor. After the cylinder was shut off to purge the feed line, leakage of UF<sub>6</sub> was observed around the valve stem and a dry ice fire extinguisher was used to freeze the valve. As a cap was being placed on the valve outlet, the hex plug in the valve broke loose, and UF<sub>6</sub> escaped rapidly from the valve outlet. The Fire Department succeeded in stopping the leak with the use of

#### Other Sources and Episodic Releases to the Atmosphere

Appendix K

e la

water spray. Davis (1953) gives few other details about the effluent. However, he does note that the duration of the release was 15 minutes and that there was a strong northerly wind blowing at the time.

The second episodic release occurred in the Pilot Plant sometime between November 12 and November 16, 1960, when slightly enriched uranium was lost from dust collector G20-\_0. There was some question as to the amount of uranium lost and when it was lost. An assessment of the potential release is presented in Appendix V of the Task 4 Report (Killough et al. 1993). After evaluating documents pertaining to the release and environmental monitoring records, it was concluded that the release was 300 or 500 kg d<sup>-1</sup> for the first five or three days, including November 16, and about 200 kg d<sup>-1</sup> during the last three days of the event.

The third episodic release occurred in the Pilot Plant on February 14, 1966. The following description of the  $UF_6$  release was obtained from NLO (1966) and Boback and Heatherton (1966). On February 14, 1966, at approximately 8:40 AM, about 3800 lbs (1724 kg) of uranium, as  $UF_6$ , escaped from a 10-ton cylinder being heated by steam to transfer the gas to the process system in the Pilot Plant. NLO (1966) states that 2150 lbs (975 kg) were accounted for in the waste streams. Thus, as much as 1650 pounds (750 kg) may have been released to the atmosphere.

The sequence of events in the 1966 incident is as follows. The cylinder was cradled in a movable vaporizer chest and connected to the process equipment with copper tubing. The cylinder had been heated up, using steam. An operator accidentally removed the cylinder valve while attempting to open it. Another operator quickly manipulated a water deluge valve, but failed to actuate it. A full stream of  $UF_6$  gas was expelled from the container and vented to the atmosphere through a hood positioned over the vaporizer chest. Pilot Plant personnel began to spray the cylinder with a water hose and were quickly joined by the fire brigade (time = 8:47 AM), who connected fire hoses and began to direct the spray into the cloud near the place where it was leaving the chest. The hood was then raised, and a direct water stream was applied to the end of the chest so that it rebounded against the cylinder at the valve opening. Continued application of water for about one hour finally cooled the cylinder and reduced its pressure sufficiently to permit a wooden plug to be driven in the valve opening.

The escaping gas was carried by wind in a southeasterly direction over a laboratory building and the administration building. Airborne UF<sub>6</sub> hydrolyzes quickly on contact with moisture in air to form UO<sub>2</sub>F<sub>2</sub> and HF. Boback and Heatherton (1966) state that there was a "light fog of steam and hydrolyzed UF<sub>6</sub> which drifted near the lab and Administration buildings." Personnel involved in the emergency actions or who had any reason to believe that they may have inhaled some of the material were asked to submit urine samples. During the week following the incident, 280 employees and four visitors submitted 1024 urine samples which were analyzed for uranium. Of these, 115 employees had U concentratrions that exceeded 0.025 mg U L<sup>-1</sup>. Six employees, who were directly involved in emergency procedures, had uranium concentrations that exceeded 1 mg L<sup>-1</sup>. Sixty employees had a uranium concentration between 0.1 and 0.9 mg L<sup>-1</sup>. Some of these were not near the release site, but walked in the foggy area near the lab and administration buildings. After 24 hours, the urinary uranium concentration of most employees had dropped to pre-incident levels.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

And the second 
and the second of the second o

÷.

| to the Atmosphe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | ere                                   |                          |                                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|--------------------------|-----------------------------------------------------------------------------------------------------------------------|
| n de la construction de | Duration of                           | Total U                  | Meets                                                                                                                 |
| 7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | elease to the                         | released to              | episodic                                                                                                              |
| Date reported and description of incident                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | tmosphere                             | atmosphere -             | release                                                                                                               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | · · · · · · · · · · · · · · · · · · · | lbs(kg)                  | criteria?                                                                                                             |
| 11/2/52. Broken crucible in the 3037 area of the Pilot Plant.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | lot reported.                         | None reported            | No                                                                                                                    |
| (Heatherton 1952)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                       | -probably                |                                                                                                                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                       | contained.               |                                                                                                                       |
| 11/7/53. Release of UF <sub>6</sub> from defective cylinder in Pilot Plant. 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5 min                                 | 100(45)                  | Yes                                                                                                                   |
| (Davis 1953)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | •                                     |                          |                                                                                                                       |
| 4/6/54. Metal oxide spill from a cyclone in the Spray Calciner $\sim$ N                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | lot reported.                         | Probably minor           | No                                                                                                                    |
| system in the combined raffinate area. The spill was due to                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | . /                                   | - some fine              |                                                                                                                       |
| removal of an inspection plate from the cyclone. (Turner 1954)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 11 r ·                                | dust was                 |                                                                                                                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                       | observed to              | ·. ·                                                                                                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                       | blow onto stone          |                                                                                                                       |
| · .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                       | east of the              |                                                                                                                       |
| · · · · · · · · · · · · · · · · · · ·                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                       | area.                    |                                                                                                                       |
| 6/4/54. Spill of South African concentrate from drums. Drums N                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | lot reported                          | <b>&lt;2(&lt;1)</b>      | . No                                                                                                                  |
| were in transport to Plant 2 when one of the trailers broke (a                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | assume 1                              | (assuming a              | : ./                                                                                                                  |
| oose from the train and struck a light pole located at the south h                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | our).                                 | max U conc. of           | •••                                                                                                                   |
| end of the slope west of the Chemical Warehouse. Sixteen                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                       | 1.25%)                   |                                                                                                                       |
| drums spilled—14 filled in the process of cleanup. (Costa 1954)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                       | •                        |                                                                                                                       |
| 7/8/54. Small amount of leakage of UO, from juice hoppers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | lot reported.                         | None reported. $\cdot$ . | No.                                                                                                                   |
| stored on storage pad. (Walden 1954)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 12                                    | ·.                       | e -                                                                                                                   |
| 12/6/54. Spill of divrapate cake from two drums at the Plant 8 N                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | lot reported.                         | None indicated           | No                                                                                                                    |
| storage pad. (Harrell 1954)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                       | (all recovered).         |                                                                                                                       |
| 5/24/55. Fire in feeding tray of oxidation furnace (Plant 8).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | .5 hr                                 | None reported.           | No                                                                                                                    |
| Stefanec 1955)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                       | •                        | •                                                                                                                     |
| 1/25/56. Release of metal oxides from storage silos in the Plant U                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Inknown                               | Probably                 | No                                                                                                                    |
| l area resulting in widespread contamination of ground.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | t nitra                               | insignificant            | •                                                                                                                     |
| ouildings and equipment in area extending from "A" to "B"                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                       | (material                | •                                                                                                                     |
| treet, and from the North side of the Chemical Warehouse to                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                       | deposited on             |                                                                                                                       |
| he North side of the Refinery Building. Area was                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | - )                                   | snow, which              | · •.*                                                                                                                 |
| ubsequently decontaminated. (Heatherton 1956; Strattman                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                       | was then                 | s.<br>The product of the second s |
| 1956)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                       | removed).                | -                                                                                                                     |
| 5/29/56. Explosion in Extraction Area of Pilot Plant. (Halcomb In                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | nstantaneous .                        | Probably minor           | No                                                                                                                    |
| 1956)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                       | (appears to              |                                                                                                                       |
| 1555.00 (000) 10<br>1000 (1.000) 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                       | have been                |                                                                                                                       |
| san ya santa sa                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | •.                                    | contained).              | (*)                                                                                                                   |

### (continued next page)

na grant Aberta da la

II.\_\_

5

1

#### Appendix K Other Sources and Episodic Releases to the Atmosphere

!

.

. .

| to the Atmospher                                                                                                                                                                 | re (cont.)                           |                                             |                                                              | _ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|---------------------------------------------|--------------------------------------------------------------|---|
|                                                                                                                                                                                  | Duration of<br>release to the        | Total U<br>released to                      | Meets                                                        | 1 |
| Date reported and description of incident                                                                                                                                        | atmosphere                           | atmosphere                                  | release                                                      |   |
| 1/10/58. Release of UF, in Pilot Plant when Ho line in reactor                                                                                                                   | 0.75 hr                              | Probably minor                              | No                                                           | , |
| column broke and UF <sub>6</sub> backed out. (Klein 1958)                                                                                                                        |                                      | (appears to<br>have been                    |                                                              | • |
| FILMER Ferlaging of DAR 104 Houses in Direct R (Down 1050)                                                                                                                       | T                                    | contained).                                 | N                                                            |   |
| STW58. Explosion of D43-104 digestor in Flant 6. (Deers 1556)                                                                                                                    | Instantaneous                        | (appears to<br>have been                    |                                                              |   |
| CITO/ED. Balance of bot unapul situate solution from went of the                                                                                                                 | Not reported                         | contained).                                 | No                                                           |   |
| #212 sparge tank onto the denitration pad, the roadway east of<br>the Refinery and the gravel area east to Plant 4.<br>Approximately 1000 lbs. of uranium lost. (Harr 1959)      | Not reported.                        | insignificant-<br>most washed<br>into storm |                                                              |   |
|                                                                                                                                                                                  |                                      | (see Appendix<br>L)                         |                                                              |   |
| 12/29/59. Explosion in Digestor Tank 101 in Plant 8 due to<br>hydrogen buildup when vent system plugged up. (Noyes 1960;<br>Beers 1960)                                          | Instantaneous                        | None reported                               | No                                                           |   |
| 11/15/60. Dust loss from Dust Collector G20-20 in the Pilot                                                                                                                      | a. 5 or 3 days                       | -a. 3300(1500)                              | Yes. [See                                                    |   |
| Plant. The dust collector bags were found to have been<br>chemically attacked, presumably by hydrofluoric acid. Two<br>separate sequential releases occurred, the first when the | (one of 2 dates<br>possible for last |                                             | Killough et<br>al. (1993)]                                   |   |
| damaged bag was tied off and the second when all bags were<br>replaced. (Starkey et al. 1960; Killough et al. 1993)                                                              | normal collector<br>operation)       | h 1220(600)                                 | ·                                                            |   |
| 3/27/61. Spill of hot black oxide onto graveled area of Plant 9                                                                                                                  | Not reported.                        | Probably                                    | No                                                           |   |
| from 55-gallon drum containing a 10-gallon drum of the oxide.                                                                                                                    | rivereportea.                        | insignificant-                              | •                                                            |   |
| The bottom of the 55-gallon drum had burned through allowing the black oxide to fall to the gravel. (Brevard 1961)                                                               |                                      | immediately<br>cleaned up and               | •                                                            | • |
|                                                                                                                                                                                  | • • •                                | monitored.                                  | •                                                            |   |
| 22062. Remeit furnace explosion in Plant 9. (Starkey 1962)                                                                                                                       | Instantaneous .                      | Probably<br>none- appears<br>to have been   | No                                                           |   |
| 10/15/09 Fire in drummad abies stand the south sect                                                                                                                              |                                      | contained                                   | No (Sc-                                                      |   |
| corner of Plant 6. Six 30-gallon drums involved. (NLO 1962)                                                                                                                      | Not reported.                        | Not reported.                               | No. (See<br>calculations<br>in Non-<br>routine<br>Releases.) | · |
| 10/16/62. Fire in drummed chips stored near the southeast<br>corner of Plant 6. Seventeen 30-gallon drums involved. (NLO<br>1962)                                                | Not reported.                        | Not reported.                               | No. (See<br>calculations<br>in Non-<br>routine<br>Releases.) |   |

# Table K-28. Summary of Incident Reports Involving Potential Uranium Releases to the Atmosphere (cont.)

(continued next page)

10.12.1

Sec. Co

and the states which are a

-----

| n and the second se                                                            | ege                                                    | · · ·                                        |                                                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|----------------------------------------------|------------------------------------------------|
| Table K-28. Summary of Incident Reports In<br>to the Atmospher                                                                                                            | volving Poter<br>e (cont.)                             | ntial Uranium                                | Releases                                       |
|                                                                                                                                                                           | Duration of<br>release to the                          | Total U                                      | Meets                                          |
| Date reported and description of incident                                                                                                                                 | atmosphere                                             | atmosphere<br>lbs(kg)                        | release<br>criteria?                           |
| 10/17/62. Fire in drummed chips stored near the southeast corner of Plant 6. One 55-gallon drum involved. (NLO 1962) $_{L_{1}}$                                           | Not reported.                                          | Not reported.                                | No. (See<br>calculations<br>in Non-            |
| and the second                                                          | nige ag                                                |                                              | Releases.)                                     |
| 10/20/62. Fire in drummed chips stored near the southeast<br>corner of Plant 6. Twelve 55-gallon drums and 16 30-gallon<br>drums involved. (NLO 1962)                     | Not reported.                                          | Not reported.                                | No. (See<br>calculations<br>in Non-            |
| and a second and a second and a second                                                            | •                                                      | · · · · · · · ·                              | routine<br>Releases.)                          |
| atmosphere from Plant 4 due to dust collector bags not being<br>seated correctly in the tube sheet of dust collector G-4-8.<br>(Martin et. al. 1963)                      | 20 days                                                | 939(425)                                     | No. (Included<br>in routine<br>source term.)   |
| 6/4/63. Fire in Pilot Plant Pangborn Rotoblast equipment. (www.<br>(Vath 1963)                                                                                            | Not reported.                                          | Minor loss<br>reported.                      | No                                             |
| 477/65. Fire in drummed chips stored on the Plant 6 southeast pad. (Ross 1965)                                                                                            | Not reported.                                          | Not reported.                                | No. (See<br>calculations<br>in Non-<br>routine |
|                                                                                                                                                                           | 1 he                                                   | 1650(750)                                    | Keleases.)<br>Yes                              |
| 21400. Or 6 release from a 10-ton cylinder of uranium                                                                                                                     |                                                        |                                              |                                                |
| uncanneed the milinder neither (NLO 1000 Babaah                                                                                                                           |                                                        |                                              |                                                |
| Unstrewed the cylinder valve. (NLO 1966; Bonack &                                                                                                                         |                                                        |                                              |                                                |
| 7/25/69. Orange oxide (400 lbs) discharged from the Refinery<br>gulping systems onto the roof of the Denitration Area. Release                                            | 0.5 hr                                                 | None indicated.                              | No                                             |
| was cleaned up or released to sewer system; material balance<br>indicates that no material was lost to the atmosphere (i.e., all<br>material accounted for). (Adams 1969) |                                                        | ••••<br>•••<br>•                             |                                                |
| 4/10/70. Depleted sludge fire in Pit #4. (Heatherton 1975)                                                                                                                | 6 hours                                                | 17.17(7.8) (See                              | No                                             |
|                                                                                                                                                                           | torego (d. 1999)<br>1999 - Barrison<br>1999 - Barrison | calculations in<br>Non-routine<br>Releases.) |                                                |

1

(continued next page)

and sold <u>partition</u> of the solution of the so

#### Appendix K Other Sources and Episodic Releases to the Atmosphere

<u>/</u>

N N

<u>.</u>

#### Page K-61

#### Table K-28. Summary of Incident Reports Involving Potential Uranium Releases to the Atmosphere (cont.)

|                                                                  | Duration of       | Total U      | Meets     |
|------------------------------------------------------------------|-------------------|--------------|-----------|
|                                                                  | release to the    | released to  | episodic  |
| Date reported and description of incident                        | atmosphere        | atmosphere   | release   |
| Classification in the Direct Onthe 1000 duct collector           |                   | 153(Kg)      | criteria? |
| 6/14/78. Dust loss in the Plant 9-NI-1039 dust collector         | Unknown, but      | 153(70)      | No        |
| servicing the NPR lumace and the crucible burnout area due t     | o at least 20-35  |              |           |
| damage to the collector bags. (Adams 1978)                       | days              | 20/15        |           |
| 6/15/81. Dust loss from Plant 4 dust collector G4-14. (Nutter    | 32 days.          | 33(15)       | NO        |
| 6/19/81 Dust loss from Plant 4 dust collector, G4-14 due to ba   | ar Adova          | 130(59)      | No        |
| foilure (Nutter 1981)                                            | g tujs            | 100(05)      |           |
| 6/29/81. Dust loss from Plant 4 dust collector G4-14 due to ba   | g 10 davs         | 25(11)       | No        |
| failure. (Nutter 1981)                                           | ,                 |              |           |
| 9/8/81. Loss of greensalt from Plant 4 dust collector G4-2 due   | 10 days           | 440(200)     | No        |
| to bag failure. (Nutter 1981)                                    |                   |              |           |
| 9/10/81. Additional loss from Plant 4 dust collector G4-2 due to | o lday            | 86(39)       | No        |
| hold-up in sampler and residual material in the collector (see   |                   |              |           |
| previous episode). (Nutter 1981)                                 |                   |              |           |
| 12/12/84. Loss from the Stacks of Nos. G5-260 and -261 dust      | Unknown           | 33(15)       | No        |
| collectors. (Martin et al. 1985)                                 |                   |              |           |
| 12/14/84. Dust loss from Plant 9 dust collector G9N1-1039 due    | unknown,          | 273(124)     | No        |
| to bag failure. (Martin et al. 1985; Adams 1985)                 | probably over a   |              |           |
|                                                                  | few months        |              |           |
| 12/18/84. Stack loss from the Plant 9 Machining precipitron.     | 2 years           | 5.7(2.6)     | No        |
| (Nutter 1984)                                                    | <b>NT A A A A</b> | 14.0.45      |           |
| 2/4/85. Uranium chip fire. (NLO 1985a)                           | Not reported.     | <1(<0.45)    | No        |
| · .                                                              | Assume 30         |              |           |
| 2/25/85 Marmasium fluorida and deplated II release inside        | Minutes           | 0.08(0.04)   | No        |
| Plant 5 (NLO 1985b)                                              | ininuces          | 0.00(0.04)   |           |
| 4/12/85. Release of uranium oxide during filter change-out in    | Not reported.     | 1.1(0.5)     | No        |
| Plant 8 Dust Collector #8035. (NLO 1985c)                        | Assume            |              |           |
|                                                                  | minutes.          |              |           |
| 11/1/85. Magnesium flash during the reduction of charge          | Instantaneous     | Probably not | No        |
| #72221. Considered a minor event. (NLO 1985d)                    |                   | significant  |           |
| 12/3/85. Smoke from #46 Rockwell Furnace due magnesium           | Instantaneous     | Probably not | No        |
| flash of charge #73003. Considered a minor event. (NLO           |                   | significant  |           |
| 1985e)                                                           |                   |              |           |
| 1/19/86. Cracking of reaction vessel #2 at the Pilot Plant,      | Unknown           | 14.5(6.6)    | No        |
| which released UF <sub>c</sub> to atmosphere. (WMCO 1988a)       |                   |              |           |

(continued next page)

#### Page K–62

0.000

WWW. WWW.

| Table K-28. Summary of In | cident Reports Involvin | g Potential | Uranium | Releases |
|---------------------------|-------------------------|-------------|---------|----------|
| <u> </u>                  | to the Atmosphere (con  | t.)         |         |          |

| Date reported and description of incident                                             | anti segli di sen<br>e<br>anti segli di se<br>anti se di secto di se<br>anti secto di                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Duration of release to the atmosphere | Total U<br>released to<br>atmosphere<br>lbs(kg) | Meets<br>episodic<br>release<br>criteria? |
|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|-------------------------------------------------|-------------------------------------------|
| 11/11/86. Spill of 300 lbs of UO3 from Bank 9                                         | fluid bed reactor                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Minutes                               | Not                                             | No                                        |
| system in Plant 4. (DOE 1986)                                                         | 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | · · · ·                               | significant.                                    |                                           |
| 12/30/86. Derby on fire in East Break Out are                                         | a of Plant 5.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Minutes                               | Probably not                                    | No                                        |
| Considered a minor event. (WMCO 1986)                                                 | the state of the s |                                       | significant.                                    | · · · ·                                   |
| 2/23/87. Spill of green salt in Reduction Area of                                     | of Plant 5.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Unknown                               | Probably                                        | No                                        |
| (WMCO 1987c)                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | · · · ·                               | none.                                           |                                           |
| 2/27/87. Fire on grizzley conveyer in area of re                                      | melt furnace pot                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Unknown                               | None                                            | No                                        |
| No. 10596 (Plant 5 East Breakout) caused by s<br>derby charge No. 31528. (WMCO 1987d) | parks emitted by                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | e e to to<br>Et el                    | indicated.                                      |                                           |
| 1/15/88. Release of UF <sub>4</sub> through dust collector Plant. (Collier 1988)      | G-2 at Pilot                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Unknown                               | None<br>indicated.                              | No                                        |
| 1/18/88. Release of uranyl nitrate from Plant 2                                       | /3. Incident was                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Unknown                               | 40(18)                                          | No. (Release                              |
| discovered when an area of the Plant 2/3 roof a                                       | nd nearby                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                       |                                                 | was containe                              |
| ground within FMPC was found contaminated                                             | with uranyl                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | ••                                    |                                                 | in the                                    |
| nitrate. (WMCO 1989)                                                                  | ;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                       |                                                 | production                                |
|                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | ·· · ·                                | • · · · •                                       | area.)                                    |
| 2/26/88. Dust release from G-2-239 Hoffman hi                                         | gh vacuum                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Minutes                               | None                                            | No                                        |
| system in Plant 8. (WMCO 1988b)                                                       | •                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | •                                     | indicated.                                      |                                           |
| 3/14/88. Depleted UF <sub>4</sub> spill in Plant 4, Deplete                           | d Packaging                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Minutes                               | None                                            | · No                                      |
| Operations. (WMCO 1988c)                                                              | • .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | •                                     | indicated.                                      |                                           |
| 6/30/88. Release of uranium from UO <sub>3</sub> and gul                              | ping operations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 4 weeks                               | 145(66)                                         | No                                        |
| at Plant 2/3 Refinery. (WMCO 1989)                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | х и <b>•</b> , <i>- г</i>             |                                                 | en 1.                                     |
| 10/4/88. Uranium chip fire in Plant 6 involving                                       | five drums.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Not reported                          | None                                            | No                                        |
| (WMCO 1989)                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                       | indicated.                                      | · · · · · · · · · · · · · · · · · · ·     |

Monitoring of the Pilot Plant following the 1966 episodic release indicates that most of the contamination occurred in the immediate area of the incident, i.e., the Pilot Plant proper and the north pad of the Pilot Plant. Offsite areas just south of the FMPC were monitored for alpha contamination with hand-held instruments and showed no contamination above instrument background. Milk samples collected offsite were analyzed on 2/15/66 and found to have uranium concentrations well below significant levels and consistent with previous samples. Soil, vegetation, and water samples collected within the FMPC at varying distances south of the Production Area, did not contain any significant concentrations of uranium.

#### **Episodic Releases Identified Using Monitoring Data**

.....

÷.,

In addition to reviewing documents, air monitoring and gummed film data obtained from 1958 through 1984 were evaluated to identify potential episodic releases. An initial screening assessment of air monitoring data indicated that 14 undocumented episodic releases may have occurred during this time period (see Appendix B-Part 2 of Shleien et al. 1993). Further analyses of these data were performed to determine if the apparent releases meet the criteria for implementing special dose assessment procedures.

First, a "baseline" concentration of airborne uranium was estimated for each location and time period of concern. The baseline concentration was defined as the average uranium concentration during the 3-week period before and the 3-week period after the elevated concentration was observed. This is illustrated in Figure K-18. If the elevated concentration was determined to be at least 10 times greater than the baseline concentration, the result was considered for further evaluation. Eight results exceeded the baseline value by this amount, as illustrated in Figures K-18 through K-25.







1. A. A. A. A.

1.1

STATES -





بريتم

.

....

Č,

Figure K-21. Uranium in air at BS-3 during the period from 11/6/80 through 12/18/80.







1040×--

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties







Figure K-25. Uranium in air at BS-5 during the period from 8/30/83 through 10/11/83.

.

. . .

Next, the airborne uranium concentrations were used to estimate the possible source term. The source term for each potential release was calculated using the following approach and assumptions:

- 1. It was assumed that the release point was the center of the FMPC. Distances to each air monitoring location are presented in Table K-29.
- 2. Average meteorological conditions for the month of the potential episode were assumed.
  - 3. The building wake model (Killough et al. 1993) was used to calculate dispersion (X/Q) parameters (s  $m^{-3}$ ) for each air monitoring location.
  - 4. For each time period and location of concern, the measured uranium concentration in air was used, along with the estimated X/Q, to calculate the release rate. (Note: All locations during the time period of concern which showed elevated airborne uranium concentrations were used to obtain a range of possible source term values.)
The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

1.0.6.1

Results of the calculations are shown in Table K-30. Based on the upper range of estimated source term values, three episodic releases are apparent. They occurred during the weeks ending on September 28, 1978, February 8, 1979, and September 20, 1983. The range of release rate values estimated for each of these episodes are 6-56 kg d<sup>-1</sup>, 12-100 kg d<sup>-1</sup>, and 47-57 kg d<sup>-1</sup>, respectively. The source of these episodic releases is unknown, as supporting documentation could not be found. Gulping of UO<sub>3</sub> in Plant 2/3 is one suspect, as it was identified in 1988 as an unmonitored radioactive emission source (Vaaler and Nuhfer (1989). However, Semones and Sverdrup (1988) indicate that this process was not in operation during the years 1978 and 1979. They estimated a total loss of 130 kg of uranium for the year 1983, which represents an average daily loss over 100 times less than the episodic release calculated here. Other possible unmonitored sources of magnitude observed include the incinerator (through 1979) and Plant 8 scrubbers.

| Station | Distance from FMPC center (m) | ter (m) FMPC Center |  |  |
|---------|-------------------------------|---------------------|--|--|
| BS-1    | 1000                          | N                   |  |  |
| BS-2    | 1200                          | NE                  |  |  |
| BS-3    | 730                           | Έ                   |  |  |
| BS-4    | 1600                          | SE                  |  |  |
| BS-5    | 1200                          | SW                  |  |  |
| BS-6    | 1100                          | W                   |  |  |
| BS-7    | 1600                          | NW                  |  |  |

**Non-routine Events** 

11

3.5

Most of the releases which occurred as a result of accidents at the FMPC did not qualify as episodic releases, using the criteria discussed in the previous section. In order to account for all of these releases, it is necessary to include them in the total annual source term. In addition, providing an estimate and the associated uncertainty for such releases provides limits which ideally encompass all accidental releases, including those for which documentation is no longer available. Clark et al. (1989) included these additional uranium emissions from "non-routine events" over the 37-year history of the FMPC. Details of the analysis can be found in Vaaler and Nuhfer (1989). The investigation involved research of historical site documents to determine the types and frequency of accidents. Estimates of uranium emissions were derived from the historical information and best engineering judgment based on familiarity with plant operations. Four categories of non-routine events were identified: uranium fires, solid spills,  $UF_6$  leaks, and releases of uranyl nitrate. Two non-routine releases (in 1966 and 1984) which were included in Boback et al. (1987) were not duplicated in the addendum report estimates for non-routine events.

| Appendix K                                            |
|-------------------------------------------------------|
| Other Sources and Episodic Releases to the Atmosphere |

X

Ş

| Page | K69 |
|------|-----|
|------|-----|

| -             |             | '.<br>                 | E                                     | ata                                    |                       | •                                  |           |
|---------------|-------------|------------------------|---------------------------------------|----------------------------------------|-----------------------|------------------------------------|-----------|
| •••• <b>-</b> |             | Air conc. X/Q          |                                       | Releas                                 | <b>Release Rate</b>   |                                    | Criterion |
| Date          | Station     | (fCi m <sup>-3</sup> ) | (10 <sup>-7</sup> s m <sup>-3</sup> ) | (10 <sup>-7</sup> Ci s <sup>-1</sup> ) | (kg d <sup>-1</sup> ) | (kg d <sup>-1</sup> ) <sup>a</sup> | exceeded? |
| 9/28/78       | BS-2        | 10                     | 4.6                                   | 0.2                                    | 5.9                   | 31                                 | No        |
|               | BS-3        | 40                     | <b>6.4</b>                            | 0.6                                    | 16                    |                                    | No        |
|               | BS-4        | 13                     | 3.2                                   | 0.4                                    | 11                    |                                    | No        |
|               | BS-5        | 47                     | 2.7                                   | 1.7                                    | 45                    |                                    | Yes       |
|               | <b>BS-6</b> | 46                     | 2.2                                   | 2.1                                    | 56                    |                                    | Yes       |
| 2/8/79        | BS-1        | 82                     | 2.4                                   | 3.5                                    | 90                    | <b>31</b> ·                        | Yes       |
|               | BS-2        | 40                     | 8.4                                   | 0.5                                    | 12                    |                                    | No        |
|               | BS-3        | 228                    | 9.0                                   | 2.6                                    | 67                    |                                    | Yes       |
|               | BS-4        | 75 ·                   | 4.2                                   | 1.8                                    | 47                    |                                    | Yes       |
| •             | BS-5        | 124                    | 4.8                                   | 2.6                                    | <b>68</b>             |                                    | Yes       |
|               | BS-6        | 81                     | 2.1                                   | 3.8                                    | 100                   |                                    | Yes       |
| 10/30/80      | BS-4        | 21                     | 3.6                                   | 0.6                                    | 15                    | 33                                 | No        |
|               | BS-5        | 7                      | 0.9                                   | 0.8                                    | 21                    |                                    | No        |
| 11/25/80      | BS-1        | .12                    | 6.6                                   | 0.2                                    | 4.8                   | 33                                 | No        |
|               | BS-3        | 23                     | 11.0                                  | 0.2                                    | 5.7                   |                                    | No        |
|               | BS-6        | 7                      | 2.5                                   | 0.3                                    | 7.2                   | •                                  | No        |
| 7/23/81       | BS-4        | 29                     | 2.3                                   | 1.3                                    | 33                    | _ 54                               | No        |
|               | BS-5        | 11                     | 1.5                                   | 0.7                                    | . 19                  | -                                  | No        |
| 9/3/81        | , BS-1      | 14                     | 2.8                                   | 0.5                                    | · 13                  | 54                                 | No        |
|               | BS-2        | 61                     | 4.6                                   | 1.3                                    | 35                    |                                    | No        |
|               | BS-7        | 7                      | 0.8                                   | 0.9                                    | 24                    | ·                                  | No        |
| 4/26/83       | BS-3        | 121                    | . 8.9                                 | 1.4                                    | 36                    | 50                                 | No        |
|               | BS-4        | 43                     | 4.1                                   | 1.1                                    | 28                    |                                    | Ňo        |
|               | BS-5        | 14                     | 3.3                                   | 0.4                                    | 12                    |                                    | No .      |
| 9/20/83       | BS-1        | 61                     | 2.8                                   | 2.2                                    | 57                    | 50                                 | Yes       |
|               | BS-5        | 49                     | 2.7                                   | 1.8                                    | 47                    |                                    | No        |

Table K-30. Calculation of Episodic Release Rates Using Weekly Air Monitoring

<sup>a</sup>Represents ten times the average daily release rate estimated for the year of operation.

The total estimated uranium emissions to the atmosphere from non-routine events between 1952 and 1988 was 2,784 kg (Vaaler and Nuhfer 1989), which is 2% of the approximately 135,000 kg U previously reported by Boback et al. (1987) for 1951–1984. The authors assigned upper limits to each category of non-routine release and state that "the total uncertainty of all the categories results in an additional 60% as an upper limit to the non-routine emission estimate." For the period 1952 through 1988, Vaaler and Nuhfer (1989) estimated releases of 931 kg from uranium fires, 1063 kg from solid spills (outdoor), 518 kg from UF<sub>6</sub> leaks, and 272 kg from liquid uranyl nitrate hexahydrate (UNH) releases, for a total release of 2784 kg over the 37-year period.

A technical review of the Vaaler and Nuhfer (1989) report by the IT Corporation (IT 1989) indicated that many of the calculational methods and assumptions were not adequately documented, and therefore may be inappropriate. In an attempt to derive a range of release rates that encompass the true values and that are defendable, RAC

Page K-70

19 19

.

A THE AND A THE PARTY OF

evaluated and, if warranted, selected more appropriate models and parameter values. In addition, uncertainty analyses were performed using Monte Carlo simuluations with Crystal Ball<sup>®</sup> software (Decisioneering 1992). The results are discussed in the following sections.

#### Airborne Emissions from Uranium Fires

Two types of fires, chip fires and a sludge fire, were considered. The chip fire estimate in Vaaler and Nuhfer (1989) involved the use of the following variables: the concentration of uranium in air above the drum containing the burning chips; the affected volume of air; wind speed; and duration of the fire. The calculational methodology is simplistic and very conservative, as it assumed a constant maximum concentration above the fire. IT (1989) observed that only one drum was assumed for each fire, while many of the fires involved multiple drums. In addition, no documentation could be found to support the number of fires used. A random check of five years of fire reports by IT (1989) showed an average underestimate of 15% by Vaaler and Nuhfer. The underestimate could be explained primarily by the fact that events other than uranium fires were included in the fire report tallies. However, the derivation of the number of fires was not documented, and there is thus some uncertainty associated with the values used. Finally, IT (1989) noted that the uranium concentration in air above the burning drum was based on one measurement of >100,000 dpm m<sup>-3</sup>. The concentration used in the calculation (100,000 dpm m<sup>-3</sup>) may or may not bound the true value. In addition, RAC observed that the mean wind speed (9.1 mph) used was for Cincinnati, not FMPC, and that the duration of the fire (30 minutes) was not necessarily representative of the fires described in the documents reviewed. 

The model used to calculate the chip fire emissions was considered to be inappropriate. Fortunately, the results of the U.S. Atomic Energy Commission (AEC) Health and Safety Laboratory (HASL) laboratory and field tests, which involved burning uranium chips, were available (Weinstein and Breslin 1959). Although the results were never published, they are very appropriate to this problem. In the laboratory, chips ranging in quantity from 20 g to 1 kg were burned on a wire screen bed in a combustion chamber. The field experiments conducted included the measurement of emissions from burning natural uranium chips contained in a 30-gallon drum. The 30-gallon drum was housed in a 55-gallon drum covered by a 12-ft stack. Both drums were provided with multiple air holes drilled near the bottom to provide a natural draft. Finally, 900 lbs (408 kg) of depleted uranium were burned in a line array of open drums. The results of the laboratory and field experiments were plotted in Weinstein and Breslin (1959). The original data were not reported in the text; however, they were shown in the plot. Because the curve fitting method was not documented, a linear regression of the experimental results was performed by RAC. A correlation coefficient of 0.88 was calculated, indicating a fairly good fit of the line with the data. The original data and the resulting plot are shown in Figure K-26.

The annual release of uranium from chip fires was calculated by taking the product of the mass of uranium in drums, the fraction of uranium released in the fire, the number of drums involved, and the number of fires per year. The simulation was performed using Microsoft Excel and Crystal Ball.



Figure K-26. Fume loss from burning uranium metal [derived from data in Weinstein and Breslin (1959)].

1

ز چ د

2

The mass of uranium contained in 30-gallon and 55-gallon drums was assumed to be represented by a range of values (a linear distribution). The experiments conducted by Weinstein and Breslin (1959) involved igniting 100 lbs (45 kg) and 160 lbs (73 kg) of natural uranium chips in a 30-gallon drum. It was thus assumed that the minimum mass that could be involved in a fire was 100 lbs (45 kg). The maximum mass was assumed to be 132 kg, which represents the maximum volume in the 30-gallon drum scaled up to a 55-gallon drum.

The percent loss of uranium from burning uranium metal was assumed to range from 0.05 to 0.15 (a linear distribution). These fractions were derived from Figure K-26 and correspond with the minimum mass (45 kg) of uranium used in the individual drum experiments and the mass (408 kg) of uranium burned in the line array of open drums. It was felt that the latter test best represents the fires involving multiple drums. A simplifying assumption implied by the use of these factors is that fires were allowed to burn to completion, as they were in the experiments. In fact, most fires were extinguished within 30 minutes.

It was assumed that the number of drums involved range from 1 to 56 (the minimum and maximum documented in incident reports). Most of the reports show that 1 to 6 drums were typically involved. (Unusually higher numbers of drums were involved during one 5day time period in October 1962 when a large number of drums were temporarily stored on a pad near Plant 6.) Thus, a lognormal distribution, with a mean of 3.5 and a maximum value of 56 was constructed to represent the number of drums.

A triangular distribution was used to represent the number of fires occurring per year. The most probable number of fires used were those presented in Table 1 of Vaaler and

> Radiological Assessments Corporation "Setting the standard in environmental health"

15.

N. . . . . .

Nuhfer (1989). The minimum and maximum values were assigned values equal to the mean value  $\pm$  15%.

Using a Monte Carlo simulation, 500 runs were made to determine the median and the 5th to 95th percentile range. The results are shown in Table K-31. The 50th percentile results are approximately equal to those calculated by Vaaler and Nuhfer (1989). However, the upper 95th percentile estimate is about 500% of the median. This greatly exceeds the 60% upper bound estimated by Vaaler and Nuhfer (1989).

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | · ·       | Most Probable         | Uranium rel  | eased (kg    | y <sup>-1</sup> ) .                     | 1 <sub>)</sub> . |  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------------------|--------------|--------------|-----------------------------------------|------------------|--|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Year      | Number of fires       | 50%          | 5% .         | 95%                                     |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1952-1961 | 1 1217 <b>100</b> . 2 | 16           | 1.9 1        | 119                                     |                  |  |
| · · · · · · · · · · · · · · · · · · ·                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 1962      | - <b>76</b>           | 13           | 1.4          | 94                                      | •                |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | - 1963    | 161                   | 26           | 3.0          | 209                                     |                  |  |
| •                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1964      | 135                   | 23           | 2.6          | 169                                     |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1965      | 131                   | 22           | 254          | 168                                     |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1966      | 102                   | 17           | 1.9          | 128                                     |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1967      | 98                    | 16           | 1.8          | 119 · · · · · · · · · · · · · · · · · · |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1968      | 64                    | 9.5          | 1.2          | 65                                      | ·.               |  |
| the state of the s | 1969      | - 73                  | 12           | 1.3          | - <b>93</b> - E                         |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1970      | . 68                  | 11 11 1      | 1.2          | 84                                      |                  |  |
| man factor for the second                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 1971      | 20                    | 3.3          | 0.4          | . 25                                    |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1972      | 17                    | 2.8          | 0.3          | 21                                      |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1973      | 4                     | 0.6          | .07          | 5.0                                     |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1974      | 0                     | 0            | 0            | 0                                       |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1975      | <b>'6</b> 5 10 1 1 10 | 1.1          | .11          | 7.3                                     |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1976      | 1                     | <b>0.2</b> - | .02          | 1.3                                     |                  |  |
| •                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1977      | 3 - 3                 | 0.5          | .005         | 3.9                                     |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1978      | 6                     | 1.0          | <b>.11</b> . | 7.5                                     |                  |  |
| •                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1979      | 1                     | 0.2          | .02          | 1.3                                     |                  |  |
| •                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1980      | <b>4 1 1 1 1</b>      | 0.7          | .07          | 5.1                                     |                  |  |
| •                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1981      | 7                     | 1.1          | 0.1          | 8.4                                     |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1982      | 18                    | 2.9          | 0.3          | 23                                      |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1983      | 17                    | 2.8          | 0.3          | 21                                      |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1984      | 16                    | 2.7          | 0.3          | 19                                      |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1985      | 20                    | 2.7          | 0.4          | .20                                     |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1986      | 16                    | 2.6 ·        | 0.3          | 19                                      | •                |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1987      | 16                    | 2.6          | 0.3          | 19                                      |                  |  |
| _                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1988      | 3                     | 0.5          | .005         | 3.9                                     | ·                |  |
| · · · · ·                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |           |                       | 1            | Ň            |                                         |                  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | TOTAL     |                       | 450          | 92           | 2260                                    |                  |  |

Table K-31. Uranium Chip Fire Emissions

The metal sludge fire, which occurred in April 1970, was estimated by Vaaler and Nuhfer (1989) to have released 120 kg of uranium. The model used was the one used to calculate emissions from chip fires, which was based on one measurement made above a burning drum of uranium chips. However, the affected volume was assumed to be very large, encompassing an area of  $6.5 \text{ m}^2$ , and extending 7.6 m vertically above the sludge. The assumption of constant activity within this volume was thought to be very conservative.

· · · · · · · · · · ·

# Other Sources and Episodic Releases to the Atmosphere

(K-1)

(K-2)

Alternatively, we used two measurements obtained during the course of the sludge fire (Heather<u>ton</u> 1970). The measurements were made 2000 ft (610 m) downwind of the fire. The results were  $7 \,\mu g m^{-3}$  and 10  $\mu g m^{-3}$ .

The building wake model (Killough et al. 1993) was used to estimate the average dispersion coefficient at a distance of 610 m during the month of April. The average dispersion coefficient was calculated to be  $1.1 \times 10^{-5}$  s m<sup>-3</sup>. A conservative bound was selected by first examining the individual dispersion coefficients calculated for each wind direction. The lowest value, which would result in the highest source term estimate, was 2.0  $\times 10^{-7}$  s m<sup>-3</sup>. A lognormal distribution was constructed with the geometric average of  $1.1 \times 10^{-5}$  s m<sup>-3</sup> and a lower limit of  $2.0 \times 10^{-7}$  s m<sup>-3</sup>. The measured downwind concentration was assumed to be represented by a normal distribution of values, with a mean of 8.4 µg m<sup>-3</sup> and a standard deviation of 2.1 µg m<sup>-3</sup>. The fire was reported to have lasted for six hours. Using Crystal Ball, the median source term value was estimated to be 30 kg, with a lower 5% confidence limit of 4.8 kg and an upper 95% confidence limit of 223 kg. This range encompasses the 120 kg reported in Vaaler and Nuhfer (1989).

#### Solid Spills

In regard to the solid spill calculations, IT (1989) state that "there is lack of clear support documentation for the assumptions used (the average wind speed used, the assumed silt content of the spilled material, the average mass of material spilled per incident, the moisture of the spilled material)." This is compounded by the fact that Vaaler and Nuhfer (1989) tried to categorize all spilled materials as either those with high uranium content and those with low uranium content. The physical characteristics of the different materials involved most likely vary greatly.

A more serious error was also discovered when examining the model used. The algorithm presented in Vaaler and Nuhfer (1989) is:

$$EF = 0.0018 (s/5)(u/5) + [(m/2)^2(L/6)]$$

where:

S

EF = emission factor (lb material airborne/ton spilled)

= material silt content (%)

u = mean wind speed (mph)

m \_ = moisture content (%)

 $L = loader capacity (yd^3)$ 

Upon further examination, it was discovered that this algorithm was derived from the EPA document entitled "Compilation of Air Pollution Emission Factors," AP-42 (EPA 1985). This algorithm originally appeared in the section entitled "Aggregate Handling and Storage Piles" in 1983 and was revised in 1988. The original equation, as it appeared in 1983, was:

 $EF = k(0.0018)(s/5)(u/5)(H/5) + [(m/2)^{2}(Y/6)^{0.33}]$ 

where: k

= particle size multiplier

| 74 | The Fernald Dosimetry Reconstruction Project  |
|----|-----------------------------------------------|
| ·  | Tasks 2 and 3, Source Terms and Uncertainties |

<u>.</u>

No.

ł

(K–3)

H Y

Page K-

# = material drop height (ft)

5-3-

= dumping device capacity (yd<sup>3</sup>)

The equation was intended to describe a batch drop operation, where aggregate material is added to or removed from an aggregate storage pile using a truck or front-end loader. The algorithm used in Vaaler and Nuhfer (1989) ignores the particle size multiplier and material drop height, which makes their results more conservative. The exponent associated with the "Y/6" parameter was also ignored. This makes the model extremely conservative. It is also questionable as to whether or not the algorithm, even if properly transcribed, is appropriate to small spills and subsequent cleanup. The user is cautioned in AP-42 that the quality of the model is reduced if the source conditions used in developing the equation are not met. Those conditions include a material silt content of from 1.3-7.3%, moisture content of from 0.25-0.7%, and dumping capacity of from 2.1-7.6%. The silt content of the FMPC material greatly exceeds the range of recommended values and the loading capacities used are far less than the recommended values. The 1988 version of "Aggregate Handling and Storage Piles" no longer includes this equation, but rather has replaced it with a modified version of the continuous drop operation equation found in the 1983 version:

 $EF = k(0.0032)(u/5)^{1.3} + (m/2)^{1.4}$ 

This equation is recommended for both drop batch and continuous drop operations. EPA also assigns a higher quality rating to this equation than it did to the original equations. The quality rating is retained if the following source conditions are met: 1) silt content ranges from 0.44 to 19%; 2) moisture content ranges from 0.25-4.8%; and 3) wind speed ranges from 1.3-15 mph. Again, the FMPC material exceeds the silt content conditions.

Model bias between equations K-2 and K-3 was tested using Microsoft Excel and Crystal Ball. Table K-32 presents the values used in the simulations. For the sake of simplicity, and lacking specific particle size distribution data, the particle size multiplier (k) was not used. This makes the results more conservative by, at most, a factor of two. Similarly, the drop height in equation K-2 was not used, making the results more conservative by, at most, an additional factor of two.

The mean (geometric) emission factor calculated using equation K-2 is 4.6 g kg<sup>-1</sup>, with a 5th-95th percentile range of from 0.3 to 29 g kg<sup>-1</sup>. In contrast, the mean (geometric) emission factor calculated using equation K-3 is 0.3 g kg<sup>-1</sup>, with a 5th-95th percentile range of from 0.03 to 1.5 g kg<sup>-1</sup>. The bias introduced by the model selected is thus considerable. Although equation K-3 is the most recent model recommended by the EPA, it appears that the original batch drop model is more appropriate to the spill scenario since it includes a factor to account for the size of the spill and cleanup operation. Neither model was intended for small spill scenarios; however, the results of the calculations using the batch drop equation seem reasonable — it estimates that as much as 3% of the material spilled could become airborne.

Using the parameter values shown in Table K-32, and the number of spills found in Vaaler and Nuhfer (1989), it was estimated that a median annual release of 2 kg of uranium occurred during the years from 1953 through 1969. The 5th to 95th percentile range is from 0.3 to 35 kg  $y^{-1}$ . This interval does not encompass the calculated emission of 57 kg  $y^{-1}$ 

# Appendix K Other Sources and Episodic Releases to the Atmosphere

reported in Vaaler and Nuhfer (1989). The emissions from spills in later years were estimated to be insignificant (a median value of 0.25 kg y<sup>-1</sup>).

| Table K-3                 | 2. Parameter Val | ues Used in                           | Estimating | Spill Emissions             |
|---------------------------|------------------|---------------------------------------|------------|-----------------------------|
| •                         | ••               | •                                     | Std.       |                             |
| Parameter                 | Distribution     | Mean/Min                              | Dev./Max   | Comments                    |
| u (m/s)                   | Lognormal        | 2.14                                  | 1.43       | FMPC met data               |
| m (%)                     | Uniform          | 0.1                                   | 1.0        | Assume material is very     |
|                           | (range)          |                                       |            | dry.                        |
| s (%)                     | Uniform          | · 50                                  | 99         | Material varies, but        |
|                           | (range)          |                                       |            | Vaaler and Nuhfer           |
|                           |                  |                                       |            | indicate that as little as  |
| • :                       | •                |                                       |            | 35–70% and as much as       |
|                           | • • •            |                                       |            | 99% of the material is      |
|                           | · .              | : :                                   |            | siit.                       |
| Loader                    | Lognormal        | 0.2                                   | 0.38       | Most likely spill is 55-gal |
| capacity_                 |                  |                                       |            | drum. Largest spill was     |
| spill (m <sup>3</sup> )   |                  | •                                     |            | equivalent to 18.4          |
|                           |                  |                                       |            | drums.                      |
| Loader                    | Uniform          | 0.005 ,                               | 0.01       | Smallest cleanup device     |
| capacity_                 | (range)          | • • • •                               |            | is a shovel. Largest is     |
| cleanup (m <sup>3</sup> ) |                  |                                       |            | that used in Vaaler and     |
| <u></u>                   |                  | · · · · · · · · · · · · · · · · · · · |            | Nuhfer (1989).              |

## UF<sub>6</sub> Releases

IT (1989) found little documentation to support the  $UF_6$  emission estimates made in Vaaler and Nuhfer (1989). Most notably, information on the number of releases and the magnitude of the releases is lacking. We could not find documentation to add any new insights to these estimates. For this reason, the methods used by Vaaler and Nuhfer (1989) were considered to be adequate, although probably conservative.

Vaaler and Nuhfer (1989) note that samplers located throughout the  $UF_6$  process area indicate low levels of airborne radioactive material. Based on these data, the emission to atmosphere from UF<sub>6</sub> leaks or releases to the building from 1980–1988 is considered to be very small. The only event found in documentation for which a reasonable quantitative amount (6 kg) was determined was the 1986 vessel crack (WMCO 1988a).

More frequent releases were indicated during the 1950s and 1960s, when a cold trap system did not exist to remove residual UF<sub>6</sub> from the process piping. When connections were broken for maintenance or cylinder changes (pigtail connection), a portable Hoffman vacuum was used to reduce the quantity of UF<sub>6</sub> released.

Vaaler and Nuhfer (1989) estimated the release of UF<sub>6</sub> from pigtail and maintenance operations prior to 1980 to be approximately 0.4 kg y<sup>-1</sup>. This was estimated assuming an average annual production rate for this period. The number of pigtail connections and subsequent releases to the building are proportional to the production rate. The number of

> Radiological Assessments Corporation "Setting the standard in environmental health"

24

· ·

,it

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

 $\geq 1$ 

2

÷.,

XEAN ST

Ę

maintenance operations were assumed to be 52 times per year. The amount of release that occurred during pigtail and maintenance operations was related to the pigtail and pipe volumes. All of the  $UF_6$  was assumed to react with moisture in air to form solid  $UO_2F_2$  and HF). The Hoffman vacuum was then assumed to withdraw 70% of the release (of which 99% was assumed to retained.) Ten percent of the amount entering the building was assumed to enter the atmosphere via exhaust systems.

We estimated the  $UF_6$  leaks due to pigtail and maintenance operations using the equations described in Vaaler and Nuhfer (1989), which model the  $UF_6$  leaks as a function of  $UF_4$  production. However, to provide some estimate of uncertainty, parameters were arbitrarily varied according to Table K-33. In addition,  $UF_4$  production data for the years 1953 through 1967 (see Appendix C) were used in place of the average annual values used by Vaaler and Nuhfer (1989). [Note that the former authors indicate no  $UF_6$  releases during the years 1958 through 1961. However, based on production data (Appendix C), we estimated  $UF_6$  releases for all years from 1953 through 1967, with the exception of 1957.]

Table K-33. Parameter Values Used in Estimating UF<sub>6</sub> Releases from Pigtail and Maintenance Operations

|                                                                                                  |                                      | HUM I Igrail | and mainter   | lance oper |                                                                                                  |
|--------------------------------------------------------------------------------------------------|--------------------------------------|--------------|---------------|------------|--------------------------------------------------------------------------------------------------|
|                                                                                                  | Parameter                            | Distribution | Minimum       | Maximum    | Comments                                                                                         |
|                                                                                                  | Maintenance/<br>.y                   | , Uniform    | . 48          | 52         | Plant not always<br>operating                                                                    |
| с<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1<br>1 | .% of release<br>entering<br>Hoffman | Uniform      | <b>50</b>     | 70         | Efficiency unknown.<br>Assume value reported in<br>Vahler and Nuhfer (1989)<br>is maximum value. |
|                                                                                                  | % leaving<br>building                | Uniform      | 10            | 20         | Unknown. Assume value<br>reported in Vahler and<br>Nuhfer (1989) is minimum<br>value.            |
|                                                                                                  | % not retained<br>by Hoffman         | Uniform      | 0.01 -        | 0.10       | Unknown. Assume value<br>reported in Vahler and<br>Nuhfer (1989) is minimum<br>value.            |
| 5. 1997<br>1997 - 1997<br>1997 - 1997                                                            | Pipe volume .<br>(cc)                | Uniform      | - 44 an o<br> | 136        | Vary value estimated in<br>Vahler and Nuhfer (1989)<br>by ±10%.                                  |
|                                                                                                  | Pigtail volume _ (cc)                | Uniform      | 408           | <b>498</b> | Vary value estimated in<br>Vahler and Nuhfer (1989)<br>by ±10%.                                  |

Releases from pigtail and maintenance operations were estimated to be minor, amounting to a less than 1 kg of uranium per year during the years prior to 1968. The highest value was estimated for 1964, the highest year for production. A 50th percentile value of 0.8 kg  $y^{-1}$  (with a 5th to 95th percentile range of possible values of from 0.6 to 1.2 kg  $y^{-1}$ ) was estimated for that year. This is a factor of two higher than the Vaaler and Nuhfer (1989) estimate of 0.4 kg  $y^{-1}$ .

.

34

#### Other Sources and Episodic Releases to the Atmosphere

UF<sub>6</sub> leaks from vessel cracks were also varied to provide bounding ranges for the years 1953 through 1956, and 1958 through 1967. The methods of Vaaler and Nuhfer (1989) were used. It was assumed that the emissions from vessel cracks ranged from 4 to 6 kg, with a maximum value corresponding to that measured during the 1986 vessel crack (WMCO 1988a). It was further assumed that from 2 to 6 cracks occur per year [Vaaler and Nuhfer (1989) assumed an average of 4 cracks per year before 1980]. The results show a median value of 20 kg of U released per year [approximately the value calculated by Vaaler and Nuhfer (1989)], with a 5th to 95th percentile range of from 11 to 31 kg y<sup>-1</sup> for the years prior to 1968.

No vessel cracks were modelled after 1980, with the exception of the 1986 event. The 6 kg release reported for the 1986 vessel crack was assumed to be a good estimate. To calculate the total  $UF_6$  released during that year from all non-routine events, however, we assumed a triangular distribution with 6 kg as the likliest value, 5.1 kg as the minimum value, and 6.9 as the maximum value (i.e. 6 kg ± 15%).

Miscellaneous UF<sub>6</sub> releases were calculated by Vaaler and Nuhfer (1989) by assuming that an average of 22.5 kg of UF<sub>6</sub> (15.4 kg U) was released per month inside the building, and that 10% of the material exits the building as  $UO_2F_2$ . Lacking any other data, it was assumed that from 10 to 30 kg of UF<sub>6</sub> was released per month inside the building. Furthermore, it was assumed that anywhere from 5 to 15% of the material exits the building. The results ranged from 11 to 31 kg U y<sup>-1</sup> (5% to 95%), with a 50% value of 20 kg U y<sup>-1</sup>. Miscellaneous releases after 1980 were determined by Vaaler and Nuhfer (1989), based on data from samplers in the UF<sub>6</sub> process area and on incident reports, to be very small. They arbitrarily assigned an annual emission rate of 2 kg per year after 1980. We assumed a uniform distribution of 1 to 2 kg per year.

Vaaler and Nuhfer (1989) also estimated uranyl nitrate (UNH) releases. Although considered to be rare [only two documented cases were found by Vaaler and Nuhfer (1989)], the authors assumed that six incidents occurred over the operating history. One of the documented cases occurred in 1959 and involved a release of 454 kg. The second occurred in 1988 and released 18 kg of UNH. Nevertheless, Vaaler and Nuhfer (1989) assumed that each event released 454 kg of UNH. A careful examination of data from the 1988 incident cleanup led them to assume that only 10% of the UNH becomes airborne. Thus, a total of 272 kg of UNH was estimated to be released to the air during the entire operating period. Rather than assuming the entire release, we used the original data reported in Vaaler and Nuhfer (1989) for the two documented incidents (note we could not locate these reports). We then varied the airborne fraction from 0.1 to 0.25.

# Summary of Non-routine Releases

Non-routine releases are summarized in Table K-34. A total release of 1300 kg for the entire operating period was estimated. Leaks of  $UF_6$  account for the majority of the total quantity of estimated non-routine releases. However, this comparatively large value is a function of the lack of information concerning the miscellaneous leaks and subsequent releases from buildings and should be considered to be very conservative.

# Page K-78

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

. .

NAMES -

ないなど

· · · · · · ·

į.

|                                                                                                      |               |                | Solid Spills          | UF <sub>6</sub>    | Concentrated Liq | aid    |
|------------------------------------------------------------------------------------------------------|---------------|----------------|-----------------------|--------------------|------------------|--------|
|                                                                                                      | Year          | <u>U Fires</u> | (Outdoors)            | Leaks <sup>c</sup> | UNH Releases     |        |
|                                                                                                      | 1952          | 16             | Litte Real            | - an <b>144</b> ,  | •                |        |
|                                                                                                      | 1953          | 16             | 2.1                   | 44                 | •                |        |
|                                                                                                      | 1954          | 16             | 2.1                   | 44                 | •                |        |
|                                                                                                      | 1955          | 16             | 2.1                   | 44                 |                  |        |
| 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1                                                                | 1956          | 16             | • <b>3.2.1 1</b> 40 s | ± ∞ 44             | •                | ,<br>, |
| · · · · ·                                                                                            | 1957          | • 16           | 2.1                   | <b> 0</b>          | •                | , , ,  |
|                                                                                                      | 1958          | , 16           | <b>2.1</b>            |                    | • •              | . ,    |
| $\tilde{Z}^{\pm} = \tilde{U}$                                                                        | 1959          | 16             | 2.1                   | . 45               |                  |        |
| •                                                                                                    | 1960          | 16             | 2.1                   | 45                 |                  |        |
|                                                                                                      | 1901          | 10             | 2.1                   | 45                 |                  |        |
|                                                                                                      | 1962          | 13             | 2.1                   | 45                 |                  |        |
|                                                                                                      | 1963          | 20             | 2.1                   | 45                 |                  |        |
|                                                                                                      | 1904          | 23             | 2.1                   | 45                 |                  | 4      |
| ·                                                                                                    | 1900          | 22             | 2.1                   | 45                 |                  | •      |
|                                                                                                      | 1067          | 10             | Z.1 ****              | 45                 | · · ·            |        |
| 1.1 2 2 4                                                                                            | 1008          | 10 -           | 2.1                   | 44                 | • • •            |        |
|                                                                                                      | 1969          | 11             | 2.1                   | · · · ·            |                  |        |
|                                                                                                      | 1020p<br>Taoa | 12             | Z.1                   | •                  |                  |        |
| A DOWN ALTON                                                                                         | 1970-         | 40             | 0.0                   | · ~ .:             |                  | · · ·. |
| the state of the state                                                                               | 1079          | ວ.ວຸ<br>ດຸ ຂ   | 0.0                   |                    |                  |        |
| •                                                                                                    | 1372          | 4.0<br>0 F     | 0.0                   |                    |                  | -      |
| · · · ·                                                                                              | 1970<br>-1077 | 0.0            | 0.0                   | · •                |                  | ···    |
|                                                                                                      | 1075          | 10             | 0.0                   |                    |                  |        |
|                                                                                                      | 1976          | . U ð          | 0.0                   |                    |                  |        |
|                                                                                                      | 1977          | 0.2            | 0.0                   |                    |                  |        |
| م بر العرب | 1978          | 10             | 0.0                   | 1                  |                  |        |
| · · · · · · · · · · · · · · · · · · ·                                                                | 1979          | . 0.2          | 0.6                   |                    | t                | •.     |
|                                                                                                      | 1980          | 0.2            | 0.0                   |                    |                  |        |
|                                                                                                      | 1981          | 11<br>1        | . 0.0                 | ,                  | •                | A. A.  |
| . •                                                                                                  | 1982          | 29             | 0.0                   |                    | · · · ·          | • *.   |
| •                                                                                                    | 1983          | 2.8            | 0.0                   |                    | · · ·            |        |
| the following the                                                                                    | 1984          | 27             | <u></u>               | ્યત્વર્થ           | · · · · ·        |        |
| • •                                                                                                  | 1985          | 33             | <0.0                  | 1.5                |                  | •      |
| ·                                                                                                    | 1986          | 27             | ~0.1                  | 75                 |                  | ,      |
| · · · · · · · · · · · · · · · · · · ·                                                                | 1987          | 2.6            | <0.1                  | 1.5                | · .              |        |
|                                                                                                      | 1988          | 0.5            | <0.1                  | 1.5                | 3.2              |        |
| •                                                                                                    | TOTAT         | 446            | 31                    | 676                | g <sub>A</sub> d |        |
| 41 . S.S.S.                                                                                          | 5%            | 92             | 5                     | <sup>413</sup>     | 50               |        |
|                                                                                                      | 95%           | 2260           | 635                   | 995                | 115              | 4      |

and Nuhfer (1989). Data for years 1985 through 1988 are based on building air

sampler data and cold trap incident reported in Vaaler and Nuhfer (1989). <sup>d</sup> Data from Vaaler and Nuhfer (1989). Original reports could not be found to verify.

HE LEAST AND A CONTRACT OF A CONTRACT

E.

s all more start of start

# EMISSIONS FROM WASTE PITS

....

.

A series of waste disposal pits has been used for storage of low-level radioactive wastes during the course of the operations at the FMPC. These pits were located near the western boundary of the site, close to Paddy's Run Creek (Figure K-1). The waste pits consist of waste pit numbers 1 through 6, the burn pit and the clearwell. The waste pits are numbered chronologically in order of construction. The pits also are typically referred to as "wet" if they received waste via pipes in slurry form or "dry" if they received solid waste from trucks. General characteristics of the waste disposal pits are summarized in Table K-35.

| Pit Number<br>and Type     | Lining                    | Volume<br>(yd <sup>3</sup> ) | Maximum<br>Depth (ft) | Period of<br>Use                                   | Status                                               |
|----------------------------|---------------------------|------------------------------|-----------------------|----------------------------------------------------|------------------------------------------------------|
| Pit 1<br>Dry               | Clay from burn<br>pit     | 40,000                       | 17                    | 1952–1959                                          | Retired, covered with topsoil                        |
| Pit 2<br>Dry               | Compacted<br>- clay       | 13,000                       | 13                    | 1957–1964                                          | Retired, covered<br>with topsoil                     |
| Pit 3<br>Wet               | Compacted<br>clay         | 227,000                      | 27                    | 1959–1968<br>(wet mode)<br>1975–1977<br>(dry mode) | Retired, covered<br>with topsoil                     |
| Pit 4<br>Dry               | Compacted .<br>clay       | 53,000                       | 24                    | 1960–1986                                          | Retired, covered<br>with clay and<br>synthetic cover |
| Pit 5<br>Wet               | Rubberized<br>elastomeric | 102,500                      | 30                    | 1968–1983                                          | Retired                                              |
| Pit 6<br>Dry               | Elastomeric<br>membrane   | 9,000                        | 24                    | 1979–1985                                          | Inactive, 75% full                                   |
| Burn Pit<br>Dry            | Natural clay              | unknown                      | unknown               | 1957–1986                                          | Retired, covered<br>with topsoil                     |
| Clearwe <u>tl</u> -<br>Wet | - Clay                    | unknown                      | unknown               | 1959–1987                                          | Inactive                                             |

# Table K-35. Characteristics of FMPC Waste Pits<sup>a</sup>

<sup>a</sup>Updated from Solow and Phoenix (1987). See Table K-36 for estimated amounts of uranium in waste pits.

Types of waste sent to the dry pits include waste filter cakes, graphite, brick scrap, sump liquor and cakes, depleted slag, process residues, trailer cakes, nonburnable trash, asbestos, barium chloride, slag leach slurry, and lime sludge. Wet pits received lime neutralized raffinate concentrate, slag leach residues, filter cakes, fly ash, depleted slag, scrap green salt,

たいに

Ś.

1000

1.000

15100

process residues, and filter cakes (Solow and Phoenix 1987). The burn pit is discussed further in the following section on incineration of FMPC wastes. The clearwell received surface runoff from the waste pit area and was used until March 1987 as a final settling basin prior to discharge of liquids to the Great Miami river through manhole 175 (see Appendix L).

Methodology Used to Estimate Releases from Waste Pits in Clark et al. (1989).

Historical emissions of uranium and thorium from fugitive dust from the FMPC waste pits were estimated (Clark et al. 1989) in accordance with methods recommended by the U.S. Environmental Protection Agency (EPA) for hazardous waste sites (EPA 1987) and the Ohio EPA (OEPA 1980). These methods provide equations for estimating fugitive dust releases from waste pits during:

load-in of material into the area

• wind erosion of the waste material

load-out of material from the waste pit

In the calculation of fugitive dust emissions from the FMPC waste pits, only the first two categories were judged to contribute significantly to the overall generation of dust emissions, because vehicular movement was minimal in the pits themselves, and no load-out of waste from the pits has occurred (Hill and Dolan 1988).

1.2.2

1 - 1 -

The load-in contribution to fugitive emissions was calculated only for pits receiving waste in a dry form (Pits 1, 2, 4 and 6), not for those that received waste in a wet form (Pits 3 and 5). Parameters used in the load-in calculation (OEPA 1980) include:

silt content of the stored waste material 😳

moisture content of the stored material

mean wind speed

effective loader capacity

Data were not available for the amount of material placed in each pit for each year. Therefore, a total emission estimate for the load-in operation for the four dry pits was done over their entire operating history. Parameter values and an example calculation are given in Kispert (1988).

--Estimates of the emission rate due to wind erosion depend upon the size of the contaminated area and local meteorological conditions (EPA 1987). The calculation considers the area of the waste pit that is exposed to winds that exceed 12 mph, and the number of days per year when rainfall is <0.01 inch. The percentage of time that the ground wind speed exceeded 12 mph (9.7%) was determined from FMPC meteorological records for 1987. The number of dry days per year for the Cincinnati area was estimated to be 236, from OEPA (1980). The silt content for all pits except Pit 4 was assumed to be 10% (Kispert 1988). Because of the many massive forms (e.g., drums, concrete, and graphite crucibles) deposited in Pit 4, the silt content was assumed to be much lower (1.5%) (Kispert 1988).

Operational records and historical photographs were used to determine the pit surface area that was exposed and subject to wind erosion each year. In years when the pit surface

•

÷.

# Other Sources and Episodic Releases to the Atmosphere

Page K-81

was covered completely with liquid, the surface area subject to wind erosion was assumed to be zero. When uncertainties arose regarding the amount of waste area exposed to erosion, the larger rather than the smaller area was chosen. The intent of the authors was to ensure that an *underestimate* of fugitive dust emissions would not occur (Hill and Dolan 1988). Parameter values and an example calculation are given in Kispert (1988). Over a 35-year period, the calculated wind erosion component to fugitive dust emissions contributed over 99% of the total estimate (i.e., the dust generated during load-in operations was <1% of the total).

An important simplifying assumption for both the load-in and wind erosion calculations was that the mass concentration of the uranium in the waste material in each pit was uniform and was calculated by the ratio of the total mass of uranium to the total mass of the material placed in each waste pit. Therefore, the concentration of waste material placed in each pit was assumed to be homogeneous and constant over time. The total quantities of uranium and material placed in each pit were obtained from records of the FMPC Nuclear Materials Control and Accountability Group (Kispert 1988). Although only Pit 1 values are given in Kispert (1988), the data from Poff et al. (1985), shown in Table K-36, illustrate the large variation in the calculated average concentration of uranium in the FMPC waste pits.

| Table K-36. | Variation in Estimate of Uranium and Thorium Concentrations i | n |
|-------------|---------------------------------------------------------------|---|
|             | FMPC Waste Pits <sup>a</sup>                                  | • |

|     | Waste                     |                 |                    |                 | Calculated.                    | Average Conc.                   |
|-----|---------------------------|-----------------|--------------------|-----------------|--------------------------------|---------------------------------|
| Pit | Quantity<br>(metric tons) | Uranium<br>(kg) | % <sup>235</sup> U | Thorium<br>(kg) | (g U g <sup>-1</sup><br>waste) | (g Th g <sup>-1</sup><br>waste) |
| 1   | 40,500                    | 52,000          | 0.71               | 400             | 1.3 x 10 <sup>-3</sup>         | ~ 7.7 x 10 <sup>-6 b</sup>      |
| 2   | 13,000                    | 1,206,000       | 0.21               | Unknown         | 9.3 x 10 <sup>-2</sup>         | _b                              |
| 3   | 255,000                   | 129,000         | 0.78               | 488             | 5.1 x 10-4                     | 1.9 x 10 <sup>-6</sup>          |
| 4   | 64,967                    | 3,048,087       | 0.18               | 61,800          | $4.7 \times 10^{-2}$           | 9.5 x 10-4                      |
| 5   | 88,213                    | 50,309          | 0.83               | 17.000          | 5.7 x 10-4                     | 1.9 x 10 <sup>-4</sup>          |
| 6   | 9,309                     | 843.142         | 0.21               | Unknown         | $9.1 \times 10^{-2}$           | -                               |

<sup>a</sup>From Poff et al. 1985, with the exception noted in b. Represents waste stored through 12/31/84.

<sup>b</sup>Data from Rathgens (1974).

Estimated total uranium emissions were 29 kg, 892 kg, 41 kg, 395 kg, 15 kg, and 187 kg, for Pits 1, 2, 3, 4, 5, and 6, respectively. These fugitive emissions (1559 kg over the 36-year period) are approximately 0.03% of the total 5,000 MT discarded to the waste pits during 1953 through 1988.

Thorium emissions from wind erosion were calculated using the same method as described for uranium. A minor amount of thorium (85 kg) was estimated to be released as fugitive emissions from the waste pits during 1953 through 1988.

The uncertainty in the total quantities shown in Table K-36 and the simplifying assumptions about waste homogeneity are important limitations of the analysis of fugitive

1992.1

.

2

10.04

Ë

A.N.WILSO

ŝ

dust emissions. In addition, the EPA's own analysis of their calculation technique (EPA 1987) indicated that fugitive emission estimates are good only to an order of magnitude. The results presented in Clark et al. (1989) represented their best approximation, given the data available.

Evaluation of Method Used to Estimate Releases from Waste Pits in Clark et al. (1989)

The methods presented by the EPA for estimating fugitive dust releases from hazardous waste sites (EPA 1987) fall into three categories, according to the geometry of the source: line models (e.g. contaminated roads), area models (e.g. dried lagoons, landfills), and pile models (e.g. mine tailings or aggregate piles). For the FMPC analysis, Kispert (1988) chose a pile model, an empirical equation derived from the iron and steel industry. For the same waste and climatic characteristics, pile models predict higher fugitive dust releases than area models. Based on the geometry of the Fernald pits, we believe an area model would have been more appropriate to estimate wind erosion of material.

The load-in equation is the same one used in Vaaler and Nuhfer (1989) to estimate emissions from solid spills (Equation K-1). As discussed previously, that equation was incorrectly derived from the EPA document, AP-42, and produces overly conservative results. Based on the correct equation, K-2, fugitive dust generated by the load-in of material would be insignificant, compared to that caused by wind erosion, and can therefore be dismissed from further consideration.

The parameter values used in the coal pile model were based on little data and may have been used inappropriately. Kispert (1988) used 9.7% as the percentage of time the wind blows >12 mph, based on a partial year (1987) of data from the FMPC meteorological station. The height of the wind speed measurements was not given. Based on five years of wind speed measurements collected at a height of 10 m at the FMPC, we determined the percentage of time the wind blows >12 mph to be 4.5%. The EPA source document is not clear on the height which is to be used in the equation. The empirical equation was derived based on the wind speed at a height of 1 foot (0.3 m) above the ground; however, their example calculations use the wind speed at the mean height of the pile, which was about 12 m. The Fernald waste pits were excavated below grade to maximum depths which ranged from 13 to 30 feet (4 to 9 m) (Table K-35). Because wind speed increases with height above the ground, the fraction of the time the wind speed exceeded 12 mph should have been considerably less than 4.5% in the pits themselves.

The EPA model requires as an input parameter the %silt (actually silt plus clay) of the waste, which is the percentage, by weight, of material which passes through a 200 mesh sieve (<75  $\mu$ m). Kispert (1988) assumed a silt content of 10% for the dry waste material. Measurements obtained from borings into the waste pits (Solow and Phoenix 1987) indicate that the actual silt content of waste (massive forms were avoided) is considerably higher, ranging from 43% in Pit 1 to 75% in Pit 4. A'boring from Pit 2, which contributed most of the fugitive dust during the period analyzed, was 61% silt.

The estimate of U concentration in the waste is subject to considerable uncertainty. Concentrations in five borings from Pit 2 (Solow and Phoenix 1987) ranged from 53 to 17,900 pCi  $^{238}$ U g<sup>-1</sup>, with a geometric mean of 1100 pCi g<sup>-1</sup>. The mean concentration used in the erosion calculation (Table K-36) was 0.093 g U g<sup>-1</sup> waste, or 31,000 pCi  $^{238}$ U g<sup>-1</sup>.

ŝ

, ,

1

## Other Sources and Episodic Releases to the Atmosphere

The choice of a pile model instead of an area source model provides additional bias. This model bias was examined further by conducting benchmark calculations using the coal pile model, the wind erosion equation used by agricultural scientists (Woodruff and Siddoway 1972), and the uranium mill tailings model used in MILDOS (NRC 1981). The latter two models were selected as most appropriate for modeling the pit releases, according to the criteria presented in Smith et al. (1982). Benchmark model comparisons were performed for Pit 1, because an example coal pile model calculation was provided by Kispert (1988) for this pit. The emission rates for particles less than 20 microns from Pit 1 in 1957 were estimated to be 3.2, 1.3, and 0.3 tons/acre-year using comparable data and the coal pile, agriculture erosion, and MILDOS models, respectively. (Note: The coal pile calculations were performed for particles < 20  $\mu$ m, a silt content of 61%, and frequency of winds > 12 mph = 4.5%.) As expected, the coal pile model was the most conservative; however, the results are all within a factor of 10. Because the wind erosion equation requires the use of nomograms and qualitative data, and is thus not easily adapted to uncertainty analyses, the MILDOS model was selected for use in providing more realistic and site-specific estimates of pit releases.

The MILDOS algorithms for estimating dust emissions are:

$$u_{t}^{*} = C_{t} ([(\rho_{s} - \rho)/\rho] \text{ gd})^{\frac{1}{2}} (1.8 + 0.6 \log_{10} \omega)$$

| where:         |                                                           |
|----------------|-----------------------------------------------------------|
| u*t            | = threshold shear velocity (cm s <sup>-1</sup> )          |
| C <sub>t</sub> | = dimensionless coefficient = 0.1                         |
| ρ <sub>s</sub> | = particle density, $g \text{ cm}^{-3}$                   |
| ρ              | = density of air, $1.2 \times 10^{-3}$ g cm <sup>-3</sup> |
| g              | = gravitational acceleration, cm $s^{-2}$                 |
| d              | = average diameter of saltating particle, cm              |
| ω              | = water content expressed in weight percent               |

$$q_h = C_h u^{*2} (u^* - u^*_t)$$

| where:           |                                                                                                              |
|------------------|--------------------------------------------------------------------------------------------------------------|
| q <sub>h</sub>   | = horizontal flux of particulate matter (<20 $\mu$ m), g cm <sup>-2</sup> s <sup>-1</sup>                    |
| u*               | = shear (or friction) velocity, cm s <sup>-1</sup>                                                           |
| C <sub>h</sub> _ | = empirical constant relating shear velocity to horizontal flux, $10^{-6}$ g s <sup>2</sup> cm <sup>-4</sup> |

$$q_{v} = q_{h} (C_{v}/C_{h})(1/u^{*}t^{3})[(u^{*}/u^{*}t)^{p/3} - 1]$$
(K-6)

where:

| $\mathbf{q}_{\mathbf{v}}$ | = vertical flux of particulate material, g cm <sup>-2</sup> s <sup>-1</sup>                                |
|---------------------------|------------------------------------------------------------------------------------------------------------|
| Cv                        | = coefficient of proportionality for vertical flux, $2 \times 10^{-10}$ g cm <sup>-2</sup> s <sup>-1</sup> |
| Р                         | = percent of material that has a diameter < 20 $\mu$ m                                                     |

Two possible sets of source terms were considered prior to beginning calculations — field measurements and estimates based on waste records. However, first, the radionuclides of

> Radiological Assessments Corporation "Setting the standard in environmental health"

(K-4)

(K-5)

.

Page K-84

47 W 105.0

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

concern were selected through a simplistic screening process. Solow and Phoenix (1987) analyzed pit samples for various radionuclides using radiochemistry and gamma spectrometry. The radionuclides that were routinely detected were compared by using a hazard index, calculated by multiplying the average concentration in each pit by the respective dose conversion factor for inhalation. The total hazard for each pit was estimated by summing the values associated with each nuclide. The relative hazard index was then derived by dividing each nuclide hazard value by the sum. The results are shown in Figure . K-26. The figure shows that  $^{230}$ Th and  $^{238}$ U could potentially contribute the majority of the dose from inhalation of resuspended particulates. (Note: the relatively significant contribution from  $^{234}$ U in Pit 2 is a function of an apparent outlier in the measured data.) Based on this screening assessment, further analyses focused on  $^{230}$ Th and  $^{238}$ U.



# Figure K-26. Relative hazard index of radionuclides in Pits 1-6.

The next step was to select the radionuclide concentrations in the pits. The measured concentrations (Solow and Phoenix 1987) were compared with the values calculated from disposal records (Table K-36) to see if they were representative of those estimates: Figures K-27 and K-28 show the wide disparity between measured and estimated values. The small number of samples (4-7 per pit) contributes to the large uncertainty associated with the measured values. Because we have more confidence in the source terms estimated from disposal records, these values were used in subsequent calculations, with two exceptions. Thorium concentrations for Pits 2 and 6 were not available from disposal records, so the mean measured values reported in Solow and Phoenix (1987) were used in these instances.

Table K-37 presents the parameter value distributions used in the Crystal Ball simulations. The friction velocities used in the simulation, derived using FMPC meteorological data and Equation G-1 in Killough et al. (1993), are reported in Table K-38. The vertical flux calculated for each pit is shown in Table K-39. The flux was then multiplied by the area of pit exposed each year, as presented in Kispert (1988), by the

. بر ا

Other Sources and Episodic Releases to the Atmosphere









Radiological Assessments Corporation "Setting the standard in environmental health"

Page K-85

11.\_\_

A. 1.

radionuclide concentration estimated for each pit, and by the fraction of the year that there is no moisture [0.65 according to Kispert (1988)]. Pit 4 is unique in that it was shown by geophysical survey to contain a very high volume of buried ferrous metal objects (Solow and Phoenix (1987). Approximately 25-30% of the pit area has a high density of solid buried objects. It was thus assumed that an average 25% of the surface area was not erodible. A normal distribution was used, with a 10% standard deviation, to represent the nonerodible fraction in the final release calculation for Pit 4.

The uncertainties associated with the area exposed and the radionuclide concentrations are unknown and are not included in the calculations. However, Kispert (1988) states that the estimated areas are conservatively high. It was thus assumed that any potential underestimates of the radionuclide concentrations are offset by the conservative estimates of pit areas exposed.

# Table K-37. Parameter Value Distributions Used in Uncertainty Analyses of Waste

|            |                     |                   | · · ·                                 | Std. Dev /     |                             |
|------------|---------------------|-------------------|---------------------------------------|----------------|-----------------------------|
| Pit number | Parameter           | Distribution      | Mean/Min                              | Max.           | Comments                    |
| 1          | ω (%)               | uniform           | 10                                    | • 17           | Maximum value for each      |
|            |                     |                   |                                       |                | pit is an average of        |
|            |                     |                   | •                                     | · 3            | measurements from Solow     |
|            |                     |                   |                                       |                | and Phoenix (1989).         |
| •          | •                   |                   |                                       |                | Minimum value for all dry   |
|            | -                   |                   |                                       |                | pits assumed to be 10%.     |
|            | p(%)                | normal            | 21                                    | 2.1            | Mean values for each pit    |
| •          |                     |                   |                                       |                | derived from Solow and      |
| ÷.,†       | • • •               | ·                 | 1                                     |                | Phoenix (1989). Assume SI   |
| <i>,</i> . |                     | . •               |                                       |                | = 10% of the mean.          |
| 2          | ພ (%)               | uniform           | 10                                    | 32             |                             |
| -          | p (%)               | normal            | 32                                    | 3.2            |                             |
| 3          | w(%)                | uniform           | <b>45</b>                             | 50             | Minimum values for all we   |
|            |                     |                   |                                       |                | pits assumed to be 90% of   |
|            | •                   |                   |                                       |                | the value reported in Solov |
|            |                     |                   | · · · · · · · · · · · · · · · · · · · |                | and Phoenix (1987).         |
|            | p (%)               | uniform           | 26.5                                  | 2.5            |                             |
| <b>4</b>   | ω (%)<br>= (%)      | uniform           | 10                                    | . 28           |                             |
|            | p (%)               | uniform           | 170                                   | - 2.3          | · ~                         |
|            | 00 (70)<br>D (76) - | uniform           | 10                                    | 190            |                             |
| e \.       | p(70)               | umform            | 19 23.5                               | 1.9<br>EE      |                             |
| • .        | u (%)               | uniform           | 24                                    | . 55<br>9 A    |                             |
| A]]        | C.                  | nominal value     | 01                                    | 2.4            | NRC (1981)                  |
|            | 0 L                 | nominal value     | 24                                    |                | NRC (1981)                  |
|            | Г.Я.<br>            | - nominal value . | - 980                                 |                | NRC (1981)                  |
|            | d                   | nominal value     | 0.03                                  |                | NRC (1981)                  |
|            | -<br>u*             | varies with       | See Table K-                          | -38 for values | Killough et al. (1993)      |
|            |                     | wind speed and    | WVU AUDIO AS                          |                |                             |
|            |                     | atability aloga   | 25 • FT •25 10-27                     |                |                             |

A state of the sta

| Appendix | K | , | · |  |
|----------|---|---|---|--|
|          |   |   |   |  |

Other Sources and Episodic Releases to the Atmosphere

|                      | Tabl  | e K-38. Sl | hear Veloc | ities (m s | <sup>-1</sup> ) |       |
|----------------------|-------|------------|------------|------------|-----------------|-------|
| Wind .<br>Speed      |       |            | Stabilit   | y Classes  |                 | · · · |
| (m s <sup>-1</sup> ) | A     | В          | С          | D          | Е               | ·F    |
| 1                    | 0.1   | 0.1        | 0.1        | 0.1        | 0.1             | 0.1   |
| 2                    | 0.4   | 0.4        | 0.3        | 0.3        | 0.3             | 0.2   |
| 5                    | . 0.7 | 0.7        | 0.6        | 0.5        | 0.4             | 0.4   |
| 7                    | 1.0   | 0.9        | 0.8        | 0.7        | 0.6             | 0.5   |
| 9                    | 1.3   | 1.2        | 1.0        | 0.9        | 0.8             | 0.7   |
| 11                   | 1.6   | 1.4        | 1.3        | 1.2        | · 1.0 ·         | 0.8   |

Table K-39. Vertical Flux Rates (10<sup>-10</sup>g cm<sup>-2</sup> s<sup>-1</sup>) from Waste Pits<sup>a</sup>

| number | 50% | 5%         | 95% |
|--------|-----|------------|-----|
| 1      | 2.8 | 1.0        | 7.8 |
| 2      | 42  | <b>7.3</b> | 228 |
| 3      | 3.5 | 1.0        | 11  |
| 4      | 3.4 | 1.0        | 11  |
| 5      | 0.2 | 0.15       | 0.3 |
| 6      | 2.5 | 0.7        | 11  |

Total emissions for all pits, over their operating lifetimes, are presented in Table K-40. As expected, the results for five of the six pits exceed or, in the case of Pit 2, approximate those presented Kispert (1988). However, surprisingly, the results for Pit 2, calculated by MILDOS, exceed the Kispert calculations by a factor of three.

| Pit    |      | <sup>238</sup> U |       | • •   | <sup>230</sup> Th |       |
|--------|------|------------------|-------|-------|-------------------|-------|
| Number | 50%  | - 5%             | 95%   | 50%   | 5%                | 95%   |
| 1      | 6    | 2                | 8     | 0.03  | 0.01              | 0.08  |
| 2      | 2500 | 410              | 12400 | 1     | 0.2               | 6     |
| 3      | 10   | 3                | 29    | 0.07  | 0.01              | 0.1   |
| 8      | 410  | 130              | 1350  | 9     | <b>3</b> ·        | 32    |
| 5      | 0.2  | 0.15             | 0.3   | 0.07  | 0.05              | 0.1   |
| 6      | 32   | 9                | 110   | 0.001 | 0.0004            | 0.006 |

Table K-40. Total Fugitive Emissions (kg) from Waste Pits

The major source of this large difference is the parameter "p" used in Equation K-6 of the MILDOS model. This parameter represents the percentage of material that has a physical diameter less than 20  $\mu$ m. Because the vertical flux of material is proportional to this parameter raised to the power of three, small changes are amplified. It is thus the most

> Radiological Assessments Corporation "Setting the standard in environmental health"

11\_\_

# Page K-88

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

sensitive parameter in the equation. For example, a change in "p" from 21% (the value measured in Pit 1) to 32% (the value measured in Pit 2) results in a 20-fold increase in the vertical flux. For comparison, an increase of 10% in the silt content parameter used in the coal pile model used by Kispert results in only a 3-fold increase in the flux. Because of this sensitive parameter, the uranium emissions are the largest contributor to total unmonitored releases from the FMPC.

The uranium emissions calculated for Pits 2, 4, and 6 are shown in Table K-41. The uranium releases from Pits 1, 3, and 5 were less than 1 kg y<sup>-1</sup>. The thorium emissions for these pits were neglible (<0.1 kg y<sup>-1</sup>). Given the low relative hazard index (see Figure K-26) of <sup>230</sup>Th calculated for Pits 2, 4, and 6, <sup>230</sup>Th disposed in the waste pits will not be included in the final source term. However, daughter radionuclides resulting from the decay of U-238 will be estimated and included in the source term. Because of the close physical proximity of the pits, the fugitive uranium releases from Pits 2, 4, and 6 will be modeled as a single pit for the final dose calculations. The total release from all pits was estimated to be 2961 kg . (50th percentile).

|      |                    | AI MOVIMATCA A      | agitive million               |                  | , , unu u           |
|------|--------------------|---------------------|-------------------------------|------------------|---------------------|
|      | PIT 2              | Area <sup>a</sup>   | <sub>,</sub> 238 <sub>ປ</sub> | emission rate (k | g y <sup>-1</sup> ) |
|      | Year               | ft <sup>2</sup>     | <b>50%</b> : «                | 5%               | 95%                 |
| •.   | 1957               | 17781               | 127                           | 27               | 615                 |
|      | 1958               | 35562               | 229                           | 51               | 1308                |
| •    | 1959 <sup>11</sup> | 35562               | 229                           | 51               | 1308                |
|      | . 1960             | 40008               | 289 ·                         | 52               | 1531                |
| ·• · | - 1961             | 44453               | 330                           | 55               | 1711                |
|      | 1962               | 44453               | 330                           | 55               | 1711                |
|      | 1963               | 44453               | 330                           | 55               | 1711                |
|      | 1964               | 44453               | 330                           | 55               | 1711                |
|      | 1965               | 22227               | 150                           | 24               | 846                 |
|      | 1966               | 13336               | 96                            | 15               | 501                 |
| -    | PIT 4              | Area <sup>a,b</sup> | 238 <sub>U</sub>              | emission rate (k | g y <sup>-1</sup> ) |
|      | Year               | ft <sup>2</sup>     | 50%                           | 5%               | 95%                 |
|      | 1960               | 9583                | 2.2                           | 0.8              | 6.8                 |
|      | .1961              | 19166               | 4.4                           | 1.4              | 14                  |
|      | 1962               | 38333               | 8.81                          | 2.6              | 27                  |
|      | 1963               | 43124               | 10 1. sept                    | 2.9              | 30                  |
|      | 1964               | 47916               | 110 Bann -                    | 3.2              | 30                  |
|      | 1965 -             | 47916               | 11                            | 3.2              | 30                  |
| •    | 1966               | 52708               | 11                            | 3.5              | 37                  |
|      | 1967               | 52708 ,             | 11                            | 3.5              | 37                  |
|      | 1968               | 57499               | 13                            | <b>4</b> - 3.95  | 39                  |
| •    | 1969               | 57499               | .13                           | 4                | 39                  |
| ·:   | 1970 ·             | 57499               | 13                            | 4                | 39                  |
| 140  | 1971               | 57499               | 13                            | <b>.4</b>        | 39                  |
|      | 1972               | 62291               | 13                            | 4                | 40                  |
|      | 1973               | 62291               | 13 <sup>613 (12)</sup>        | 4                | 40                  |
|      |                    |                     | •                             |                  |                     |
|      | 1974               | 62291               | 13                            | <b>°4</b> − 4    | , <b>40</b> , .     |

Table K-41. Estimated Fugitive Emissions from Pits 2, 4, and 6

Other Sources and Episodic Releases to the Atmosphere

Page K-89

| Table K-41  | Estimated | Engitiva  | Emissions f      | rom Pite 2 | 4 and 6  | (cont) |
|-------------|-----------|-----------|------------------|------------|----------|--------|
| TUNIC IL TI | Commanded | L UKITIKG | 1211113310113 11 |            | T, and U | COHL.  |

|                           |                   | . /                   | · · · _ · _ · _                 |      |
|---------------------------|-------------------|-----------------------|---------------------------------|------|
| PIT 4                     | Area <sup>a</sup> | <sup>238</sup> U emis | sion rate (kg y <sup>-1</sup> ) |      |
| Year                      | n <sup>2</sup>    | 50%                   | 5%                              | 95%  |
| 1976                      | 71874             | 17                    | 5                               | 49   |
| 1977                      | 81457             | 18                    | 5                               | 54   |
| 1978                      | 91040             | 20                    | 6                               | 61   |
| 1979                      | 95832             | 25                    | · 9                             | 75   |
| 1980                      | 95832             | 25                    | <b>9</b> .                      | 75   |
| 1981                      | 95832             | 25                    | 9                               | 75   |
| 1982                      | 95832             | 25                    | 9                               | 75   |
| 1983                      | 95832             | 25                    | 9                               | 75 . |
| 1984                      | 95832             | 25                    | 9                               | 75   |
| 1987                      | 95832             | 25                    | 9                               | 75   |
| 1988                      | 95832             | - 25                  | 9                               | 75   |
| PIT 4                     | Area <sup>a</sup> | 238U emise            | sion rate (kg y <sup>-1</sup> ) |      |
| Year                      | a <sup>2</sup>    | 50%                   | 5%                              | 95%  |
| 1979                      | . 3240            | 1.2                   | 0.4                             | 4.6  |
| 1980                      | 4860              | • 2.1                 | 0.6                             | 7.1  |
| 1981                      | 8100              | 3.6                   | 1.1                             | 13   |
| 1982                      | 8100              | 3.6                   | . 1.1                           | 13   |
| 1983                      | 8100 .            | 3.6                   | 1.1                             | 13   |
| 1984                      | 8100              | 3.6                   | 1.1                             | 13   |
| 1985                      | 8100              | 3.6                   | <b>1.1</b>                      | 13   |
| 1986                      | 8100              | 3.6                   | 1.1 .                           | 13   |
| 1987                      | 8100              | 3.6                   | 1.1                             | 13   |
| 1988                      | 8100              | 3.6                   | 1.1                             | 13   |
| <sup>a</sup> From Kispert | (1988).           |                       |                                 |      |

<sup>D</sup>An average of 75% (± 7.5%) of the area shown was assumed to be erodible, due to the presence of solid ferrous objects in Pit 4.

# **RADON RELEASE FROM K-65 SILOS, APRIL 25, 1986**

Two projects were undertaken by the FMPC in 1986 to preserve the structural integrity of the K-65 Silo domes (WMCO 1987a). In January, 20-ft diameter, protective covers were placed on the centers of the domes. A subcontractor began applying a weatherproof coating to the domes. Then, on April 25, 1986, the Silos were vented to the atmosphere for several hours. The application of the weatherproofing was not completed.

#### Description of the April 25, 1986, Episodic Release

Two reports describing the April 25, 1986, Rn release have been located. The first was apreliminary letter report, issued by the DOE (Reafsnyder 1986). The second was the formal report of the DOE Incident Investigation Board (DOE 1986). The following description of the incident and Rn release is taken from DOE (1986).

On April 14, 1986, a subcontractor began applying the weatherproof coating to the K-65 Silo domes. The coating material was a neoprene hapalon, applied as a fluid. This work was stopped on April 17, 1986, due to radiation safety concerns. Work resumed on April 18,

> Radiological Assessments Corporation "Setting the standard in environmental health"

\_\_\_ !

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

1986, but only for part of the day. On the afternoon of April 18, 1986, work was again stopped, after it was discovered that air from the Silos was escaping through the protective coating and apparently causing high radiation levels above the dome areas. It was then noticed that bubbles were present in the coating on Silo 2, and cracks and holes were also visible on Silo 2.

On Friday, April 25, 1986, the K-65 Silos were vented, without authorization, by FMPC staff. The venting was apparently performed in order to reduce the pressure in the Silos and to reduce the high radiation above the Silo domes, to allow the application of the coating to the domes to proceed. The venting was accomplished by removing one of the blank flange on the Silo domes, and installing a new two inch flange, an elbow, a quick release coupling, and lengths of flexible, schedule 80, plastic pipe. The blank flange was removed from Silo 2 at about 10:15 am, and the blank flange from Silo 1 was removed immediately after. Between 10:30 and 10:40 am, two 50 ft sections of the pipe were attached to the new flange on Silo 2. Between 10:50 and 11:00 am, one 50 ft section of the pipe was attached to the new flange on Silo 1. At 1:00 pm, it was agreed that the blank flanges were to be reinstalled. At 2:00 pm, it was reported that the blank flanges had been reinstalled on the K-65 Silos. Thus, the venting took place from about 10:15 am to 2:00 pm, a total of about 3¼ hours.

#### Current Estimate of Rn Release

None of the documents obtained include estimates of the quantities of Rn released during the Silo venting. The preliminary report (Reafsnyder 1986) and the incident investigation report (DOE 1986) did report hourly measurements of Rn concentrations in air near the Silos. However, the location of the measurement instrument was not clearly described, and the exact locations of the release points (the ends of the flexible pipe) were not described, although they were within about 35 ft of the Rn monitor (DOE 1986). These data cannot be used to reconstruct the Rn release rate.

Instead, we will estimate an upper-bound release rate that could reasonably have occurred, using the models for Rn releases that are used in Appendix J for ongoing Rn releases from the Silos. It seems likely that attaching a 2-inch vent pipe to the Silo domes would have increased the air exchange ventilation of the Silo air space. So we calculate the excess releases as air exchange releases, using an equation similar to that used for the ongoing air exchange Rn releases for the 1980–1987 period (see Appendix J):

 $Q_{\rm epi,max} = C_{\rm a} \lambda_{\rm v} V_0 CFU$ 

(K–7)

Ċ.

# where

|   | 6 | epi,max |
|---|---|---------|
| - |   |         |

 $C_{a}$ 

 $V_0$ 

CF

U

= the (estimated maximum reasonable) Rn release rate from the K-65 Silos during the April 25, 1986, episodic release,

- = the Rn concentration in the Silo head space air,
- = the ventilation rate of the Silo head space air,
- = the volume of the Silo head space air,
- = a units conversion factor, and

. . . . . .

= an uncertainty factor, the reason for which will be discussed later.

#### The quantity of Rn released can then be calculated by:

# Appendix K Other Sources and Episodic Releases to the Atmosphere

....

Page K-91

 $R_{\rm epi,max} = Q_{\rm epi,max}t$ 

where t is the length of time the release continued. This approach assumes that the release rate remains constant. However, it actually would decrease during the release time, because the Rn concentration,  $C_a$ , would decrease due to the additional ventilation of the air space. Thus, our simplification results in estimates that are biased somewhat high.

As for the ongoing releases for 1980–1987, calculated in Appendix J, we assume the Rn concentration in the head space air is the same at the time of the release as at the time it was measured in November 1987. The concentration is assumed to be represented by a normal distribution, with mean  $2.62 \times 10^7$  pCi L<sup>-1</sup>, and with standard deviation  $4.1 \times 10^6$  pCi L<sup>-1</sup>.

The head space ventilation rate,  $\lambda_{v}$ , is very uncertain for this episodic release. For the 1980–1987 period, air exchange releases are presumed to have occurred through the numerous cracks in the Silo domes. For that period, the driving force was thought to be the temperature-induced expansion and contraction of the head space air. For the 1959–1979 period, releases occurred through open penetrations through the domes, including a 6-inch diameter gooseneck vent pipe and many smaller penetrations (Appendix J). For that period, the releases were thought to be caused also by wind across the Silo domes. The ventilation of the Silos with a 2-inch pipe open to the atmosphere is not really similar to either of the previous situations. However, we are trying to place an upper bound on the releases. The ventilation rate during this episodic release would be less than the ventilation rate for the 1959–1979 period, since for the episodic release, the areal extent of openings in the Silo domes is considerably less. Thus, we assume that the ventilation rate for the episodic release is the same as that calculated for the 1959–1979 period.

In the calculations of ongoing releases for the 1959–1979 period (Appendix J), we actually calculated the fractional loss rate for air exchange plus diffusion Rn releases from the Silos,  $\lambda_{v+d,pre}$ . Because of the way the calculations were performed, the diffusion releases were not separated from the air exchange releases. However, the diffusion releases are probably only a small fraction of the total releases (based on estimated diffusion releases for 1980–1987, the difference in Rn concentrations for 1959–1979 and 1980–1987, and estimated total releases for the two periods). Thus, it seems reasonable to assume that, for the 1959–1979 period, the ventilation rate,  $\lambda_{v,pre}$ , is equal to the total fractional loss rate,  $\lambda_{v+d,pre}$ . This is done for our calculations here. From the calculations in Appendix J,  $\lambda_{v+d,pre}$  had a broad distribution with median value 2.4 d<sup>-1</sup>, and 90% probability range (5th to 95th percentiles) of 0.83 to 16 d<sup>-1</sup>. For the calculations here, we use the exact distribution as calculated in Appendix J.

For the volume of the Silo head space, we use the same values used in the calculations of ongoing releases (Appendix J). Thus, a uniform distribution is assumed, with minimum  $40,000 \text{ ft}^3$ , and maximum  $62,000 \text{ ft}^3$  (per silo).

For the units conversion factor, we desire the Rn release rate,  $Q_{epi,max}$ , to have units Ci h<sup>-1</sup>. The component factors have units pCi L<sup>-1</sup> for  $C_a$ , d<sup>-1</sup> for  $\lambda_v$ , and ft<sup>3</sup> (per silo) for  $V_0$ . Thus, the conversion factor is:

$$CF = [(28.317 L ft^{-3})(10^{-12} Ci pCi^{-1})(2 silos) + (24 h d^{-1})]$$
(K-9)

 $= 2.36 \times 10^{-12} \text{ d L Ci h}^{-1} \text{ ft}^{-3} \text{ pCi}^{-1}$ 

Radiological Assessments Corporation "Setting the standard in environmental health"

(K--8)

#### Page K-92

1999 - N. S.

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

It is felt that the uncertainty in the calculation of release rate for this episodic release has not been totally accounted for by the parameter uncertainties. In particular, the previous calculation of  $\lambda_{v+d,pre}$ , which is now used for  $\lambda_v$ , assumes  $\lambda_{v+d,pre}$  to be a long-term average value. In the present calculations, we are concerned with the ventilation rate for a short period of time on a single day. The same criticism applies to the Rn concentration  $C_a$ . Because of these additional uncertainties, we apply an additional uncertainty factor, U. In this case, we assume (somewhat arbitrarily) U to have a lognormal distribution, with geometric mean 1, and geometric standard deviation 1.4 (for a 95% confidence interval, this gives an uncertainty of about x/+ 2).

Calculations were performed as a Monte Carlo simulation, with 10,000 iterations, using the methods described in Appendix J for the calculations of ongoing Rn releases. The initial results for the upper bound on the Rn release quantity,  $R_{\rm epi,max}$ , are a median estimate of 29 Ci, with 90% probability range (5th to 95th percentiles) of 8-210 Ci. However, the 95th percentile value is not a realistic estimate, because this quantity is significantly more than the quantity of Rn in the Silo air spaces. The total quantity of Rn in the sir spaces is just the concentration,  $C_a$ , times the volume,  $V_0$ , times 2 silos. If the uncertainties in these two parameters (described above) are accounted for, the 90% probability range for the quantity of Rn in the air spaces of the two Silos is 52-100 Ci, with median 74 Ci. The unrealistically high value of 210 Ci released is partly due to our simplying assumption that the concentration in the Silos remains constant during the release. The 95th percentile of the upper bound on the Rn release quantity,  $R_{\rm epi,max}$ , can be assumed to be no greater than 100 Ci. We thus conclude that the upper bound of the excess Rn released during the episodic release is probably within 8-100 Ci, with a best estimate of the upper bound being around 30 Ci.

The median estimate of the upper bound on the Rn release rate,  $Q_{epi,max}$ , is about 7.6 Ci h<sup>-1</sup>. From information in Appendix J, the median estimates of diffusion and air exchange releases for the 1980–1987 period correspond to a Rn release rate of about 0.2 Ci h<sup>-1</sup> during daylight hours. From a comparison of these release rates, it appears that this Rn release of April 25, 1986, could meet the criteria for an episodic release. (Since we have only made upper-bound estimates, we cannot be more definite.)

#### Supplemental Environmental Measurements

At the time of this episodic release, a few Rn monitoring programs were in place at the FMPC (Reafsnyder 1986; DOE 1986). These included (1) onsite measurements at 17 locations and offsite measurements at three locations within two miles of the site, performed by Mound Laboratories; (2) measurements at the boundary air monitoring stations, onsite locations, and some offsite locations, using alpha-track monitors for three-month-long measurements, performed by the FMPC; and (3) continuous measurements (actually provided hourly results) with a Rn gas monitoring instrument, very near the K-65 Silos.

Regarding results of the Mound Laboratories measurements, the DOE (1986) report indicates that average measured concentrations, for onsite and offsite locations, for the twoweek period that included April 25, 1986, were higher than similar averages for the preceding 1<sup>1</sup>/<sub>2</sub>-year period. We have compiled results of the Mound measurements in the Task 4 report of this Project (Killough et al. 1993). Based on our compilation (Table PS-1 of the Task 4 report), the averages for this two-week period were generally higher than the

13

75

# Appendix K Other Sources and Episodic Releases to the Atmosphere

long-term averages, but were not higher than the range of results for other one- or twoweek periods measured by Mound.

Regarding the alpha-track measurements performed by the FMPC, due to the Rn release the detectors were retrieved and analyzed earlier than scheduled. For the period March 18–April 29, 1986, concentrations at two offsite locations appeared higher (at 1.29 pCi L<sup>-1</sup>) than average offsite concentrations for 1985 (at 0.59 and 0.37 pCi L<sup>-1</sup>) (DOE 1986). From the 1986 annual environmental monitoring report (WMCO 1987a), however, it appears that the two offsite locations, called OS1 and OS2, were in opposite directions from the K-65 Silos. This suggests that the episodic Rn release is not the only reason for the potentially elevated concentrations measured.

The hourly Rn measurements were made within about 35 ft of where the Rn was discharged from the flexible pipes (DOE 1986), although the exact locations of the measurements and the discharge points were not indicated in the report. Measurement results for April 23 and April 24, 1986, were markedly different from those of April 25, 1986. For April 23 and 24, peak concentrations, occurring from mid-morning to mid-afternoon, were about 10 and 40 pCi  $L^{-1}$ , respectively. On April 25, the peak concentration was 694 pCi  $L^{-1}$ . This significant difference may indicate that Rn releases on April 25 were substantially greater than on April 23 and 24. However, on April 23 and 24, the releases are assumed to be from the domes of the Silos, while on April 25, the releases were from the domes plus from the flexible pipes that had been attached. The exact locations of the release points in relation to the measurement point are not known. In addition, wind directions around the Silos on these days are not known. Thus, we really cannot make a quantitative comparison.

#### **Conclusions** — Episodic Radon Release

: ;;

~2

م<sup>ن</sup>ة أ

In conclusion, there was a Rn release on April 25, 1986, that may meet our criteria for an episodic release. The information available for quantitatively estimating the release rate and release quantity is quite limited. Thus, we have only performed upper-bound estimates. Radon monitoring was performed for time periods surrounding the episodic release. Of these data, the hourly measurements, made close to the K-65 Silos, provide the best corroboration (though only qualitative) that an episodic release occurred on April 25, 1986. However, it appears that comparisons of concentrations measured during the release time with concentrations measured at other times will not be useful for quantitative assessments of the release.

#### SUMMARY AND CONCLUSIONS - OTHER SOURCES AND EPISODIC RELEASES

A variety of historical unmonitored sources of uranium releases to the atmosphere have been evaluated in this appendix. This concluding section will summarize the estimated releases from these miscellaneous sources, compare them with previous estimates, and attempt to place them in perspective with the major atmospheric releases from FMPC operations. Table K-42 presents the total release estimates from the unmonitored sources over their entire period of operation. In addition, the table illustrates the difference between our reconstructed source terms and those previously developed by the FMPC contractor. In

Page K–94

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

|                       | Miscellane                    | ous Sources a | t the FMPC                            |                             |
|-----------------------|-------------------------------|---------------|---------------------------------------|-----------------------------|
|                       | Total Release Estimate (kg U) |               |                                       |                             |
|                       | Inclusive                     | •             | 5th–95th Percentile                   | Previous                    |
| Source                | Dates                         | Median        | Range                                 | <u>Estimate<sup>a</sup></u> |
| Old Solid Waste       | 1954-1979                     | 2200          | 1600-2900                             | 2471                        |
| Incinerator           | ·                             |               | · · · · · · · · · · · · · · · · · · · | . 1                         |
| Oil Burner            | 1962-1979                     | 5. <b>370</b> | 270-470                               | 467                         |
| Graphite Burner       | 1965–1984                     | 230           | 61-730                                | 129                         |
| New Solid Waste       | 1979–1986                     | 8             | 0.6-90                                | 14                          |
| Incinerator           |                               |               |                                       | , .                         |
| Liquid Waste          | 1983–1986                     | 4             | 0.9–9                                 | 12 <sup>d</sup>             |
| Incinerator           |                               |               | • •                                   | •                           |
| Building Ventilation  | 1954–1987                     | 4100          | 970–15,000                            | 390                         |
| Miscellaneous Process | 1953-1988                     | Ъ             | 110-970°                              | . 324                       |
| Emissions             | -                             | -             |                                       |                             |
| Lab Hoods             | 1953–1987                     | h             | 20–200°                               | . 66.5 ·                    |
| Waste Pits            | 1953–1988                     | 3000          | 900-12,000                            | 1560                        |
| Non-routine Releases  | 1952-1988                     | . 1300        | 780–2900                              | 2784                        |
| Episodic Releases     | See Table                     | See Table     |                                       |                             |
|                       | K-43                          | - K-43        | 3 :                                   |                             |

 Table K-42. Summary of Total Estimated Releases of Uranium to the Air from

 Miscellaneous Sources at the FMPC

<sup>a</sup>From FMPC operating contractor. See individual sections of Appendix K for sources of information.

<sup>h</sup>Not reconstructed.

"Subjective uncertainty of a factor of 3 applied to previous estimate.

<sup>d</sup>Based on maximum processing rate.

contrast to previous estimates, the reconstructed source terms all carry some estimate of uncertainty and are well documented.

The agreement between past and revised release estimates is good for the incinerators. With the exception of the new liquid waste incinerator, which is a minor source, the 5th-95th percentile range of our estimate encompasses the previous estimate. The reconstructed release estimate from building ventilation is significantly higher than the previous estimate, due to two main reasons: (1) the use of a lower dilution factor for building make-up air and (2) the use of higher in-plant airborne contamination levels, measured in the 1950s, to make a forward projection through 1970.

Median estimates of releases from the waste pits were about two times higher than previous results. This difference is a function of the use of a model which relied on sitespecific data, particularly soil characteristics. The model was highly sensitive to particle size, which varied greatly among pits and was highest for pits 2 and 4. These pits also had the highest estimated U concentrations, thus resulting in substantially higher release estimates during time periods when these pits were active.

The median release estimate for non-routine releases is less than that previously calculated by Vaaler and Nuhfer (1988), although the 5th to 95th percentile range

# Appendix K Other Sources and Episodic Releases to the Atmosphere

. . .

•••

зŶ.

Page K-95

encompasses the previous estimate. The lower median estimate reflects the selection of different models and the use of site-specific data for fires and spills. Uranium hexafluoride release models were not revised, although subjective uncertainty limits were assigned to input parameters.

Most of these miscellaneous sources were not releasing uranium to the atmosphere over the entire production history at the FMPC. Figure K-29 illustrates the time-dependent nature of the release estimates for the three most significant of the unmonitored sources. All three sources were most important in the late 1950s and early 1960s. The waste pit source term is strongly influenced by the timing of use of Pit 2, which was closed in the mid-1960s. The building exhaust source term is highly dependent upon the production rate of scrap recovery operations, which peaked in 1960. By 1970, each of these sources contributed less than 100 kg uranium per year to the atmosphere (Figure K-29).



Figure K-29. Time-dependent median source term estimates for the more important sources of unmonitored releases of uranium at the FMPC (excluding the  $UO_3$  gulping process).

Six incidents involving releases of uranium were identified which met our criteria for special treatment as episodic releases. Three of these episodic releases were documented in incident reports and occurred on November 7, 1953, between November 12 and 16, 1960, and on February 14, 1966. The remaining three episodic releases were identified by air monitoring data, although documentation could not be found to identify the sources. These events occurred sometime during the weeks ending on September 28, 1978, February 8, 1979, and September 20, 1983. The six episodic releases are summarized in Table K-43. In terms of total quantity of uranium released, the dust loss which began on 11/12/60 had the most impact. However, the incident on 2/14/66 had the largest rate of release.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

でいた

ŝ

A release of about 30 Ci of radon occurred on April 25. 1986, from unauthorized venting of the K-65 silos. This source term also may be treated separately as an episodic release.

# Table K-43. Summary of Six Episodic Releases of Uranium Which Were Identified from Incident Reports and Air Monitoring

| Start Date                                                                                               | Description                                                                      | Uranium Released<br>(kg) | Duration of .<br>Release |  |  |
|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|--------------------------|--------------------------|--|--|
| 11/7/53                                                                                                  | Release of UF <sub>6</sub> from defective<br>cylinder in Pilot Plant             | 45                       | 15 min                   |  |  |
| 11/12/60                                                                                                 | Dust loss from dust collector<br>bags in Pilot Plant                             | 310                      | 1 or 3 days              |  |  |
| • •                                                                                                      | Replacement of bags                                                              | 470                      | 5 days                   |  |  |
| 2/14/66                                                                                                  | Release of UF <sub>6</sub> from cylinder in<br>Pilot Plant due to operator error | -<br>750                 | 1 hr                     |  |  |
| 9/21/78                                                                                                  | Unknown                                                                          |                          | 7 days                   |  |  |
| 2/1/79                                                                                                   | Unknown                                                                          | 60–680ª                  | 7 days                   |  |  |
| 9/13/83 ·                                                                                                | Unknown                                                                          | 290-360ª                 | - 7 days                 |  |  |
| <sup>a</sup> Range of values is based on results from several different ambient air monitoring stations. |                                                                                  |                          |                          |  |  |

After careful examination of many types of information, the conclusion is well supported that the magnitudes of uranium releases from the miscellaneous unmonitored sources are minor relative to the three major sources of emissions from the FMPC, which are: the scrubbers in Plant 8, the scrubbers in Plant 2/3, and the plant-wide dust collectors. Figure K-30 illustrates the relative importance of the various sources — Figure K-30a is plotted on a logarithmic scale, so that the uncertainty distributions can be seen more clearly. Figure K-30b is plotted using a linear scale, which more accurately illustrates the true relative magnitude of these sources.

When all of the sources investigated in Appendix K are combined, using appropriate statistical measures, the grand total of the releases is 16,000 kg (median estimate), with a 5th-95th percentile range of 9,300 to 28,000 kg. This total does not include the November 1960 dust loss from the Pilot Plant, which is included with the total dust collector source term. See the main text of this report for an overview of total source terms from historic atmospheric releases at the FMPC.

Page K-96

See Table K-30

ر. در در

2

# Other Sources and Episodic Releases to the Atmosphere







## Figure K-30b. Note linear scale.

Figure K-30. Relative importance of miscellaneous unmonitored sources of atmospheric releases of uranium compared with releases through scrubbers and dust collectors. The 50% point represents the median (best estimate). The 5% and 95% points encompass a 90% probability range on the total estimates.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

5

. .

1.1.1.1.1.1

The second second

1. X. V. V. V.

÷.

# REFERENCES

Adams, W. J. Report of the orange oxide discharge from the roof stacks of the refinery denitration area on July 25, 1969. Cincinnati, OH: National Lead Company of Ohio; 4 August 1969.

na tha phù

- Adams, W. J. Incident report covering the dust loss in the plant 9-NI-1039 dust collector. Internal memorandum to S. F. Audia. Cincinnati, OH: National Lead Company of Ohio; 14 July 1978.
- Adams, W. J. Listing of major dust collector uranium releases. Attachment to letter to M. R. Theisen, DOE-ORO. Cincinnati, OH: National Lead Company of Ohio; 3 January 1985.
- AEC (Atomic Energy Commission). Permit Application Plibrico Incinerator, Feed Materials Production Center. NLO database number 2121714. Cincinnati, OH: National Lead Company of Ohio; circa 1971.
- Anonymous. Analytical data sheet Incinerator ash. Cincinnati, OH: National Lead Company of Ohio; 1 October 1956 (1956a).
- Anonymous. Analytical data sheet Incinerator ash. Cincinnati, OH: National Lead Company of Ohio; 9 October 1956 (1956b).
- Anonymous. Oil burner and incinerator operations. Handwritten ledger sheets. NLO database number 2259926. Cincinnati, OH: National Lead Company of Ohio; 1964–1968.
- Anonymous. Modification of the plant incinerator. Construction proposal CP-69-17. Cincinnati, OH: National Lead Company of Ohio; 20 May 1969.
- Anonymous. Incineration of radioactive wastes. Cincinnati, OH: National Lead Company of Ohio; 18 February 1970.
- Anonymous. Solid Waste Incinerator Project Proposal CP-78-7. Cincinnati, OH: National Lead Company of Ohio; 11 August 1978.
- Anonymous. Liquid Waste Incinerator Project Proposal CP-78-8. Cincinnati, OH: National Lead Company of Ohio; 3 August 1979.
- Anonymous. FMPC Solid waste incinerator Chronology of events. and NLO Incinerator stack test data. Cincinnati, OH: National Lead Company of Ohio; 1982.
- Anonymous. Additional stack loss estimates CY 1984 emissions. Handwritten notes. Cincinnati, OH: NLO, Inc.; Circa 1985.
- Anonymous. Removal site evaluation Contaminated soils adjacent to solid waste incinerator at the sewage treatment plant. R-015-101.1. Cincinnati, OH: Westinghouse Materials Company of Ohio; October 1990.
- Audia, S. F. Scrap materials going to the burn pit. Internal memorandum to distribution. Cincinnati, OH: National Lead Company of Ohio; 28 December 1964.
- Audia, S.F. Drum decontamination residues (Code 021) and incinerator ashes (Code 032). Internal memorandum to S. Marshall. Cincinnati, OH: National Lead Company of Ohio; 6 January 1969.
- Audia, S.F. Ohio EPA permit application Liquid waste incinerator FMPC. Letter to H.D. Hickman, DOE Oak Ridge Operations, with attachments. Cincinnati, OH: National Lead Company of Ohio; 2 May 1980.
- Baer, C.W. SOP Processing and burning waste oil. Cincinnati, OH: NLO, Inc.; 10 November 1966 (1966a).

.

.

0

## Other Sources and Episodic Releases to the Atmosphere

-

Baer, C.W. SOP — Graphite Burner. Cincinnati, OH: NLO, Inc.; 16 August 1966 (1966b).

Baer, C.W. SOP - Incinerator. Cincinnati, OH: NLO, Inc.; 10 November 1981.

- Beers, H. M. Investigation report explosion of D43-104 digester in Plant #8. Internal memorandum to M. S. Nelson. Cincinnati, OH: National Lead Company of Ohio; 11 June 1958.
- Beers, H. M. Meeting of the investigation committee on the ciolent reaction in the D43-101 water slurry make-up tank at the Recovery Plant. Internal memorandum to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 6 January 1960.
- Bipes, R.L. Air dust evaluation of smoke plume, trash incinerator. Letter to K.E. Brandner. Cincinnati, OH: National Lead Company of Ohio; 18 July 1962.
- Boback, M. W. ; Heatherton, R. C. Bioassay aspects of a UF<sub>6</sub> fume release. Presentation at 12th annual Bioassay and Analytical Chemistry Meeting, Gatlinburg, Tenn., October 13-14, 1966, NLCO-986. Cincinnati, OH: National Lead Company of Ohio; 1 November 1966.
- Boback, M. W. Low-cost incinerator units for disposal of waste graphite and oils. Prepared for presentation at the AEC Pollution Control Conference, Oak Ridge, TN, October 25– 27, 1972. Rep. NLCO-1093. Cincinnati, OH: National Lead Company of Ohio; 1972.
- Boback, M. W.; Dugan, T. A.; Fleming, D. A.; Grant, R. B.; Keys, R. W. History of FMPC radionuclide discharges. Rep. FMPC-2082. Cincinnati, OH: Westinghouse Materials Company of Ohio; 1987.
- Bostick, W.D.; Bunch, D.H.; Gibson, L.V.; Hoffman, D.P.; Shoemaker, J.L. Effluent testing for the Oak Ridge Mixed Waste Incinerator: Emissions test for August 27, 1990. Knoxville, TN: Proceedings of the 1991 Incineration Conference; 13-17 May, 1991.
- Brandner, K.E.; Bipes, R.L.; Williams, L. Incineration of waste contaminated oil. In: Proceedings of the Eighth AEC Air Cleaning Conference. Report no. TID-7677, pp. 674-679; Springfield, VA: National Technical Information Service; 1963.
- Breslin, A.J. Occupational exposures to uranium air contamination in feed materials production facilities, 1948–1956. In: Symposium on Occupational Health Experience and Practices in the Uranium Industry, New York City, October 15–17, 1958. Rep. HASL– 58. Springfield, VA: National Technical Information Service; 1958.
- Brevard, R. F. Incident report of ground contamination of gravel area south of Plant 9. Internal memorandum to L. M. Levy. Cincinnati, OH: National Lead Company of Ohio; 30 March 1961.
- CIV (Committee on Industrial Ventilation). Industrial ventilation, a manual of recommended practice. 16th Ed. Lansing, MI: American Conference of Governmental Industrial Hygienists; 1980.
- Clark, T. R.; Elikan, L.; Hill, C. A.; Speicher, B. L. History of FMPC radionuclide discharges—Revised estimates of uranium and thorium air emissions from 1951–1987. Addendum to FMPC-2082. Cincinnati, OH: Westinghouse Materials Company of Ohio; 1989.
- Coates, R.C. Contaminated oil disposal. Memo to C.R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 27 August 1962.
- Collier, R. Anhydrous hydrogen fluoride release at the feed materials production center (FMPC) on September 29, 1987. DOE memorandum to J. LaGrone, DOE; 15 January 1988.

Costa, J. J. Spillage of South African Concentrates - Lot 247. Internal memorandum to C. H. Walden. Cincinnati, OH: National Lead Company of Ohio; 9 June 1954.

Davis, J. O. Hex Leak, Nov. 7, 1953. Internal memorandum to F. L. Cuthbert. Cincinnati, OH: National Lead Company of Ohio; 7 November 1953.

Davis, J. O.; Davies, H. J. Uranium content of burning pit residues. Internal memorandum to L. M. Levy. Cincinnati, OH: National Lead Company of Ohio; 21 August 1964.

 Davis, J. O. Uranium content of burn pit residues-project P4800-2. Internal memorandum to W. A. Smith, Jr. Cincinnati, OH: National Lead Company of Ohio; 24 August 1965 (1965a).

Davis, J. O. Uranium content of burn pit residues-project P48000-2. Internal memo to B. Gessiness. Cincinnati, OH: National Lead Company of Ohio; 22 November 1965 (1965b).

Davis, J. O.; Palmer, W. E. Evaluation of uranium content of various plant incinerator residues. Internal memorandum to J. B. Stevenson. Cincinnati, OH: National Lead Company of Ohio; 9 April, 1968.

Decisioneering. Crystal Ball Version 2.0 for Windows. Boulder, CO: Decisioneering, Inc.; 1992.

DeFazio, P.G. Contaminated oil. Internal memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 10 January 1961.

- DeFazio, P.G. Contaminated oil. Internal memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 26 February 1962.
- DeFazio, P.G. Consumption of scrap oil to treat coal. Memo to S.F. Audia. Cincinnati, OH: National Lead Company of Ohio; 18 October 1972.
- DOE (U.S. Department of Energy). Investigation of April 25, 1986 radon gas release from Feed Materials Production Center K-65 silos. DOE Incident Investigation Board; Rep. DOE/OR-877; 27 June 1986.
- DOE (U. S. Department of Energy). Investigation of uranium trioxide spill at the Feed Materials Production Center, Plant Four. DOE/ORO-878; 11 November 1986.

DOE. Operable Unit 3 Work Plan Addendum. Fernald Environmental Management Project, Fernald, Ohio. Remedial Investigation and Feasibility Study. Volume 2 of 4. Appendices A, B & C. Revision 1. Cincinnati, OH: U.S. Department of Energy, Fernald Office; June 1992.

Engineering Drawing 10X-5500M-00322, Rev. 1. Waste Oil Burner, Plan and elevation; 6 May 1971.

Engineering Drawing 10X-5500M-00324. Graphite burner. Plan and section; 19 September 1972.

EPA (U.S. Environmental Protection Agency). Compilation of air pollutant emission factors. AP-42. Research Triangle Park, North Carolina: U.S. Environmental Protection Agency; September 1985.

EPA (U.S. Environmental Protection Agency). Method for estimating fugitive particulate emissions from hazardous waste sites. Document EPA/600/2-87/066 (PB87-232203). Springfield, VA: National Technical Information Service; 1987.

Farr, J. Request for engineering services. Cincinnati, OH: National Lead Company of Ohio; 6 December 1972.

. مە

#### Other Sources and Episodic Releases to the Atmosphere

- Glauberman, H.; Loysen, P. The use of commercial incinerators for the volume reduction of radioactively contaminated combustible wastes: Health Physics. 10:237-241; 1964.
- Grant, R.B. Handwritten notes. Stack heights, diameters, flow rates, and temperatures for four FMPC incinerators. NLO database document no. 2631108. Cincinnati, OH: NLO Inc.; 2 April 1986.

Grant, R.B. Personal communication with S.K. Rope; 7 July 1993.

- Halcomb, R. N. Explosion in Pilot Plant on 6/29/56. Internal memorandum to A. J. Stefanec. Cincinnati, OH: National Lead Company of Ohio; 6 July 1956.
- Harmon, L.H. Incinerator ashes. Internal memorandum to L.M. Levy. Cincinnati, OH: National Lead Company of Ohio; 12 January 1973.
- Harr, G. R. Uranyl nitrate release. Internal memorandum to J. H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 23 July 1959.
- Harrell, E. M. Spillage of SF material. Internal memorandum to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 8 December 1954.
- Heatherton, R. C. Air contamination from broken crucible in 3037. Internal memorandum to J. A. Quigley, M.D. Cincinnati, OH: National Lead Company of Ohio; 7 November 1952.
- Heatherton, R. C. Weekly report Industrial Hygiene & Radiation Department, February 1, 1956. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 1 February 1956.
- Heatherton, R. C. Airborne uranium from metal fires. Internal memorandum to L. M. Levy. National Lead Company of Ohio; 24 April 1975.
- Heatherton, R.C. Incinerator stack test. Letter to W.C. Hill. Cincinnati, OH: NLO, Inc. 14 May 1981.
- Hill, C. A. Emission estimates for unmonitored uranium processes other than UO<sub>3</sub> gulping. Internal memorandum to T. R. Clark. Cincinnati, OH: Westinghouse Materials Company of Ohio; 21 March 1989 (1989a).
- Hill, C. A.; Thorium process emissions and upper limit estimate. Internal memorandum to T. R. Clark. Cincinnati, OH: Westinghouse Materials Company of Ohio; 21 March 1989 (1989b).
- Hill, C.A. Building exhaust emissions methods and estimates. Internal memorandum to T.R. Clark. Cincinnati, OH: Westinghouse Materials Company of Ohio; 13 March 1989 (1989c).
- Hill, C. A.; Dolan, L. C. Addendum to FMPC-2082, History of FMPC radionuclide discharges. Cincinnati, OH: Westinghouse Materials Company of Ohio; Draft document; 1988.
- Huey, T.N.; Scheel, S.K.; Aas, C.A. Investigation of ineffective control of material burned in the solid waste incinerator. Report no. WMCO:PO(CH):86-119. Cincinnati, OH: Westinghouse Materials Company of Ohio; 25 June 1986.
- IT (International Technology Corporation). Sampling and evaluation of supporting documentation and calculational methodology for selected items in WMCO report no. FMPC-2082 and addendum. Report no. IT/NS-89-108. Oak Ridge, TN: U.S. Department of Energy; 23 May 1989.

1.5

S. W. V.C.

- Investigation Board. Investigation report on Plant 2/3 gulping emission at the Feed Materials Production Center, June 1988. Document DOE-ORO-897. Oak Ridge, TN: U.S. Department of Energy; November 1988.
- Karl, C. L. Incinerator air pollution testing. Letter to J.H. Noyes, NLO. Cincinnati, OH: U.S. Atomic Energy Commission, Oak Ridge Operations, Cincinnati Area; 11 April 1967.

Karl, C. L. Temporary shutdown of plant incinerator. Letter to M.S. Nelson, Nation Lead Company of Ohio. Cincinnati, OH: U.S. Atomic Energy Commission, Oak Ridge Operations, Cincinnati Area; 22 December 1969.

Killough, G. G.; Case, M. J.; Meyer, K. R.; Moore, R. E.; Rogers, J. F.; Rope, S. K.; Schmidt, D. W.; Shleien, B.; Till, J. E.; Voillequé, P. G. The Fernald dosimetry reconstruction project, task 4: environmental pathways analysis — models and validation. Draft interim report for comment. Neeses, South Carolina 29107: Radiological Assessments Corporation; Rep. CDC-3; February 1993.

Kispert, R. C. Fugitive dust emissions from FMPC waste pits. Internal memorandum to L. C. Dolan. Cincinnati, OH: Westinghouse Materials Company of Ohio; 8 November 1988.

Klein, F. J. Report of fume release Pilot Plant, Area 3620. Cincinnati, OH: National Lead Company of Ohio; 10 January 1958.

Klein, F. J. Uranium fallout study in adjacent vicinity of the oil burner and the incinerator. Internal memorandum to R. L. Fischoff. Cincinnati, OH: National Lead Company of Ohio; 12 July 1963.

Klein, F.J. Uranium fallout study in adjacent vicinity of the oil burner and the incinerator. Internal memorandum to R. L. Fischoff. Cincinnati, OH: National Lead Company of Ohio; 1 May 1964.

Klein, F. J. Incident Observation Report-Weekly inspection, burn pit. Internal memo to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 24 March 1965.

Kreuzmann, A.B.; Neblett, F.W. Completion report – PTA 297 – Screening incinerator ash (032 material) in plant 5. Internal memorandum to W.J. Adams. Cincinnati, OH: National Lead Company of Ohio; 12 August 1976.

Martin, H; Bipes, R.; Gessiness, B.; Roeder, C.; Wolf, R. Report of investigation uranium loss in G-4-8 dust collector. Cincinnati, OH: National Lead Company of Ohio; 7 June 1963.

Martin, J. R.; Slattery, P. L.; Marciante, G. J. Investigation of enriched uranium release at the feed materials production center - September 4 to December 7, 1984. Memorandum to J. LaGrone. Cincinnati, OH: National Lead Company of Ohio; 7 February 1985.

McKelvey, J.W. Incineration of contaminated waste materials. Letter to H. Zeitz. Cincinnati, OH: National Lead Company of Ohio; 30 April 1957.

Mead, J.C. History of FMPC residue recovery operations. Document NLCO-1096 special. Cincinnati, OH: National Lead Company of Ohio; 25 August 1972.

National Air Pollution Control Administration. 1969. Interim guide of good practice for incineration at federal facilities. Rep. AP-46. Springfield, VA: National Technical Information Service; November 1969.

Neblett, F.W. Estimate for historical releases-graphite burner and oil burner. Internal memo to M.W. Boback. Cincinnati, OH: National Lead Company of Ohio; 8 October 1985.

Nelson, M.S. Temporary shutdown of plant incinerator. Letter to C.L. Karl, AEC. Cincinnati, OH: National Lead Company of Ohio; 8 December 1969.

- 34

.

2

#### Other Sources and Episodic Releases to the Atmosphere

- NLO (National Lead Company of Ohio). Fire in stored drummed chips near Plant 6. Cincinnati, OH; 18 October 1962.
- NLO (National Lead Company of Ohio). Uranium hexafluoride gas release Feed Materials Production Center, Fernald, Ohio, report of investigating team. Cincinnati, OH: National Lead Company of Ohio; 16 March 1966.
- NLO (National Lead Company of Ohio). Environmental incident report uranium chip fire. Cincinnati, OH: National Lead Company of Ohio; 5 February 1985a.
- NLO (National Lead Company of Ohio). Environmental incident report Indoor release of particulate. Cincinnati, OH: National Lead Company of Ohio; 25 February 1985b.
- NLO (National Lead Company of Ohio). Environmental incident report uranium oxide release to the atmosphere. Cincinnati, OH: National Lead Company of Ohio; 13 April 1985c.
- NLO (National Lead Company of Ohio). Supervisor's report of minor event mag flash. Cincinnati, OH: National Lead Company of Ohio; 1 November 1985d.
- NLO (National Lead Company of Ohio). Supervisor's report of minor event smoke from #46 Rockwell furnace. Cincinnati, OH: National Lead Company of Ohio; 13 December 1985e.
- Noyes, J. H. Digester tank explosion in Plant 8. Internal memorandum to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 4 January 1960.
- Noyes, J.H. Study of incinerators used for burning contaminated combustible waste. Cincinnati, OH: National Lead Company of Ohio; 27 March 1962.
- Noyes, J. H. Scrap materials going to the burn pit. Internal memorandum to division directors. Cincinnati, OH: National Lead Company of Ohio; 6 January 1965.
- Noyes, J.H. Idea Letter Modification of the plant incinerator. Letter to C.L. Karl, U.S. AEC. Cincinnati, OH: National Lead Company of Ohio; 20 March 1969.
- NRC (U.S. Nuclear Regulatory Commission). MILDOS-a computer program for calculating environmental radiation doses from uranium recovery operations, NUREG/CR-2011. Richland, WA: Battelle Pacific Northwest Laboratories; April 1981.
- Nutter, E. M. Incident report Plant 4 stack discharge. Report to R. M. Spenceley. Cincinnati, OH: National Lead Company of Ohio; 9 November 1981.
- Nutter, E. M. Incident report stack loss of 2.6 kg uranium. Report to R. M. Spenceley. Cincinnati, OH: National Lead Company of Ohio; 31 December 1984.
- OEPA (Ohio Environmental Protection Agency). Reasonably available control measures (RACM) for fugitive dust sources. Columbus, OH: Ohio Environmental Protection Agency; September 1980.
- Ostendorf, C.W. Application for Permit to Install Kelley Solid Waste Incinerator. Cincinnati, OH: National Lead Company of Ohio. 14 March 1979
- Perkins, B.L. Incineration facilities for treatment of radioactive wastes: A review. Rep. LA-6252. Los Alamos, NM: Los Alamos Scientific Laboratory; July 1976.
- Poff, T. A.; Pepper, C. E.; Gessiness, B. Elemental constituents in the FMPC pits and silos. Internal memorandum to W. J. Adams. Cincinnati, OH: National Lead of Ohio; 21 February 1985.
- Rathgens, L. Internal memorandum to M. Boback. Cincinnati, OH: National Lead Company of Ohio; 19 April 1974.
|  | Page | K-104 |
|--|------|-------|
|--|------|-------|

 $\chi^{1}$ 

11. j

, , ż

1.11

CANCY.

- Reafsnyder, J. A. Report on the venting of radon gas at Fernald, Ohio. Letter to various, with attached report. Oak Ridge, Tennessee: U.S. Department of Energy, Oak Ridge Operations; 29 May 1986. ់ 🗠 ភ្លូន នាយក្រភាំ ព្រះភ្ល
- Riestenberg, E.B. Application for a Permit to Operate an Air Contaminant Source -Appendix C. Incinerator Data. Cincinnati, OH: Feed Materials Production Center. 28 July 1978.
- Ross, K. N. Incinerator. Internal memo to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 3 January 1958.
- Ross, K. N. Drum fire Plant 6. Internal memorandum to distribution. Cincinnati, OH: National Lead Company of Ohio; 13 April 1965.
- Ross, K.N. Stack loss from graphite burner. Internal memo to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 12 April 1966.
- Ross, K. N. Particulate emission from burning paraffin in the oil burner enclosure. Internal memo to M.W. Boback; 17 May 1976.
- Ross, K. N. Particulate emissions from the incinerator stack. Internal memorandum to M. W. Boback. Cincinnati, OH: National Lead Company of Ohio; 20 May 1977.
- Semones, T.R.; Sverdrup, E.F. Uranium emissions from gulping of uranium trioxide. Report no. FMPC/SUB-019, Cincinnati, OH: Westinghouse Materials Company of Ohio; December 1988.
  - Shleien, B.; Rope, S.K.; Case, M.J.; Killough, G.G.; Meyer, K.R.; Moore, R.E.; Schmidt, D.W.; 7 Till, J.E.; Voillequé. The Fernald Dosimetry Reconstruction Project. Task 5. Review of historic data and assessments for the FMPC. Rep. CDC-4. Neeses, SC: Radiological Assessments Corporation; May 1993.
  - Smith, W.J.; Whicker, F.W.; Meyer, H.R. Review and characterization of saltation, 🔅 suspension, and resuspension models. Nuclear Safety 23(6), November-December 1982.
  - Solow, A.J.; Phoenix, D.R. Characterization investigation study. Volume 2: Chemical and radiological analysis of waste pits. Report no. FMPC/SUB-008, Vol. 2. West Chester, PA: Roy F. Weston, Inc.; November 1987.
- Starkey, R.H. Burning of contaminated oil. Internal memorandum to J.W. McKelvey. Cincinnati, OH: National Lead Company of Ohio; 8 April 1959.
  - Starkey, R. H.; Davis, J. O.; McCreery, P. N., Hill, W. C.; Turmelle, O. J. Report of investigation, uranium loss in the FMPC Pilot Plant between November 8 and November 25, 1960. Cincinnati, OH: National Lead Company of Ohio; 22 December 1960.
  - Starkey, R. H. Investigation of remelt furnace explosion Plant 9 2/21/62. Internal memorandum to J. A. Quigley, M. D. Cincinnati, OH: National Lead Company of Ohio; 21 February 1962.
  - · Starkey, R. H. Information pertaining to unmeasured uranium losses. Internal memorandum to L. M. Levy, Cincinnati, OH: National Lead Company of Ohio; 16 July 1964 (1964a).
    - Starkey, R.H. Disposal of contaminated TBP kerosene and oil sludge at the incinerator. Memo to E.B. Riestenberg. Cincinnati, OH: National Lead Company of Ohio; 30 April 1964 (1964b).
  - Starkey, R. H. Uranium at the burn pit. Internal memorandum to P. G. DeFazio et al. Cincinnati, OH: National Lead Company of Ohio; 12 March 1965 (1965a).

Appendix K

......

1.2

9

#### Other Sources and Episodic Releases to the Atmosphere

....

3

- Starkey, R.H. Burning uranium contaminated graphite. Internal memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 18 November 1965 (1965b).
- Stefanec, A. J. Fume contamination from fire in Plant 8. Internal memorandum to H. M. Beers. Cincinnati, OH: National Lead Company of Ohio; 30 June 1955.
- Stevenson, J.B. Evaluation of uranium content of various plant wastes. Cincinnati, OH: National Lead Company of Ohio; 24 April 1968.
- Stevenson, J.B. Information on current status of incineration of radioactive wastes at the
  FMPC. Letter to Mrs. R. Perkins. Cincinnati, OH: National Lead Company of Ohio; 7
  February 1975.
- Strattman, W. J. Metal oxide spillage Silo Area. Intermal memorandum to A. Stewart, Jr. Cincinnati, OH: National Lead Company of Ohio; 30 January 1956.

Turner, P. L. Metal oxide spill in the combined raffinate area. Internal memorandum to R. C. Heatherton. Cincinnati, OH: National Lead Company of Ohio; 6 April 1954.

- Vaaler, S. C.; Nuhfer, K. R. Airborne emission from historical non-routine events. Internal memorandum to B. L. Speicher. Cincinnati, OH: Westinghouse Materials Company of Ohio; 9 March 1989.
- Vath, J. E. Fire in Pilot Plant pangborn rotoblast derby cleaning equipment, June 4, 1963. Internal memorandum to B. Gessiness. Cincinnati, OH: National Lead Company of Ohio; 5 June 1963.
- Vath, J.E. Review of NMC data on the recovery of burn pit and incinerator residues. Memo to J.B. Stevenson. Cincinnati, OH: National Lead Company of Ohio; 15 August 1967.
- Voillequé, P.G.; Meyer; K.R.; Schmidt, D.W.; Killough, G. G.; Moore, R.E.; Ichimura, V.I.; Rope, S.K.; Shleien, B.; Till, J.E. The Fernald Dosimetry Reconstruction Project. Tasks 2 and 3. Radionuclide source terms and uncertainties — 1960–1962. Draft interim report for comment. Neeses, SC: Radiological Assessments Corporation; December 1991.
- Walden, C. M. Spillage of UO<sub>3</sub> on storage pad. Internal memorandum to M. M. Cawdrey. Cincinnati, OH: National Lead Company of Ohio; 8 July 1954.
- Weinstein, M.S.; Breslin, A.J. Environmental contamination from burning uranium metal. Health and Safey Laboratory. New York Operations Office, U.S. Atomic Energy Commission. Unpublished draft manuscript. NLO database document number 2214439; Circa 1959.
- Wing, J.F. Radioactive emissions from FMPC incinerators. Letter to D.W. Lu, SW Ohio Air Pollution Control Agency. Oak Ridge, TN: Department of Energy. 5 September 1980.
- Wing, J.F. Hazardous waste information requested concerning the new liquid waste incinerator, Feed Materials Production Plant, Fernald, Ohio. Letter to K. Humphrey, Ohio EPA. Oak Ridge, TN: Department of Energy. 30 August 1982.
- WMCO (Westinghouse Materials Company of Ohio). Minor event report fire at east break out. Cincinnati, OH: 30 December 1986.
- WMCO (Westinghouse Materials Company of Ohio). Feed Materials Production Center environmental monitoring annual report for 1986. Cincinnati, Ohio: WMCO; Rep. FMPC-2076; 1987a.
- WMCO (Westinghouse Materials Company of Ohio). Incident report spill of depleted UF<sub>4</sub>-Mg mixture outside enclosure. Cincinnati, OH; 19 January 1987b.

Page K-106

Rink

 $\sum_{i=1}^{n}$ 

- WMCO (Westinghouse Materials Company of Ohio). Minor event report green salt spill. Cincinnati, OH; 23 January 1987c.
- WMCO (Westinghouse Materials Company of Ohio). Unusual occurrence report derby and magnesium fire at east breakout. Cincinnati, OH: 27 February 1987d.
- WMCO (Westinghouse Materials Company of Ohio). Unusual occurrence report spill of UF4-mg blend at no. 1 "F" machine. Cincinnati, OH: 13 March 1987e.
- WMCO (Westinghouse Materials Company of Ohio). Unusual occurrence report UF<sub>4</sub>-Mg spill at no. 5 "F" machine. Cincinnati, OH: 16 March 1987f.
- WMCO (Westinghouse Materials Company of Ohio). FMPC Environmental Monitoring Report for 1987; 1988a.

WMCO (Westinghouse Materials Company of Ohio). Unusual occurrence report - dust release from G-2-239 Hoffman high vacuum. Cincinnati, OH: 26 February 1988b.

- WMCO (Westinghouse Materials Company of Ohio). Unusual occurrence report depleted UF<sub>4</sub> spill. Cincinnati, OH: 14 March 1988c.
- WMCO (Westinghouse Materials Company of Ohio). FMPC Environmental Monitoring Report for 1988; 1989.
- Woodruff, N.P.; Siddoway, F.H. A wind erosion equation. Soil Science Society of America, Proceedings (34). 1972.

Appendix K Other Sources and Episodic Releases to the Atmosphere

. . .

÷.,

÷

#### ANNEX 1 TO APPENDIX K

## CHRONOLOGICAL HISTORY OF EVENTS AND NOTES RELATED TO RECONSTRUCTION OF SOURCE TERMS FROM THE OLD SOLID WASTE INCINERATOR (OSWI)

Note: The information in this annex was compiled from Industrial Hygiene and Radiation (IH&R) Department Monthly Reports (or reports from Sections within the IH&R Department), unless noted otherwise. Comments by RAC researchers are italicized, to distinguish them from the notes and observations from the FMPC contractor documents.

| Date               | Event/Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Nov 16, 1954       | Official start-up date of OSWI given in Boback et al. 1987.                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| December<br>1954   | Three air dust samples taken at incinerator. One Analytical Data Sheet (ADS)<br>located.                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Dec 21-28,<br>1954 | Air velocity measurements made on stack of incinerator.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Jan 3-10,<br>1955  | Velocity and temperature measurements were taken in incinerator stack.                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| April 1955         | Sampler installed in incinerator.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| May 2-6, 1955      | A day was spent at the incinerator working with the stack sampler there.<br>Temperature measurements were taken along with the sample. The sampling<br>probe had deteriorated due to the heat in the chimney, but we were able to get a<br>sample of an afternoon's burning. ADS located but no volume of air sampled is<br>given. 26.3 mg U collected for afternoon (approximately 3-4 h) would be an<br>emission rate of only 7-9 mg U $h^{-1}$ . Sampling apparatus has been brought in to<br>wait for the fabrication of a new probe. |
| May 9, 1955        | Stack sampling log book started. Samples collected in the incinerator stack.                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| June 14, 1955      | New probe being fabricated for incinerator stack.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| June 1955 .        | New sampling probe for incinerator stack finished.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| July 26, 1955      | Preparing to get together a sampler impinger in series with a large diameter tube<br>with the first sampler to collect incinerator stack samples                                                                                                                                                                                                                                                                                                                                                                                          |
| July 1955          | Revisions were made in original sampler and procedure for use in incinerator stack. New sampler and procedure have not been tried.                                                                                                                                                                                                                                                                                                                                                                                                        |
| Nov 1955           | General air samples taken from downwind of incinerator stack while burning<br>normal loads, so that a background could be obtained. While a load of material<br>from Plant 9 was being burned, fifteen minute samples were taken at 1 and 3<br>stack lengths downwind. The results were 3 dpm per $m^3$ and 2 dpm per $m^3$ ,<br>respectively. On a load of refuse from the Cafeteria, fifteen minute air samples<br>were taken at 3 and 5 stack lengths downwind. The results were 0.78 and 3 dpm<br>per $m^3$ , respectively.           |

| Page K-108         | The Fernald Dosimetry Reconstruction Project                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                    | attice of Tasks 2 and 3; Source Terms and Uncertainties                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Nov 14-20,<br>1955 | An effort was made to estimate flow rate in the incinerator by measuring the flow<br>into the feed door, but the temperature was too high to allow use of velometer or<br>anemometer. We were also unable to get a temperature reading at the top of the<br>stack. L. Williams was asked to have an opening made in the stack. It was<br>decided to get general air samples downwind from the incinerator to establish a<br>background before burning of SF material is undertaken. Considerable time was<br>spent in trying to locate a portable generator. By the time the generator was<br>located the weather changed so that sampling could not be done. |
| Nov 21-27,<br>1955 | Air samples obtained downwind from incinerator while burning thorium contaminated materials. <i>ADS not located</i> . Results generally low. Additional samples obtained while burning normal uranium-contaminated material. <i>ADS located</i> .                                                                                                                                                                                                                                                                                                                                                                                                             |
| Nov 22,1955        | Twenty-one drums of uranium-contaminated wood and paper was burned and general air samples taken downwind from the incinerator. <i>ADS located</i> .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Dec 2,1955         | Preliminary work begun for air sampling tests in conjunction with burning of contaminated materials at the incinerator.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Dec 6, 1955        | Preliminary report submitted on the results of burning normal U contaminated<br>material in the incinerator. Recommendations were made to burn non-<br>contaminated refuse only until further tests can be made. Implies that results<br>indicated an unacceptable loss of material and lor worker exposure. However,<br>burning of contaminated wastes continued and a different conclusion was reached<br>next year.                                                                                                                                                                                                                                        |
| Feb 21, 1956       | Accountability requested permission to burn a large number of drums of contaminated material from GE (General Electric). Arrangements will be made ASAP. Stack and air dust samples will be taken during burning.                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Mar 2, 1956        | Preparations made for stack and downwind air sampling during burning of GE wastes.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Mar 6, 1956        | Two attempts at measuring velocity traverse of incinerator stack. Two different<br>Pitot tubes were used with an inclined manometer reading from 0-0.5 " water. At<br>no time was a differential registered. The possibility of using a "Hastings Air<br>Meter" will be investigated. Burning of contaminated materials from GE has not<br>yet started.                                                                                                                                                                                                                                                                                                       |
| Apr 9-15,<br>1956  | Air samples taken in vicinity of the incinerator.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| May 1956           | Burning of waste from GE was started May 8. Air dust sample ADS located.<br>Burning contaminated waste paper from GE, as well as paper, wood, and other<br>NLO non-contaminated material. The drums are burned between loads of refuse<br>coming from the FMPC operation. Air samples were taken downwind when<br>conditions permitted.                                                                                                                                                                                                                                                                                                                       |
| May 21, 1956       | Five fallout trays placed in vicinity of incinerator for background info prior to special burning test. ADS located.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| May 26, 1956       | On Saturday, May 26, a test burning of contaminated gloves took place at the incinerator. 100 drums of gloves were burned. The net weight for each drum was assumed to be 62 pounds. Report to be submitted. ADS located.                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| May 29, 1956       | A stack sampler for the incinerator was designed and constructed. On a trial run,<br>the sampler performed well. Rain occurred throughout test. Stack samples, air<br>dust samples at various stack lengths, breathing zone air dust on the platform,<br>and gummed paper were taken. A report will be prepared.                                                                                                                                                                                                                                                                                                                                              |

<u>,</u>,

K. Martin

1

North Cold

1.4. P . 1.1

9 .

.

.... ، نر • ر ÷.,

| Page K. 100                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Appendix K                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|
| to the Atmosphere                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Other Sources                        |
| bles from GE: Accountability accepts these shipments,<br>1 has the facilities for handling scrap materials generated<br>is "obligated to accept this type of material."                                                                                                                                                                                                                                                                                                                                                                | June 5, 1956                         |
| burning contaminated gloves, run Thursday evening June<br><i>samples.</i> The wind from W and samples could not be<br>stance of more than about 30 stack lengths.                                                                                                                                                                                                                                                                                                                                                                      | June 7,1956                          |
| ; of contaminated gloves returned; report being written.<br>be burned on Saturday June 30. ADS located – ash 0.6%                                                                                                                                                                                                                                                                                                                                                                                                                      | June 26, 1956                        |
| complete. 18.1% U on analysis of ashes from 96 drums of<br>GE paper burned Saturday, June 23.                                                                                                                                                                                                                                                                                                                                                                                                                                          | July 2, 1956                         |
| nated burnable items — several tests have been run,<br>loves, shoes, and paper. Results indicate this can be done<br>contamination of the air or ground surfaces in the vicinity.                                                                                                                                                                                                                                                                                                                                                      | July 3, 1956                         |
| ed shoes were checked on the storage pad and okayed to                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | August 1956                          |
| g of contaminated material at the incinerator. Report of naterials at the incinerator is being revised.                                                                                                                                                                                                                                                                                                                                                                                                                                | Sept. 6, 1956                        |
| r gloves, mop heads and rags resulted in ash which was<br>ous 1956a)                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Sept. 15, 1956                       |
| ving permission to burn sewage sludge.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Sept. 18,1956                        |
| gloves and rags resulted in ash which was 36% uranium                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Sept. 22, 1956                       |
| ontaminated materials at the incinerator is not complete.                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | March 4, 1957                        |
| : preliminary work was completed using a Bausch &<br>termine roughly where to expect the fallout. This survey<br>erial was falling out within 1-1/2 stack heights distance<br>t 50 feet. More background data is being obtained with<br>ticipated the proposed test burning of filter bags will be<br>h.                                                                                                                                                                                                                               | March 1957 <sup>-</sup>              |
| rage area is limited and we fully understand our<br>he elimination of any of this material. We are endeavoring<br>ound, and stream pollution effects which might result<br>relatively highly contaminated material such as dust<br>work gloves which cannot be cleaned. Previous tests have<br>ontaminated burnables can be burnt at the incinerator<br>bly to the air contamination level in the vicinity of the<br>wind locations. Before proceeding with the burning of<br>highly contaminated material, we would like to test burn | April 30, 1957<br>(McKelvey<br>1957) |
| Ims of contaminated clothing and 15 drums of dust<br>burned in incinerator. This produced about four drums of<br>ADS shows only 4.2 % U for 100 drums burned and ash<br>st and fallout samples higher than normal. Preliminary                                                                                                                                                                                                                                                                                                         | May 4, 1957                          |

report complete and will be distributed.

.

Radiological Assessments Corporation "Setting the standard in environmental health" r

#### Page K-110

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

۰.

5.4

Ŧ.

1.53.24

à

i,

2 N. A. A.

N E

į

May 1960 (Construction Proposal

CP-60-40)

A new incinerator SW of Plant 8 was proposed (CP-60-40). Justification includes a need for disposing of soil residues, such as oily or organic sludges. The amount of contaminated trash that is being burned at the present incinerator is increasing, in spite of supervisory efforts to prevent SS materials from being thrown into the non-contaminated trash containers. Assays of the existing incinerator ash as high as 12.6% U and the 0.6% U assay for flue dust obtained from the ledge at the stack are indications of the amount being burned. The airborne U losses are both an accountability and health and safety problem. Estimate of plant trash generation rate is 35,000 pounds per day, which includes three open truck-loads of shipping dunnage per day and approximately twenty fork-lift skids per week. A preliminary estimate of cost for proposed incinerator is \$324,000. This proposal was not approved.

November 1961

January 1962

them to evaporate and burn in the trash incinerator. This does not seem to be an acceptable solution to the problem since this results in significant air contamination levels. Tests on burning waste extraction solvent are also planned for the near future.

Tests are now being made for disposing of problem oils and emulsions by allowing

Sludge [left after boiler or solvent reclaiming] contains combustible oils and greases as well as some chlorinated hydrocarbons. Tests are being run to see if it's feasible to dispose of this solvent by evaporating off the more volatile solvents in the back of the trash incinerator. After these solvents are evaporated, the oils left will ignite and burn to a residue which may be suitable for Plant 8 feed. No health problem has been observed, as yet, in performing these tests. However, they will continue to be followed closely for the possible discharge of uranium or phosgene from the incinerator stack.

The tests to evaporate and burn sludges containing chlorinated hydrocarbons have been continuing at the trash incinerator. It was found that if these organics are placed too near the fire and that if the flames could reach the sludge containers, then phosgene is generated. In one instance 20 ppm of phosgene was measured in the flue gas. In another instance 50 ppm of phosgene was measured in the flue gas. The present tests are being carried out with the waste organic containers back far enough from the fire so that it is unlikely that the flames can reach these containers. No phosgene has been detected under these conditions.

Samples have been taken from the plume discharging from the trash incinerator while only trash was being burned and while residues were being evaporated and burned. No unusually high uranium concentrations have been found on background samples when no residue was in the incinerator. The remaining samples have not been analyzed yet.

Results from sampling the trash incinerator while burning contaminated materials and processing residues indicate average activity (10 samples) was about 300 dpm alpha per cubic meter. This is about twice the level found in background samples when known contaminated materials or residues were not placed in the incinerator. The high sample of the ten was 1100 dpm alpha per cubic meter. ADS located. Test run 5/25/62.

Ten air dust samples were taken in the smoke plume emanating from the trash incinerator stack outlet which contaminated slug boxes were being burned and contaminated solvent residue was being burned or evaporated. Results indicated a maximum of 1100 alpha dpm per cubic meter, and a minimum of 61 alpha dpm per cubic meter (average 295). It was felt that the samples collected were quite representative. Four background air dust samples were collected at the same location while burning regular trash. This letter is discussing same set of data as presented in June 1962 IH&R report.

February 1962

May 1962

June 1962

July 18, 1962 (Bipes 1962)

| Other Sources                                      | and Episodic Releases to the Atmosphere                                                                                                                                                                                                                                                                                                                                                                           | Page K-111                                                                                                                                               |
|----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| September<br>1962                                  | Air samples taken in the exhaust stream from a vacuum<br>at the incinerator for simultaneously vacuuming and dr<br>The air dust level directly in the exhaust stream was 0.<br>material being vacuumed showed the U content to be 6.                                                                                                                                                                              | n cleaner being evaluated<br>umming incinerator ash.<br>4 MAC. An analysis of the<br>4%.                                                                 |
| March 1964                                         | The methods used to dispose of both stripped and unstri<br>(TBP-kerosene) at the trash incinerator were checked. T<br>solvent offers little potential for air contamination, and<br>However, the disposal of unstripped extraction solvent h<br>until samples can be collected to show the effect of this<br>contamination. Arrangements are being made to allow s<br>withdrawn from the trash incinerator stack. | ipped extraction solvent<br>The disposal of stripped<br>this process is continuing.<br>has been discontinued<br>process on air<br>tack gas samples to be |
| April 1964                                         | Particulate samples were collected from the trash incine<br>air contamination resulting from disposing of various ur<br>organic materials at the incinerator. ADS located. It was<br>contamination from present procedures is tolerable, but<br>by significant procedure changes or an increase in the lo<br>materials burned at this facility. See also Starkey (1964)                                           | erator flue gas to check the<br>anium contaminated<br>s reported that air<br>it should not be increased<br>ad of contaminated<br>b).                     |
| May 1964                                           | A uranium fallout study conducted for one year in the vi<br>and the incinerator indicated that fallout near the dispo-<br>between 3 and 7 times higher than the fallout at the near<br>The volume reduction processes will be further studied a<br>future in regard to uranium fallout with the stack emisse<br>operations. See Klein (1963; 1964) and analyses in text of                                        | icinity of the oil burner<br>sal equipment was<br>arby permanent station.<br>and evaluated in the<br>sions from these<br>f Appendix K, this report.      |
| July/Aug 1964                                      | The first burning of formaldehyde solution at the trash is<br>stripped extraction solvent was observed. No irritating g<br>detected or measured around the incinerator or in the di<br>from the incinerator. The simultaneous burning of stripp<br>seems to be effective in preventing accumulations of exp                                                                                                       | ncinerator along with<br>gas or vapor could be<br>iffused smoke downwind<br>ped extraction solvent<br>losive vapor-air mixtures.                         |
| 1965<br>Vath 1965)                                 | Average uranium assay on incinerator ash for the period 1965 was $8.76 \pm 3.62\%$ U. Average isotopic assay for the 0.039% $^{235}$ U.                                                                                                                                                                                                                                                                           | l May through December<br>same period was 0.784 ±                                                                                                        |
| 1968                                               | Stevenson evaluated uranium content and production of                                                                                                                                                                                                                                                                                                                                                             | various plant wastes.                                                                                                                                    |
| 1969                                               | Incinerator was operated 3 days per week in 1969, per v<br>L. Pennington, 10/8/85. B. Weisman indicated the 3 day<br>1965 and no later than 1970. The incinerator had been o<br>but was reduced to a 3 day per week operation when the<br>was halted. This information was recorded in handwritt                                                                                                                  | erbal communication with<br>per week began after<br>perated more frequently<br>burning of wooden skids<br>en notes.                                      |
| February<br>1970                                   | Modifications made to incinerator which included additi<br>with after burners, burn-off pan for liquid wastes, air jet<br>construction proposal CP-69-17 (Anonymous 1969) and a<br>Appendix K, this report.                                                                                                                                                                                                       | on of secondary chamber<br>ts, new stack. See<br>liscussion in text of                                                                                   |
| February<br>1970                                   | Report "Incineration of Radioactive Wastes" written, sur<br>incineration operations at the FMPC. See Anonymous (1                                                                                                                                                                                                                                                                                                 | nmarizing history of<br>970).                                                                                                                            |
| February<br>1977 Bioassay<br>Lab Monthly<br>Papart | A chromel elumel thermocouple sensor and a Hoskins P<br>been provided for temperature measurements of the inci                                                                                                                                                                                                                                                                                                    | yrometer indicator have<br>inerator off-gas.                                                                                                             |

Radiological Assessments Corporation "Setting the standard in environmental health"

. . . .

| Page K-112                   | The Fernald Dosimetry Reco<br>Tasks 2 and 3, Source Terms                                                                                                                                                                                                                                                                                                                                                        | nstruction Project<br>and Uncertainties                                |
|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| March 1977                   | The incinerator stack was sampled on 3/21/77 and again on 3/24/7<br>results show a particulate loading of about twice the amount allow<br>difficulty has been encountered in sampling the stack because of t<br>variations in temperature and rate of flow encountered. More wor<br>sampling needs to be done to get a better sample. Bioassay depart<br>two stack samples for particulates, water, and uranium. | 7. Tentative<br>wed. Much<br>he extreme<br>k and more<br>ment analyzed |
| April 1977                   | The incinerator stack was sampled again on April 12, 1977. result<br>emission is greater than the limit, but variations in the stack velo<br>temperature prevented isokinetic sampling. It is apparent that th<br>emitting a larger amount of particulates than allowed.                                                                                                                                         | s show the<br>city and<br>e incinerator is                             |
| Мау 1977                     | Sampling of the incinerator stack was completed. Results show a discharge of more than 0.1 lb per 100 lb of trash burned. The resu test and comments were sent to the Engineering Division for justi improved, all-purpose incinerator.                                                                                                                                                                          | particulate<br>lts of this latest<br>fication of an                    |
| May 1977<br>(Ross 1977)      | Five tests were made of particulate emissions from the incinerato<br>five tests the results were greater than the Ohio EPA limit of 0.1<br>per 100 lb burned. The average loss of uranium was 0.12 pounds p<br>0.06 to 0.17).                                                                                                                                                                                    | r stack. In all<br>lb particulates<br>per hour (range                  |
| June 1978                    | Based on data obtained during incinerator stack sampling last yea<br>incinerator which meets the present state limit for particulates we<br>3-11 pounds of uranium per year. This information was given to the<br>S&EC Division during a conference phone call with the NLO Engi                                                                                                                                 | ar, an<br>ould discharge<br>ne Oak Ridge<br>neering                    |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner. Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                      | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previ-<br>requirement for an air-cleaning device on the replacement inciner.<br>Proposal to move incinerator to a new location inside the production<br>Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                               | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner.<br>Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                   | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner.<br>Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                   | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner.<br>Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                   | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner. Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                      | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner. Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                      | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner. Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                      | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner. Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                      | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner. Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                      | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner. Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                      | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previous requirement for an air-cleaning device on the replacement inciner.<br>Proposal to move incinerator to a new location inside the production Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                                   | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previ-<br>requirement for an air-cleaning device on the replacement inciner.<br>Proposal to move incinerator to a new location inside the production<br>Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                               | ously imposed<br>ator.<br>on area.                                     |
| 1978<br>December 31,<br>1979 | Division. On the basis of this data, OR decided to drop their previ-<br>requirement for an air-cleaning device on the replacement inciner.<br>Proposal to move incinerator to a new location inside the production<br>Official shut-down date of OSWI given in Boback et al. 1987.                                                                                                                               | ously imposed<br>ator.<br>on area.                                     |

.

···.

.

.

•••

4.2

5 - 5 - 5 A

61.042

14 . U

10000-4

.

Appendix K

.

Other Sources and Episodic Releases to the Atmosphere

Page K-113

## ANNEX 2 TO APPENDIX K

## CHRONOLOGICAL HISTORY OF EVENTS AND NOTES RELATED TO RECONSTRUCTION OF SOURCE TERMS FROM BURNING OF CONTAMINATED OIL

Note: The information in this annex was compiled from Industrial Hygiene and Radiation (IH&R) Department Monthly Reports (or reports from Sections within the IH&R Department), unless noted otherwise. Comments by RAC researchers are italicized, to distinguish them from the notes and observations from the FMPC contractor documents.

| Date                        | Event/Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| January<br>1959<br>February | Industrial hygiene aspects of burning contaminated oil were investigated during<br>January. The results of air dust samples taken in the plume of the burning<br>contaminated oil varied widely however, when it was possible to get enough<br>samples thought to be adequate, they ran far higher than would be desirable for<br>such an operation. The Engineering Division is presently investigating further<br>combustion techniques on non-contaminated oil and after they have found a<br>suitable method for burning with a minimum of smoke, further air dust samples<br>will be taken by this department and recommendations made at that time.<br>Analytical Data Sheets located. The location of the tests is given as in the open<br>field SE and in the rear of the boiler plant. Dates measurements were made are:<br>Dec 30, 1958, Jan 6, Jan 13, and Jan 15, 1959. Tests appeared to be short-term<br>(i.e. an hour or less). Air samples analyzed for gross alpha activity only. Samples<br>were taken in air at various distances and ranged from not detectable (<0.3) to<br>1375 dpm alpha per cubic meter. The maximum concentration was measured on<br>Jan. 6, 20 feet from burning oil and about 15 feet off ground, in the body of smoke. |
| February<br>1959            | This department is working with the Engineering Division in attempting to find a satisfactory method for burning uranium contaminated oil. A method has been devised by the Engineering Division which permits the oil to be burned with virtually no smoke being evolved. Air dust samples taken under these conditions indicated that there is a good possibility that this oil might be disposed of in this manner without unduly exposing personnel. Another type of burner is to be tried early in March, after which a complete report will be made of the entire study. Analytical data sheets located for samples taken during burning on Feb 6, Feb 12, Feb 17, Feb 25, and Feb 26. Uranium and gross alpha activity measurements made on oil and in air during burning. On Feb 17, the oil incinerator is described as "constructed of a 30-gallon drum at the base of a stack made up of three 55-gallon bottomless drums which were placed one atop the other." The maximum concentration measured was 2 ft above this stack, at 8500 dpm alpha per cubic meter. On Feb 26, a note was made that condensate from the boiler plant cooling towers was falling in the area.                                                                              |

## Page K-114

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

**101100.00** 

ç

April 1959

May 1959

The burning of oil at the Boiler Plant is progressing in a slow, but what appears to be satisfactory manner. One new method was tried during the month of April, that of burning atomized oil. This proved to be quite unsatisfactory because of the high air dust levels that resulted. It was recommended that this method be stopped immediately, which was done. See also Starkey 1959: Air samples collected in heat waves given off during burning in steam atomizing oil burner ranged from 321 to 2913 dpm alpha per cubic meter (average 1479). Since the results were high, recommendation was made not to burn this type of oil in this fashion. Analytical data sheets located for burn on April 1. Location is given as north of the boiler plant in a home-made burner burning contaminated oil. Three samples taken 200 feet upwind ranged from 2-8 dpm alpha per cubic meter. Nine samples taken within 10 ft of the flame and smoke averaged 1700 dpm alpha per cubic meter (range 509 to 2913). Three samples taken 35 feet downwind ranged from 321 to 1379 dpm alpha per cubic meter.

This department is working with the Water Treatment Department in developing a satisfactory method for the disposal of contaminated oil. It has been determined that the present equipment, operating at a burning rate of 20 gallons per hour or less, can be operated in such a manner so as not to exceed acceptable air dust levels. However, it has been impossible to determine whether or not the equipment is operating properly after dark; therefore, the Water Treatment Department is installing flood lights in order to provide adequate lighting for a 24-hour operation. If the oil can be burned with no visible smoke, there appears to be no accompanying problem of high air dust levels. As soon as the lights have been installed, this department will run a check on the operation to determine if the operators will be able to tell with the naked eye whether a satisfactory operation is being carried out or not. This will permit much more oil to be disposed of in addition to reducing the quantity of uranium being released to the atmosphere by eliminating the high concentrations caused when the burning is begun and terminated each day.

June 1961

**August 1961** 

September 1961 A final report on the field test which was conducted to determine the advisability of disposing of contaminated oil by dumping it onto the fly ash pit was submitted to management. See DeFazio (1961). The field tests indicate that stream pollution is quite possible, if not inevitable, if large quantities of oil are disposed of in this manner at the FMPC fly ash pit. It was recommended that no further disposal of oil by this method be carried out, since the proximity of Paddy's Run and the fly ash pile makes this a very precarious method of disposal.

Oil burning tests are scheduled to start on 9/5/61 for the purpose of determining whether or not a satisfactory procedure can be developed for the burning of uranium contaminated oil in air. A full month's operation is presently planned with more burning possible as required to secure additional health and safety information.

Oil burning tests are still being carried out to determine a suitable method of disposing of the back log of contaminated oil. Numerous revisions are being made to the burning rig to improve its performance. Samples of the oil, the residue after burning, and the off-gases from burning have been analyzed and indicate that very little of the uranium in the oil comes off in the off-gas. It is planned to measure the rate of burning, weigh the residue, and analyze the off-gas by an orstat analyzer and by alpha count to evaluate the performance of the oil burning rig. These tests should be completed during October. Analytical data sheets located for burning on Sept 8, Sept 12, 18, Sept 22, Sept 26, Sept 27, and Sept 29. Appendix K

Other Sources and Episodic Releases to the Atmosphere

October 1961

The material balance study for the oil burning operation was completed during October. This special test was conducted on 18 drums of oil drawn from the Plant 8 storage tank. This blend had been centrifuged and was one of the easiest oils to burn encountered to date. Visually it appeared as though a high recovery rate was accomplished; however, we are awaiting analytical results before making any final conclusions. Analytical data sheets located for burning on Oct 11, 13, 14, 16, 17, 18, and 19. October 13th was the beginning of the special material balance test. See text of appendix K for discussion of results.

Page K-115

November 1961 A report was written summarizing the oil burning tests which have been performed as a possible means of disposing of the backlog of contaminated oil at the FMPC. These data were located in a draft version of DeFazio (1962) and confirmed by examination of analytical data sheets. See text of this appendix. The recovery of uranium which could be expected by burning the oil was estimated (approximately 90%). It was found that airborne uranium could be held to acceptable levels for continued burning of a reasonably good grade of oil. It was recommended that future burning be performed using an improved facility. Tests are now being made for disposing of problem oils and emulsions by allowing them to evaporate and burn in the trash incinerator. This does not seem to be an acceptable solution to the problem since this results in significant air contamination levels. Tests on burning waste extraction solvent are also planned for the near future.

January 1962

February

1962

3/31/62

May 1962

ر می در ا

÷.

A detailed design for a new waste contaminated oil burner has been completed. The Engineering Division will guide the construction of this unit, the Production Division will obtain the approval for its construction, and the unit will be built by the Maintenance Department. The Health and Safety Division is closely following these oil burning tests to see if a burner can be operated without too much uranium in the flue gas.

Construction of the final oil burner began around the end of February 1962 (DeFazio 1962).

March 1962 The new waste oil burning facility is almost completely constructed. The initial tests of waste oil burning in this facility will be monitored as was done with the previous facility.

Official start-up date given for oil burner by Boback et al. 1987.

Sampling has been started on the flue gas from the waste oil burner; however, it is not completed at this time. Analytical data sheets located for May 22 in smoke downwind of burner, but burner was not operating as expected. Concentrations were low (4 and 7 dpm alpha per cubic meter).

June 1962

The off-gas from the new oil burner has been sampled with various amounts of smoke being emitted from the burner. Results thus far indicate that the presence of smoke indicates uranium contamination in the off-gas as was found with the old oil burner. Light smoke indicates about 500  $\alpha$  dpm per cubic meter. More samples will be collected to show the conditions on starting up and shutting down the burner. Analytical data sheets located for sampling on June 4, June 8, and June 27. See table in text of appendix.

| Page K–116           | The Fernald Dosimetry Reconstruction Projec<br>Tasks 2 and 3, Source Terms and Uncertaintie                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| July 1962            | Samples were taken in the off-gas from the oil burner while it was being started<br>up and after stable operation had been obtained. The start-up samples ranged<br>from 65 to 800 alpha dpm per cubic meter. This was lower than had been expected<br>since some of these samples were taken in heavy smoke. After the burner had<br>reached a stable operation, the levels in the off-gas ranged from 350 to 700 alpha<br>dpm per cubic meter. These samples were higher than expected since there was<br>no visible smoke from the burner for this set of samples. The results from this<br>sampling contradict our previous conclusion that contamination levels can be<br>estimated from the amount of smoke being discharged from the burner. The levels<br>found are higher than desired from the industrial hygiene and contamination<br>control standpoints, therefore further investigation of the procedure will be<br>carried out. Analytical data sheets located. See table in text of appendix. |
| September<br>1962    | A report that the operator of the waste oil burner might be exposed to organic vapors as well as fumes and dust was investigated. A respirator equipped with organic vapor cartridges has been issued.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Мау 1963             | The operation of the waste oil burner was checked several times in May. There<br>was little evidence of smoke or entrained ash in the stack gas, and the burning<br>seemed to be under good control. As a result, no additional stack gas samples<br>were taken. This operation is being considered as a subject for a paper. Additional<br>work will be performed as required to obtain sufficient data for this paper.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| June 1963            | Oil feed to the waste oil burner was sampled and analyzed for uranium to evaluate the performance of the burner.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| July/Aug<br>1963     | Additional monitoring has been done of the off-gas from the waste oil burner.<br>Results confirm previous conclusions that uranium discharge is not excessive<br>under good operating conditions. Analytical data sheets located. See table in main<br>text of appendix K, this report.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| September<br>1963    | A paper titled "Burning Waste Contaminated Oil" was prepared for presentation<br>at the Eighth AEC Air Cleaning Seminar to be held at ORNL on October 22-25,<br>1963. See Brandner et al. (1963).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| May 1964             | A uranium fallout study conducted for one year in the vicinity of the oil burner<br>and the incinerator indicated that fallout near the disposal equipment was<br>between 3 and 7 times higher than the fallout at the nearby permanent station.<br>The volume reduction processes will be further studied and evaluated in the<br>future in regard to uranium fallout with the stack emissions from these<br>operations. See Klein (1963; 1964) and analyses in text of Appendix K, this report.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| August 1964          | Plans underway to burn blends of oils contaminated with normal uranium, enriched uranium, and thorium at the oil burner.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 1969                 | During calendar year 1969, approximately 650 drums of waste were processed at the oil burner (Anonymous 1970).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 1972 .               | Proposal to dispose of contaminated oil by applying to the coal pile and burning in<br>the boiler was criticized by DeFazio (1972). Contaminated oil (two samples)<br>contained 1500 and 490 ppm uranium and was certain to contaminate boiler plant<br>equipment. Recommendation was to burn this oil in existing oil burner.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| February 14,<br>1974 | Air sample taken on coal pile SW of oil burner showed 929 µg m <sup>-3</sup> particulates, 56 µg m <sup>-3</sup> oil and 23 µg m <sup>-3</sup> uranium. Source: analytical data sheet.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 1975                 | Processing rate estimated at 7500 gal per year waste lubricating oils, spent coolants, etc, and 1,200 gal per year spent TBP-kerosene solvents . <i>See Stevenson</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

CAN'S

hare C.

PAL-NAV

12 1.21-1

.

752.14

•

•

الله المراجعة . المراجعة المراجعة .

# Appendix K

1976

## Other Sources and Episodic Releases to the Atmosphere

Radiological Assessments Corporation "Setting the standard in environmental health" 1

------., 1

On 5/13/76 a sample of the emission from the oil burner and measurements of its emission rate were obtained. A sample of the particulate emission was collected on a pleated filter for six hours. The emission velocity was measured with a rotating van anemometer. The area of the smoke column and temperatures in the stack and rotometer were estimated since they continually fluctuated. The results of this test are at best an approximation but the results are great enough (1.8 lb/hour) so that if they are high by 50% they are still above the OEPA Standard of 0.2 lb/100 lb. See Ross (1976). Analytical data sheet located; sample was also analyzed for uranium. Concentration of uranium in off-gas was 45.4  $\mu$  g m<sup>-3</sup>.

Official shut-down date for oil burner given in Boback et al. 1987.

June 15, 1979

i:fit

. اختدا

Page K-118

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

.

Č,

Ties - In-

Ţ.

ちょういい

ALLANS .

PACKAT I

÷

# HERE AND IN

# 

n an ann an Arland ann an Arland ann an Arland ann an Arland an Arland ann an Arland an Arland ann an Arland a An Arland a

|         | •   | -     | *          |       |         |          |           |
|---------|-----|-------|------------|-------|---------|----------|-----------|
| TITTE I | n A | CD    | 13.7753733 | TTONT | AT T 37 | ¥ 131373 | THT ANTTE |
| THIS    | РА  | 1.455 |            |       | ALLY    | 1.P.P.1  | RLANK     |
|         |     |       |            |       |         |          |           |
|         |     |       |            |       |         |          |           |

|               |         | · · · · ·  | ••• • • •   | •   | · · · · · · · · · · · · · · · · · · · |         |
|---------------|---------|------------|-------------|-----|---------------------------------------|---------|
| · · · · · · · | • •     |            | · · · · ·   |     | -                                     |         |
|               | · · · · |            |             |     | •                                     | **      |
| ţ.            |         | 1          |             | د.  |                                       | :       |
| •             | • • •   | ·          | E.V.        |     |                                       |         |
| ,             | · · ·   | `          |             | f   | :                                     | -       |
|               | ,. •    | •          | 1.632 . 1   |     | · · · ·                               | a.      |
|               |         |            | [# <u>]</u> | :   |                                       |         |
| • • •         | • .     |            |             |     |                                       | · · ·   |
| · ;•          | •.      | ·          |             |     |                                       | · ·     |
| · · •         |         |            |             |     | -                                     | ,       |
| •             |         | · · · ·    | 1 j.        |     |                                       |         |
|               | ÷       | • •        |             | •   |                                       |         |
| ·· · ·        |         | •          |             | •   | •••                                   | · · · · |
|               |         | · ·        | · ·         | • : | :                                     |         |
|               |         | •          | ا بۇن ت     | · . | •                                     |         |
|               |         | <u></u>    | f : 1       |     |                                       |         |
| 5             | • • •   | <u>a</u> t |             |     | <b>a</b>                              |         |
|               |         |            | 0.85        |     |                                       | • •     |

entre de la servicie d la servicie de la serv la servicie de la serv la servicie de la servicie destructions de la servicie de la servicie de la servicie de la servicie de la servi

Appendix K Other Sources and Episodic Releases to the Atmosphere

Page K-119

#### ANNEX 3 TO APPENDIX K

#### DETAILED INFORMATION FOR RECONSTRUCTION OF URANIUM RELEASES FROM FMPC BUILDING EXHAUSTS

An estimated source term for uranium in building exhausts was projected forward in time from airborne activity measurements made in 1954, 1955, and 1956. The projection to future years (through 1970) was made by scaling the estimated release to certain key production processes which were associated with high airborne contamination levels. See the main text of appendix K for further explanation of the rationale and method. Table K3– 1 includes the production data which were used to make this forward projection. Appendix C contains a comprehensive set of production data tables.

# Table K3-1. Uranium Production Data (in metric tons) Used For Projected SourceTerm for Uranium in Building Exhaust between 1957 and 1970

|                   | •     | Plant             |                |                |            |              |  |  |
|-------------------|-------|-------------------|----------------|----------------|------------|--------------|--|--|
| Year              | 2/3   | 4                 | 5 <sup>a</sup> | 6 <sup>b</sup> | . 8        | 90           |  |  |
| 1956              | 5329  | 5029              | 20596          | 12470          | 1764       | 0            |  |  |
| 1957              | 8370  | 9358              | 18793          | 15074          | 1927       | 0            |  |  |
| 1958              | 10039 | 12117             | 19476          | 13665          | 2018       | 732          |  |  |
| 1959              | 11540 | 9454              | 21124          | 14033          | 2568       | 1251         |  |  |
| 1960              | 12187 | 11388             | 27294          | 18532          | 3188       | 1388         |  |  |
| 1961              | 11039 | 10642             | 21161          | 15370          | 2902       | 2364         |  |  |
| 1962              | 6288  | 9468              | 21428          | 15430          | 2820       | 2663         |  |  |
| 1963              | 0     | 10482             | 24528          | 14507          | 2657       | 3660         |  |  |
| 1964              | 0     | 7203              | 19303          | 11313          | 3505       | 529 <b>7</b> |  |  |
| 1965              | 543   | 6797              | 16666          | 12310          | 2134       | 5361         |  |  |
| 1966              | 1347  | 6174              | 16405          | 7683           | 1617       | 1197         |  |  |
| 1967              | 1835  | 6263 <sup>•</sup> | 18141          | 7576           | 1837       | 1258         |  |  |
| 1968              | 3251  | 4809              | 15483          | 5029           | 2222       | 691          |  |  |
| ·1969             | 2028  | 2821              | 10655          | 3380           | . 1036     | 778          |  |  |
| 1970              | 880   | 1923              | 8310           | 3309           | <b>649</b> | 499          |  |  |
| 1971 <sup>d</sup> | 809   | 580               | 3719           | 1068           | 307        | 422          |  |  |
| 1972 <sup>d</sup> | 2761  | 347               | 2900           | 0              | 111        | 599          |  |  |

<sup>a</sup>Sum of derby and ingot production. See Appendix C.

<sup>h</sup>Rolling operations only.

<sup>c</sup>Ingot production only.

Ĉ.

.

<sup>d</sup>A projection was made through 1972 in order to permit comparison with the backwards projection from 1987 measurements (see text of appendix K). However, for the reconstructed source terms, the forward projection was used through 1970. Page K-120

:::

.

.

Charles - 2

action are

ş

| Percentile of Distribution |       |                                         |              |     |      |  |
|----------------------------|-------|-----------------------------------------|--------------|-----|------|--|
| Year                       | 5%    | 25%                                     | 50%          | 75% | 95%  |  |
| 1954                       | 35    | 68                                      | 155          | 395 | 728  |  |
| 1955                       | 37    | 73                                      | 218          | 416 | 763  |  |
| 1956                       | 37    | 76                                      | 192          | 394 | 650  |  |
| 1957                       | 48    | 100                                     | 241          | 468 | 801  |  |
| 1958                       | 63    | 126                                     | 277          | 511 | 860  |  |
| 1959                       | 69 .  | 129                                     | 306          | 603 | 1007 |  |
| 1960                       | 81    | 153                                     | 366          | 735 | 1239 |  |
| 1961                       | 82    | 152                                     | 347          | 681 | 1138 |  |
| 1962                       | 74    | , 139                                   | 303          | 643 | 1072 |  |
| 1963                       | 64    | 129                                     | 277          | 607 | 1017 |  |
| 1964                       | 63    | 129                                     | 284          | 719 | 1222 |  |
| 1965                       | 62    | 127                                     | 261          | 520 | 871  |  |
| 1966                       | 36    | 69                                      | 150          | 350 | 590  |  |
| 1967                       | 39    | 74 -                                    | -158         | 386 | 652  |  |
| 968                        | 32    | 60                                      | 134          | 421 | 721  |  |
| 969                        | 22    | 41 -                                    | - 89         | 216 | 364  |  |
| 970                        | 15    | 28                                      | 60           | 141 | 238  |  |
| 971                        | 2     | . 5                                     | . 11         | 24  | 41   |  |
| 972                        | 3     | 5                                       | 12           | 27  | 46   |  |
| 973                        | 4     | 8                                       | 18           | 40  | 67   |  |
| 1974                       | 5     | 10                                      | 22           | 49  | 84   |  |
| 975                        | 6     | 11                                      | 25           | 55  | 94   |  |
| 976                        | 6     | 12                                      | 27           | 60  | 102  |  |
| 977                        | . 3   | 6                                       | 13           | 29  | 49   |  |
| 1978                       | 2     | 4                                       | 9            | 20  | - 34 |  |
| 1979                       | 1     | 3.                                      | 7            | 15  | 25   |  |
| 1980                       | 2     | 4                                       | 9            | 20  | 34   |  |
| 1981                       | 2     | 4                                       | 10           | 23  | 39   |  |
| 1982 -                     | 4     | 7                                       | 17           | 37  | 62   |  |
| 1983                       | · 4 😒 | 9                                       | <b>19</b> 71 | 43  | 74   |  |
|                            | 5     | 10 1.2                                  | 23           | 52  | 89   |  |
| 1985                       | 4     | 8                                       | 19           | 42  | 71   |  |
| 1986                       | 5     | · · · · • • • • • • • • • • • • • • • • | 21           | 46  | 79   |  |
| 1987                       | 3     | 6                                       | 15           | 33  | 56   |  |

;. .

सरे कर्ष अस्ति

.

<u>K-17.</u>

| Appendix K                                            | Page K-121 |
|-------------------------------------------------------|------------|
| Other Sources and Episodic Releases to the Atmosphere | •          |

Figure K3-1 illustrates the typical distribution shape for the annual source term estimate from building exhausts. Monte Carlo sampling (5000 trials) was performed for each year and for the sum of 1957-1970. Uncertainties in the following parameters were propagated:

- Plant-specific uranium concentration in in-plant air
- Dilution factor for exhaust air vs. working area air

These input parameter distributions are provided in the tables and figures which follow Figure K3-1.



Figure K3-1. Illustration of typical distribution shape for building exhaust source term.

## Distributions for Assumptions used in Building Exhaust Uncertainty Analysis

## Dilution Factor for Exhaust vs. Working Area Air

Triangular distribution with parameters:

| Minimum   | 0.10 |
|-----------|------|
| Likeliest | 0.33 |
| Maximum   | 1.00 |

Selected range is from 0.10 to 1.00

Radiological Assessments Corporation "Setting the standard in environmental health"

\_\_\_\_

Page K-122

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

Ι.

.

なからだ

Sector Sector

i.

1



Airborne Uranium Contamination (dpm m<sup>-3</sup>) Around Rolling Operations (Used for FMPC Plant 6)

| Custom distribution with p | arameters.                            |          | Relative Prob |
|----------------------------|---------------------------------------|----------|---------------|
| Continuous range           | 0.00 to                               | 55.00    | 0.280000      |
| Continuous range           | 55.00 to                              | 110.00   | 0.250000      |
| Continuous range           | 110.00 to                             | 220.00   | 0.240000      |
| Continuous range           | 220.00 to                             | 440.00   | 0.110000      |
| Continuous range           | 440.00 to                             | 880.00   | 0.020000      |
| Continuous range           | 880.00 to                             | 1,800.00 | 0.100000      |
| Total Relative Probability |                                       |          | 1.000000      |
|                            |                                       | 18.3.71  | .* .          |
|                            | dpm/m3 - rolling-Plant 6 (1955)       | · · ·    | ere di e      |
|                            | · · · · · · · · · · · · · · · · · · · |          |               |



Airborne Uranium Contamination (dpm m<sup>-3</sup>) Around Refining Operations (Used for FMPC Plant 2/3)

| Custom distribution with parar          | neters: 3 · · · | e ç  | 216 |        | <u>Relative I</u> | rob. |
|-----------------------------------------|-----------------|------|-----|--------|-------------------|------|
| Continuous range                        | 0.00            | · to |     | 55.00  | 0.820000          |      |
| Continuous range                        | 55.00           | to   |     | 110.00 | 0.030000          |      |
| Continuous range                        | 110.00          | to   | •   | 220.00 | 0.060000          |      |
| Continuous range                        | 220.00          | to   |     | 440.00 | 0.090000          |      |
| <sup>.</sup> Total Relative Probability |                 |      |     |        | 1.000000          |      |
|                                         |                 |      |     |        |                   |      |

Appendix K. Other Sources and Episodic Releases to the Atmosphere

1

Page K-123



## Airborne Uranium Contamination (dpm m<sup>-3</sup>) Around Reduction and Recasting Operations (Used for FMPC Plants 4, 5, and 9)

| Custom distribution with param | neters: |    |        | <b>Relative Prob</b> |  |
|--------------------------------|---------|----|--------|----------------------|--|
| Continuous range               | 0.00    | to | 55.00  | 0.780000             |  |
| Continuous range               | 55.00   | to | 110.00 | 0.190000             |  |
| Continuous range               | 110.00  | to | 220.00 | 0.010000             |  |
| Continuous range               | 220.00  | to | 440.00 | 0.010000             |  |
| Continuous range               | 440.00  | to | 880.00 | 0.010000             |  |
| Total Relative Probability     | •       |    |        | 1.000000             |  |



Page K-124

. .

. . . . . . the state of

> and a strength

. . . . 1. 1. 177 LA

11 A. L. 1943

.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

. 1

Airborne Uranium Contamination (dpm m<sup>-3</sup>) Around Scrap Recovery Operations (Used for FMPC Plant 8)

| · · · · · | <sup>:</sup> : | 2127年 |  |
|-----------|----------------|-------|--|
|-----------|----------------|-------|--|

| Custom distribution with para | ameters:                  |    |   |          | <u>Relative</u> | Prob. |
|-------------------------------|---------------------------|----|---|----------|-----------------|-------|
| Continuous range              | 0.00                      | to |   | 55.00    | 0.350000        |       |
| Continuous range              | 55.00                     | to |   | 110.00   | 0.120000        |       |
| Continuous range              | 1,800.00                  | to |   | 3,000.00 | 0.340000        | •     |
| Total Relative Probability    | - 11 <sup>2</sup> 2 41 12 | •  | : |          | 0.810000        |       |

238 1. 1997 S. HULL

#### dpm/m3, scrap recovery (plt 8), 1955

|                    | and the second sec |                           |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| (, #72.00) · · · · | and the second data provide the formation of the                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | t                         |
|                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | •                         |
|                    | n en ander statt de derekteren en er er                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | *                         |
| •                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | · · · · · ·               |
|                    | and the second                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | •                         |
| • • • • • •        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | .1 -                      |
|                    | a da en a caretarra <u>en acorece</u> nte                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 4. <b>*</b> , <b>*</b> *1 |
|                    | 0.00 750.00 1,500.00 2,250.00 3,000.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 10                        |

and the second • ;. . . . . . . , , , , . . . . .

Table K3-3. Ventilation Capacities and Fan Operating Factors used in Building Exhaust Estimates

|                                              | - DAnause Doumates             | · · · · · · · · · · · · · · · · · · ·            |
|----------------------------------------------|--------------------------------|--------------------------------------------------|
| en la <u>setta de <b>Plant</b>a de setta</u> | Ventilation Capacity (cfm      | 1 <sup>a</sup> Fan Operating Factor <sup>h</sup> |
| $\mathbf{D}_{1,n}$                           | 62,000                         | 0.08                                             |
|                                              | 262,500                        | <b>0.33</b>                                      |
| 4                                            | 316,050                        | 0.42                                             |
| 5                                            | 62,000                         | 0.33                                             |
| антан са стор болекто ба <b>б</b> а се е с   | 126,000                        | 0.36                                             |
| 8 · · · · · · · · · · · · · · · · · · ·      | 91,000                         | 0.33                                             |
| <u> </u>                                     | <b>219,150</b>                 | 0.25                                             |
| <sup>a</sup> From Hill 1989c. Maximur        | n ventilation capacity of exha | ust fans.                                        |

<sup>b</sup>From Hill 1989c. Fraction of year in which fans were assumed to operate at maximum capacity. and the second 
> with city task .

For each plant, the annual release rate was computed using the following equation: 

Annual release (kg U  $y^{-1}$ ) = Concentration in working areas (dpm U  $m^{-3}$ ) × Ventilation Capacity (ft<sup>3</sup> m<sup>-3</sup>) × Dilution factor (unitless) × Fan Operating Factor (unitless) ×  $(2.83 \times 10^{-2} \text{ m}^3 \text{ ft}^{-3}) (5.256 \text{ x} 10^5 \text{ min y}^{-1}) (1 \times 10^{-3} \text{ kg g}^{-1}) +$  $[(2.22 \times 10^{12} \text{ dpm Ci}^{-1})(6.8 \times 10^{-7} \text{ Ci U g}^{-1})].$ 

and the second state of the state of the second state of the secon and a second strategy and the second strategy have a second

· :.

## APPENDIX L

#### SURFACE WATER DISCHARGES

#### INTRODUCTION

.

1

Liquid wastes that are generated at FMPC come from three main sources: process water, sanitary sewage, and storm water. Detailed descriptions and diagrams of some of these processes are available (Pennak 1973). These waste streams from the FMPC facility include sump water from the plant production areas, waters from the waste pit area, and waters flowing into the storm sewers from surface runoff over soil contaminated with uranium from spills or deposition of airborne effluents. Liquid effluent streams from FMPC are released to the offsite environment at two locations. These include: (1) The combined sewer and process effluents discharged through the main effluent pipeline at Manhole 175 into the Great Miami River at a point almost directly east of the plant site. This point is about 3 miles (5 km) upstream from New Baltimore; (2) Paddy's Run Creek, a small stream with intermittent flow, lying along the west boundary of the site that joins the Great Miami River approximately 1.5 miles (3 km) south of the FMPC, which received discharges from the storm sewer outfall ditch, and surface runoff from a portion of the production area. The flow in Paddy's Run Creek generally exists only during the period January to May. For the balance of the year it is considered a dry stream bed with occasional flows of a few hours to a day following heavy rains (Patton 1985). Figure L-1 shows the general features of the liquid waste discharge points from the FMPC site.

Initially, source term estimates and uncertainties for surface water discharges were derived for the 1960 to 1962 period and presented in an interim draft report (Voillequé et al. 1991). Based on the sources of information and data for that time period, we developed methods for estimating uranium releases to the Great Miami River and to Paddy's Run Creek on a monthly basis. In the present report, we use similar methods of investigation to derive source term estimates for uranium and other radionuclides discharged in liquid effluents from the FMPC for all years of operations. These estimates are reported on an annual basis and the data from original analytical data sheets and other records are tabulated in an annex at the end of this appendix. The tables of daily or monthly data, presented as Tables L1-1 through L1-36 in the annex, will be referenced in the appropriate sections of this report. Much of the background information provided in the interim draft report for the early sixties is presented in this report as well.

## FACILITIES FOR HANDLING LIQUID EFFLUENTS

#### General Sump System

Each of the individual production plants at the facility had collection sumps and treatment equipment to remove the uranium and thorium from the process waste water. After sampling and analysis was performed to check that uranium content was within pre-

Page L-2

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

. .

1

į.,

• :: . .

.

1979 - 1974 1974 - 1974 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977 - 1977

-7

Ş.

set allowable discard limits (in the sixties, these were pH > 6.3 and uranium concentration < 0.01 g  $L^{-1}$  or 0.05 g  $L^{-1}$  depending upon the source of effluent) (McCreery 1965), the filtrate was pumped to the General Sump. Thorium wastes were segregated, co-precipitated with barium carbonate and aluminum sulfate to reduce <sup>228</sup>Ra activity and then pumped to the wet chemical pit (Pit 3 until 1968, Pit 5 after late 1968) (Keller 1978). From here the water passed to the chemical waste pit where settling occurred, and the liquid was decanted to the clearwell portion of the pit before discharge through Manhole 175 which carried it by pipe to the Great Miami River. . . . St .



Figure L-1. Liquid effluent flow and discharge points from the FMPC site. they deal and provide the second

.....

In the early years of facility operation, the General Sump System consisted of three 20,000 gallon receiving tanks (F18-1, F18-2, F18-3), one 5,000 gallon receiving tank (F18-4),

. . . . **(**\*

Appendix L Surface Water Discharges

and three 50,000 gallon settling tanks(F18E-1, F18E-2, F18E-3) (NLCO 1957). The settling tanks were installed in late 1956 which accounted for the reduction in contaminants released in the river (Starkey 1958a). The functions of the receiving and settling tanks are summarized below.

#### Three 20,00 Gallon Receiving Tanks:

- F18-1 received effluents from the Refinery sump area, condensate from the digestion area, sampling plant (Plant 1) effluents, and in emergencies, Neutralized Evaporated Product from Plant 2/3.
- F18-2 received Pilot Plant effluents, and when necessary, Plant 8 filtrates.
- F18-3 received waste streams from contaminated sewers of Plants 5, 6 and 9, the Decontamination pad and building, and condensate return to the Water Treatment Plant.

If the uranium concentration was above the limit of 0.01 g  $L^{-1}$  in these tanks, it was sent back to Receiver Tanks in the Refinery Sump of Plant 2/3 for further processing. If the waste was within the pH and uranium concentration limits, it was pumped to one of three 50,000 settling tanks.

#### One 5,000 gallon Receiving Tank:

: ; ; ; ;

•

÷....

5

Received high fluoride content waste liquors from Plant 4. Then the effluent was either pumped back to the neutralizer tank in the Plant 2/3 Refinery Sump, or pumped to one of the settling tanks.

#### Three 50,000 gallon Settling Tanks:

 F18E-1 and F18E-3 received waste liquid from F18-1, F18-2 and F18-3 where grab samples were taken from the top for uranium analysis. If the uranium concentration was greater than 0.02 g L<sup>-1</sup> it was designated a "rush" sample, and taken to the analytical laboratory for total soluble and insoluble uranium analysis and pH measurements (NLCO 1957).

If the estimated total uranium in the tank was greater than 100 pounds (e.g.  $0.24 \text{ g L}^{-1}$  in 50,000 gallons) it was "mandatory to notify the Plant superintendent" according to the Standard Operating procedures in effect at that time (NLCO 1957). If there were less than 100 pounds of uranium in the tank, the sump supervisor could use his judgment on the possibilities of reclaiming the uranium.

• F18E-2 received Neutralized Evaporator Product (NEP) from Plant 2/3. Samples were taken from a bottom valve. If the concentration was above the limit of 0.01 g U L<sup>-1</sup>, the effluent was sent back to the Plant 2/3 refinery sump. If below the limit, the effluent was pumped to either of the other two 50,000 gallon tanks (F18E-1 or F18E-3).

100000

ざんでおう

In 1968, major improvements were made in the General Sump area for waste effluent processing facilities involving the installation of two new 15,000 gallon sludge settling tanks with hopper bottoms and decanting pipes; a new 50,000 gallon sludge settling and decant tank with a flat bottom; and a new head tank for regulated continuous discharge to the river (OHIO 1968).

#### Individual Plant Sumps and Normal Operations

The descriptions of the individual plants which follow provide an overview of liquid effluent flow at FMPC. The liquid effluent volume and uranium releases from the various site facilities were provided in monthly loss reports (Yoder 1955, Cuthbert 1960-1961, Marshall 1963, Schwan 1967-1984). Table L-1 provides monthly data on uranium quantities in effluents to the General Sump from the process areas. Although these data are from the early sixties, the relative fraction of uranium discards remained fairly steady over the years.

**Plant 1.** Due to the infrequency of pumping of liquid effluent from Plant 1, effluent was usually pumped to the Plant 2/3 Refinery Sump Receiver Tank (Fl-608) for recovery of uranium (Cahalane 1961).

**Plant 2/3.** Three waste streams from Plant 2/3 are important: the sump effluent, the Neutralized Evaporated Product (NEP), and the slag leach slurry from the refinery. While the volume of Neutralized Evaporated Product (NEP) was measured as it was pumped to the General Sump, the Plant 2/3 sump effluent volume was calculated by subtracting the sum of all other individual plant discards into the General Sump from the total volume pumped from the General Sump to the chemical pit. The Plant 2/3 Sump Effluent accounted for roughly 70-80% of the total volume sent to the General Sump, and 25-30% of the uranium in effluents. Table L-1 shows that the NEP waste stream contributed over 60% of the uranium to the General Sump each month, but only 5% of the total volume. The slag leach slurry was pumped directly to the chemical waste pit.

**Plant 4.** Waste liquors from plant 4 which were high in fluorides but rather low in uranium, were pumped directly to the only 5000 gallon tank in the General Sump (F18-4). Routinely, Plant 4 contributed less than half a percent to either the volume or total uranium quantity each month.

**Plant 5.** Liquid waste from the remelt or casting area accounted for approximately 1–2% of the volume, and less than 1% of the uranium, sent to the General sump (Tank F18-3).

**Plant 6.** Contaminated effluents from the machining area were pumped to the General sump (Tank F18-3), contributing on the average 5% of the volume and less than 1% of the uranium to the General Sump. The Heat-Quench Water from the Metal Fabrication Area was pumped directly to the wet chemical pit.

**Plant 8.** Routinely, effluents were pumped directly to the waste pits from Plant 8, and are not listed in Table L-1. In an emergency when discard limits were exceeded, they were pumped through the General Sump (Tank F18-2) for processing and sampling (Cahalane 1961). Because this was an infrequent occurrence, Plant 8 effluents contributed less than a half percent to the volume and uranium totals of the General Sump. However, records summarized in Appendix M indicate that Plant 8 contributed approximately 1200 kg per month directly to the waste pits during 1960, 1961 and 1962.

#### Appendix L Surface Water Discharges

 $\sim 10$ 

.....

م الم

ŝ

|       | Plant 2/3 |       |       | Plt 5 | Plt 6       | Pilot | Anal. | Decon | Plt 9 |       |
|-------|-----------|-------|-------|-------|-------------|-------|-------|-------|-------|-------|
| Date  | Effluent  | NEP   | Plt 4 | Cast. | Mach        | Plant | Lab   | Area  | (Enr) | Total |
| 1960  | 6406      | 15312 | 35    | 152   | 54          | 920   |       |       | 24    |       |
| 1961  | 5511      | 17144 | 54    | 81    | 290         | 2830  | •     |       | 20    |       |
| 1962  | 3874      | 4283  | 32    | 108   | 245         | 560   |       |       | 16    |       |
| Total | 15791     | 36739 | 121   | 340   | 59 <b>0</b> | 4310  | 1105  | 85    | 60    | 59140 |
| % of  |           |       |       | ·     |             |       | • •   |       |       |       |
| Total | 27        | 62    | <0.2  | <0.5  | 1           | 7     | 2     | < 0.1 | <0.1  | 100   |

| Table L-1.  | Uranium | Discards | (kg) to | the General | Sump | From P   | rocess Areasa |
|-------------|---------|----------|---------|-------------|------|----------|---------------|
| I ADIC L-I. | oranium | Discarus | (BE) W  | the defiera | Samp | L'LOULL' | UCC33 m cas   |

<sup>a</sup> From NLCO 1960–1962.

Pilot Plant. Waste effluents from the Pilot Plant refinery, which contained enriched uranium, were pumped to General Sump (Tank F18-2) before being pumped to the pit. Several different waste solutions from at least seven or eight different areas of the Pilot Plant were discharged into the sump including the tin decladding decantation liquors, 3620 area caustic scrub solutions, Winlo filtrate, extraction area raffinate, open air reduction rotoclone scrubber solution, derby shock wastes, and runoff from outside storage pad areas (Cseplo 1961). Only the first two solutions were neutralized to a pH of 7 or higher before being pumped to the sump. Discards from the Pilot Plant were variable from month to month, contributing from as little as 2% up to 10% of the total volume, and from 2% to 9% of the uranium quantity to the General Sump.

Surface and subsurface drainage in the Pilot Plant Area, however, flowed into a manhole on the warehouse storage pad, and then, by gravity, into an open drainage ditch which discharged into Paddy's Run Creek (DeFazio 1962). Analysis of samples indicated that uranium concentrations varied from 7 to 28 ppm with some flows over 5 gallons per minute to the ditch.

**Decontamination Building and Area.** Effluents from this area were variable, but usually contributed less than 1% of the volume, and up to 3% of the total uranium quantity to the General Sump in some months.

Analytical Laboratory. Approximately 10% of the volume and 3% of the uranium discharged to the General Sump each month came from the Analytical Laboratory.

There are three process waste streams from the plants which are routed directly to the wet chemical waste pit. They were:

1. Zirnlo Slurry from Plant 9 (Special products)

2. Heat-Treat Quench Water from Plant 6 (Metal Fabrication)

3. Slag Leach Slurry from Plants 2/3 (Refinery).

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

*.*,,

19 A A

1.1.1.1.1.1.

2

#### **Chemical**.Waste Pits

Six chemical waste pits have been constructed since operations began at the FMPC. Pits are identified by number based on chronological sequence of their construction, and by type, "dry" or "wet" pits depending upon the main type of material discarded or discharged. Pits 1 (1,080,000 cubic feet) and 2 (351000 cubic feet) were dry, although some wet materials were added to Pit 2 just prior to completion of Pit 3. Completed in 1959, Pit 3 (6,115,500 cubic feet) was designated a wet chemical pit, and received effluents from the General Sump (Settling Tanks F18E-1, F18E-2, and F18E-3) until it was filled in 1968 (NLCO 1974).

Pit 4 (1,431,000 cubic feet) was built in 1960 as a dry pit. A tabulation of recorded monthly discards of dry and wet wastes to the pits for the time period 1960 to 1962, and annual totals for 1952 to 1974 is located in Appendix M. Characteristics of the waste pits and a description of the methodology used to estimate atmospheric releases from them are given in Appendix K.

In the early years, two overflow lines with valves extended from the "fluoride" pit (Pit 3) to a short tributary of Paddy's Run that lies just west of the pit. In a site review by the US Department of the Interior, Theis (1955) noted that these outlets were apparently not used customarily, and that the tributary and Paddy's Run were usually dry. He did suggest the possibility of groundwater contamination from the waste pits (See Appendix M).

#### Sanitary Sewage

The sanitary waste collection and treatment system was a completely separate system from the process waste system. The sewage was treated in a recirculating trickling filter facility, originally sized for 750,000 gallons per day (gpd) but by the late 1970s was receiving only about 125,000 gpd (Keller 1978). The sewage sludge was then incinerated onsite (Pennack 1973). Sampling and analysis were performed on the waste stream before it joined the other effluent streams at Manhole 175. Daily records of waste volume discharged, river flow and calculated concentrations of uranium, nitrates, and fluorides added to the river were maintained, and reported monthly to the Ohio Department of Health (Carr 1955, Walden 1957, Flowers 1960–1961, P&G 1985).

The Chemical Feed Sump from the Water Treatment and the Boiler Plant Area was sampled for Nuclear Materials Control (Starkey 1964a). The results routinely indicated that the stream, although high in volume (approximately 90,000 gallons per day), contributed approximately 5 pounds (2.5 kg) uranium per month to the river.

1

#### Storm Sewer System

The storm water system consists of a grid work of catch basins and about 70,000 feet of buried pipe lines which drains the surface runoff from the immediate vicinity of the processing areas of the facility, a 5,500,000 square foot area (Nelson 1971). Although it was assumed, when operations began in 1952, that the storm sewer system would handle only water, recommendations to install a storm sewer lift station were frequent when sampling of storm sewer drainage indicated uranium contamination. The initial storm sewer system included a storm water detention basin and sump to handle small quantities of contaminated liquids, but no provisions had been made to empty the sump (Quigley 1952).

## Appendix L Surface Water Discharges

.

<u>, i</u>.,

 $\sim$ 

The detention sump had not been placed in service by February 1954 (Ross et al. 1954). In late 1955, a Storm Sewer Lift Station, located about 2800 feet south and 4100 feet east of the center of the production site (Theis 1955), near the southern end of the system, was installed (OHIO 1955). It was designed to divert and pump waste water flows in the storm sewer system to the process waste discharge line (Manhole 175) to the Great Miami River. A recording flow meter and continuous proportional sampler monitored the discharges, and provided daily data for uranium and liquid effluents discharged to the Miami River from that point (Pennack 1973). Since the storm sewer lift station was not connected to any process, all the uranium lost through it was assumed to be from leaks and spills (Ross 1972). The lift station in place in the early years was designed to take only the initial runoff during a heavy rain. The pumping capacity of the system was approximately 500,000 gallons per day or 350 gallons per minute (DeFazio 1960).

Throughout the late 1950s and 1960s, daily storm sewer samples continued to reflect spills or releases of radioactive process effluents and chemical materials (Starkey 1961a). As a consequence, the majority of the uranium and radioactivity in the combined plant effluent originated from the storm sewer. When the capacity of the storm sewer lift station was reached, water overflowed through the storm sewer outfall to Paddy's Run Creek, a small intermittent stream lying along the west boundary of the site that joins the Great Miami River approximately 3 km south of the FMPC. The volume of storm water that overflowed the storm sewer lift station to Paddy's Run was related to rainfall amounts and patterns. Storm water flow lagged the actual precipitation event by several hours, usually showing an increase in flow the pext day (Patton 1985).

Memoranda and various reports suggest growing concern about the liquid effluent handling system at the FMPC from the mid-1950s onward. Table L-2 summarizes the major changes that were proposed and undertaken in response to many of the considerations about unmonitored runoff to the storm sewer and to Paddy's Run. By the late 1960s, water at the Storm Sewer Lift Station was sampled by two proportional automatic samplers: one sampled effluents going to Manhole 175, while the other was activated by an overflow of water going to the storm sewer outfall ditch to Paddy's Run Creek(Nelson 1971). Both samplers were equipped with recording flow meters.

#### DOCUMENTATION OF LIQUID WASTE DISCHARGES FROM FMPC

Appendix A outlines the sources of information and the types of documents that were found in a variety of repositories around the country for use in the completion of this project. A significant number of documents were related to the liquid effluent system onsite and uranium discharges in liquid wastes from the site because these losses were documented rather thoroughly over the years. Specific documentation is referenced throughout the report. In this section, the documentation used in compiling daily or monthly data for liquid effluent discharges for all years of operation are described briefly.

| Page L-8 | The Fernald Dosimetry Reconstruction Project  |
|----------|-----------------------------------------------|
| <u>.</u> | Tasks 2 and 3. Source Terms and Uncertainties |

| Date              | Modification to System                                                                                                                              |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Oct 1951          | First Operations at the FMPC; Storm Sewer System with detention basin and sump                                                                      |
| 2                 | installed, but detention basin sump not yet in service in 1954.                                                                                     |
|                   | Process Effluents to River-Measured                                                                                                                 |
|                   | All Runoff to Paddy's Run-Periodically Measured                                                                                                     |
| Feb 1954          | Recommendation to install a continuous sampler at the discharge point to the river                                                                  |
| :                 | (MH 175)                                                                                                                                            |
| Jul 1955          | Storm Sewer Lift Station Installed                                                                                                                  |
|                   | Process Effluents & Most Runoff-Measured                                                                                                            |
| · . · · · ·       | Some Runoff & Storm Sewer Overflow-Not Measured                                                                                                     |
| May 1962          | Recommendation to install sampler and flow meter in Paddy's                                                                                         |
|                   | Run near Willey Road at southern plant boundary (Jeffers 1962).                                                                                     |
|                   |                                                                                                                                                     |
| Nov 1965          | Recommendation to install sampler and flow meter at the storm                                                                                       |
| 1. 11             | sewer outfall ditch (Starkey 1965c)                                                                                                                 |
| • • •             | a = 0 ( $b = -3$ ) ( $b = -3$                                                                                                                       |
| Jan 1966          | Installation of pH cell and recorder in Storm Sewer Lift station; alarm sounds in<br>Water Plant when a high or low pH recorded (Riestenberg 1966). |
| - May 1966        | Renovations to outfall nine to the river so that discharge of the FMPC effluent is in                                                               |
|                   | deen nortion of the stream (Starkey 1966a)                                                                                                          |
|                   |                                                                                                                                                     |
| Aug 1968          | Storm Sewer Ditch Monitor Installed                                                                                                                 |
|                   | Process Effluents Runoff & Overflow Measured                                                                                                        |
| en                | Some Runoff to Paddy's Run Not Measured                                                                                                             |
|                   |                                                                                                                                                     |
| Fall 1968         | New tanks installed and key improvements in effluent handling at the                                                                                |
|                   | General Sump                                                                                                                                        |
|                   |                                                                                                                                                     |
| Jan 1969          | Waste Pit 5 opens, replacing Pit 3 which had been at capacity for months                                                                            |
|                   |                                                                                                                                                     |
| Apr 1973          | Renovations to outfall sewer to river (CP-73-8) caused by "wear, tear, decay.                                                                       |
|                   | and action of the elements".                                                                                                                        |
| 18 18 <b>-</b> 19 |                                                                                                                                                     |
| Aug 1986          | Storm Water Retention Basin Installed with capacity of 6 million gallons and                                                                        |
|                   | emergency chillway everflow at 365 feet                                                                                                             |

A WAR

1.000

1.

• Original analytical data sheets from the Health and Safety Division for various times from 1954 through 1974 provided uranium, radium and thorium concentrations on a daily, weekly, biweekly or monthly basis on daily or composite samples taken at the MH 175. Similar data sheets provided concentration results for uranium at the Storm Sewer Lift Station.

## Appendix L Surface Water Discharges

12

53

- "Discharge of Liquid Wastes into the River" (DLW), was a monthly report listing the daily discharge of liquid wastes from the Sanitary Sewer, Storm Sewer, Manhole 175, and Storm Sewer Outfall. Measured volumes and uranium concentrations were listed on a daily basis for these waste streams.
- "Measured Losses and Removals of SS Material From the Production Stream" (MLR) reports, changed to "Routine Operating Losses" report in 1964, provided a monthly summary of uranium discards to the General Sump and stack losses. Volumes and quantities of normal and enriched uranium discarded as liquid waste from each process area are listed for the month. In addition, the MLR reports give the losses to Paddy's Run, discards to the chemical or wet pit, and effluents pumped from the clearwell of the pit to the river. Many of these reports were located covering all years of operations.
- Descriptive reports on key topics were prepared by different departments on a regular basis. Monthly river and effluent flows, and concentrations of uranium and other contaminants in effluents at Manhole 175, the storm sewer, the waste pits, and Paddy's Run outfall were provided in a monthly report, "Comments on Monthly River and Effluent Flow". The Industrial Hygiene and Radiation Department issued monthly reports describing various radiation and air dust studies, stack losses, environmental sampling activities, liquid effluent measurements in the river, and special investigations of problem areas at the facility. Finally, "Aquifer Contamination Control" Reports to the Manager provided quarterly highlights of contamination problems or action taken to improve the effluent control system at the storm sewer, the General Sump, the pit area. the river and the test wells (Starkey 1965a, 1965b, 1967a, 1967b, 1967c, 1968).
- "Comments on Ground Contamination" biweekly reports described ground contamination areas onsite, results of ground contamination surveys of process areas, and charted estimated uranium losses to the storm sewer and rainfall totals for the month. These latter types of reports, which are more descriptive in nature, have been useful in providing background information for conditions that existed at the site in the early years, and in highlighting unusual events and unplanned releases, and are referenced at appropriate locations within the text.

## ESTIMATES OF URANIUM DISCHARGED IN LIQUID EFFLUENTS VIA MH 175 TO THE GREAT MIAMI RIVER

Uranium in liquid effluents leave the FMPC production area by the main effluent line to the Great Miami River or to Paddy's Run Creek via the Storm Sewer Outfall Ditch (SSOD) or runoff from the west side of the production area. Principal contributors to these uraniumbearing effluents included storm sewer runoff, effluent from the clearwell of the liquid waste pit, and treated effluent from the sanitary sewage treatment plant. To calculate the quantity of uranium lost from the FMPC, two key measurements are necessary:

- the concentration of uranium, and
- the volume of effluent to the river (MH 175) or to Paddy's Run.

The total uranium discharged each day via MH 175 to the river was calculated by multiplying the daily uranium concentration (mg  $L^{-1}$ ) and the volume of water discharged

|           | •                                             |  |  |  |
|-----------|-----------------------------------------------|--|--|--|
| Page L-10 | The Fernald Dosimetry Reconstruction Project  |  |  |  |
| ·         | Tasks 2 and 3. Source Terms and Uncertainties |  |  |  |

per day (liters). For Paddy's Run Creek discharges, the measured concentration of uranium and the total volume to the creek taken during specific outfall events, i.e., heavy rainfalls, or for a particular month were used to estimate uranium losses. The uncertainty analyses of these computations are discussed in a later section. Figure L-2 shows the annual uranium release estimates to the Great Miami River and to Paddy's Run Creek for all years. This and the next major sections of this appendix describe the documentation, methodology, and uncertainty analyses computations employed to arrive at these estimates. Data on uranium concentration in liquid effluent taken at MH 175 before discharge to the river are shown in Tables L1-1 to L1-13 in the annex for 1954 through 1969. The results of uranium concentration measurements in the storm sewer and storm sewer outfall ditch to Paddy's Run Creek for 1954 to 1966 are displayed in Tables L1-14 to L1-22 in the annex.



N. 200 A

Figure L-2. Uranium losses to the Great Miami River via Manhole 175 and to Paddy's Run Creek from the FMPC for all years of operation. The uncertainty of each estimate is described by the 95th percentile (top, broken line), and the 5th percentile (lower, dotted line).

The magnitude of the uranium releases to the river peaked in 1961 with  $7300 \pm 140$  kg uranium. From 1974 onward, the annual releases were below 1000 kg. The uranium losses to Paddy's Run show much more month to month variation than do the uranium loss estimates to Manhole 175. However, the average quantity of 500 kg uranium discharged through Manhole 175 to the Great Miami River each month during the early 1960s (Table L -3) was roughly five times greater than the average quantity of 100 kg of uranium lost to Paddy's Run during that same time (Table L-6). The volume of effluent to Paddy's Run averaged from 2 to 3 million gallons per month during this time period, while Manhole 175 discharged approximately 30 to 40 million gallons each month during the same period (Figure L-3).

Figure L-3 compares the monthly average liquid effluent flow from the FMPC to the river and to Paddy's Run for all years. The average volume of liquid to the river via MH 175 from the FMPC shows a gradual decrease from 30 to 35 million gallons (110 to 130 million

| Appendix L<br>Surface Water Discharges | 4 |  | Page L-1 |
|----------------------------------------|---|--|----------|
|                                        |   |  |          |

liters) per month in the early sixties to about 15 million gallons (60 million liters) per month in the seventies and eighties. The highest average volume of effluent to the river through the main discharge pipeline (1,400,000 gallons per day) occurred in 1961. Average monthly effluent flow to Paddy's Run is approximately ten times lower than the flow directly to the river, although flow from the site to the storm sewer outfall ditch generally occurs only during heavy rainfall events. The relative difference in flow and variation from month to month can be seen in Tables L1-6 to L1-8, which list the daily and monthly volumes for 1960, 1961 and 1962 to the river, and in Tables L1-18 to L1-22, which list effluent volumes to Paddy's Run for 1960, 1961, 1964 and 1966. These monthly variations in volume are typical of other years as well. Table L1-36 lists the annual effluent volume totals to the river and to Paddy's Run for 1959 to 1984.9

The volume of effluents discharged through Manhole 175 did not show great variation for most months. It was fairly consistent from day to day, showing a gradual decrease over time from greater than a million gallons per day (MGD) in the early sixties to approximately half that volume since 1976.



Figure L-3. Comparison of the monthly average volume of effluent to the Great Miami River and to Paddy's Run Creek from 1958 to 1984.

#### Discharges to the Great Miami River Via Manhole 175

Manhole 175 (MH 175), located on the eastern side of the facility, is the discharge point for waste water leaving the site through the main effluent line to the Great Miami River. MH 175 is the final junction point of the major waste effluent streams from the facility. This station is equipped with a recording pH meter, and a Parshall flume flow station equipped with a recirculating sampling line. The discharge flow to the Miami River was continuously measured and a composite sample collected and analyzed on a daily basis. The total uranium discharged each day was calculated by multiplying the daily uranium concentration (mg L<sup>-1</sup>) and the volume of water discharged per day (liters). The uncertainty analysis of these computations are discussed in a later section.

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

5

il Surviv

145.00

Š,

For discharges to the river, both of these quantities were known on a daily or monthly basis for most years of operation, except for 1952 to 1954. Daily uranium concentration measurements on 24-hour composite samples from Manhole 175 for 1954 through 1969 were located, and used in the source term derivation. For the occasional day or month when data sources were not located, an average value for that time period was assumed. Uranium concentration measurements from original analytical data sheets from 1954 through 1969 are listed in Tables L1-1 to L1-13 in the Annex. In addition, Tables L1-6 to L1-8 contain the daily volume measurements from MH 175 to the river. For the interim source term derivation for 1960 to 1962 (Voilleque 1991), daily volume measurements were available for most of 1960 and 1961 (February, April, May, July-December 1960 and January-August 1961) in DLW monthly reports, monthly volume measurements were available from MLS reports (Cuthbert 1960-1961), and from monthly ledger tabulations (Rathgens 1974). An equivalent procedure was followed for all years, with MLS reports, routine operating loss reports and analytical data sheets providing the basis for calculating losses to the river and 当前 计图 to Paddy's Run.

Figure L-4 shows the daily uranium concentration and volume measurements taken at MH 175 before discharge to the river for July through October 1960 as an example of the type of variation seen in these parameters. Whereas, daily uranium concentrations varied by a factor of 10 during this period, the effluent volume was more constant. Figure L-5 shows that, over time, the uranium concentration at MH 175 decreased gradually with less variation seen on a day to day basis. The concentration of uranium in the liquid effluent is higher, and shows more daily variation in 1957 than in 1967. In 1967 the daily uranium concentrations as high as 20 mg L<sup>-1</sup> were seen (See Tables L1-3 and L1-12 in the annex).

#### Uncertainties Associated With Discharges to Manhole 175

Sources of uncertainty for the estimates of losses of uranium through Manhole 175 to the Great Miami River come primarily from the analytical errors in measurement of flow, and in sampling and determination of uranium concentration in the water. Generally, there were differences of 10% or less in the unaccounted-for volume going into Manhole 175 from the various areas onsite. It appeared that the effluent volume to the river was monitored reasonably well (Courtney 1965). Estimates of error for the daily uranium concentration measurements, imprecision in sample preparation for the fluorometric uranium analysis, and volume measurements were made regularly (Brown 1967).

Uranium Measurements. For the fluorometric analysis of uranium, the limit of error (LE) at the 95% confidence level was reported as  $\pm$  7.1 mg U L<sup>-1</sup> at the level of 25 mg U L<sup>-1</sup> (28%) in the mid-1960s (NLCO 1966). Control samples indicated the precision and bias of the method for an individual analysis, and were routinely analyzed in a "manner similar to the US AEC GAE program samples". These control samples had a LE of  $\pm$ 10.3 mg U L<sup>-1</sup> (bias of +0.2 mg U L<sup>-1</sup>) at the level of 50 mg U L<sup>-1</sup> (21%). The minimum detectable level of uranium by fluorometric analysis was approximately 0.5 mg L<sup>-1</sup>.

Appendix L <u>Surface Water Discharges</u>

·:::

.

· · ·

~



Figure L-4. Daily uranium concentration (left axis) and volume of liquid effluent (right axis) released to the river for four months in 1960. This figure illustrates the difference in variation seen in uranium concentrations and volume of effluent seen in early years. Whereas the concentration varied by a factor of 10, the effluent volume was more uniform, increasing gradually by a factor of 2 during this period.



Figure L-5. Comparison of daily uranium concentrations measurements at the discharge point to the river from 1957 and 1967. The annual average concentration in 1957 was  $2.5 \pm 3.1 \text{ mg } \text{L}^{-1}$ , compared to that in 1967 of  $1.5 \pm 1.0 \text{ mg } \text{L}^{-1}$ . The extremes in concentrations decreased in the 1970s and 1980s.

| Page <sup>-</sup> L-14 | The Fernald Dosimetry Reconstruction  | 1 Project |
|------------------------|---------------------------------------|-----------|
|                        | Tasks 2 and 3. Source Terms and Uncer | rtainties |

The uranium concentration of 24-hour composite samples from Manhole 175 generally averaged from 2.5 to 5 mg U L<sup>-1</sup>, about 5 times lower than measurements used for LE determinations (Tables L1-1 to L1-13, Annex). Consequently, the relative LE for the Manhole 175 uranium concentration measurements would be expected to be higher as a percentage of the uranium concentration. Based on the measured error limits, and on discussions with individuals from the analytical laboratory at FMPC, the errors associated with the daily uranium concentrations was assumed to be 50% at the 95% confidence level for the 1950s and 1960s. We assume that the daily measurement value represents the mean of a normal distribution of values. Thus the relative standard deviation for each daily measurement is assumed to be 50% divided by 1.96, or 25.5%. For the seventies and 1980s, the relative standard deviation was assumed to be 15%, because of improvements at the MH 175 discharge point and in the analytical procedures.

Volume measurements. For flow through Manhole 175, the Limit of Error (LE) for the Parshall Flume flow station was reported as 1.5% of the monthly volume totals in routine quality control reports (NLCO 1966, Brown 1967), although there was no indication whether this was at the 95% confidence limit. Water plant personnel at FMPC generally assumed a variability of about 10% on the daily flow measurements. For these tabulations, a relative standard deviation of 10% on the daily Parshall flume results was assumed to account for measurement error.

. . . J.W.

Linda ?...

1201014

For days during a month when daily volume records were not available, the daily average was calculated from the monthly total. The relative standard deviation of daily volume measurements for a month ranged from 6% to 20% for the 18 months in the 1960-1962 period, for which such measurements were available. For those days when an average daily flow was used, a total relative standard deviation of 20% was assumed to account for the normal variation in flow seen throughout the month.

Total uranium determinations. The total uranium discharged each day was calculated by multiplying the daily uranium concentration (mg  $L^{-1}$ ) and the volume of water discharged per day (liters). A standard deviation for each daily uranium concentration measurement and volume measurement was calculated by multiplying the daily measurement by the assumed relative standard deviation. The product of the variances of the daily uranium concentration and volume measurements were determined. The standard deviation of the monthly uranium totals was determined using a standard error propagation technique. To determine the 90% confidence intervals (i.e., 5% to 95% predictions) surrounding the estimates, the error was multiplied by 1.645. To illustrate the methodology that was developed previously (Voillequé 1991) to calculate losses to the river for all years, monthly estimates of uranium lost to the river for 1960 to 1962 are shown in Table L-3 with the associated standard deviations. The same method was used to compute the uncertainty of the volume measurements, and those for the 1960-1962 period are shown in Table L-4. Using the same methodology, estimates of uranium released by way of the main discharge point (MH 175) for all years of operations were calculated, and are shown in Figure L-2. The annual estimates are compiled in Table L-5, along with the documentation sources for each year. and the second second

For 14 of the 37 years, daily measurements of uranium at the discharge point to the river were used to reconstruct the annual losses of uranium to the river. For other years, except for 1952-and 1953, monthly reports were used. Figure L-6 shows very good agreement for monthly uranium losses to the river calculated from daily analytical data

•

• • • • • •

## Appendix L Surface Water Discharges

. .

4

sheets (ADS), or tabulated from monthly reports for that same period. Hence, the use of monthly reports to provide the uranium loss estimates for our source term reconstruction appears justified by this agreement.

|         | 1960  |     | 1961   |      | 1962  |     |
|---------|-------|-----|--------|------|-------|-----|
| Month   | U(kg) | SD  | U(kg)  | SD   | U(kg) | _SD |
| Jan     | 290   | 20  | 630    | 35   | 480   | 40  |
| Feb     | 340   | 25  | 730    | - 40 | 540   | 40  |
| Mar     | 300   | 20  | . 730. | 35   | 410   | 30  |
| Apr     | 540   | 40  | 1020   | 55   | 570   | 40  |
| May     | 630   | 40  | 850    | 45   | 480   | 30  |
| Jun     | 530   | 35  | 640    | 35   | 325   | 25  |
| Jul     | 330   | 20  | 530    | 30   | 320   | 25  |
| Aug     | 470   | 30  | 930    | 70   | 380   | 25  |
| Sep     | 380 · | 25  | 480    | 30   | 1480  | 240 |
| Oct     | 530   | 35  | 200    | · 20 | 390   | 30  |
| Nov     | 540   | 35  | 310    | 25   | 370   | 30  |
| Dec     | 720   | 40  | 300    | 20   | 470   | 50  |
| Annual_ | 5600  | 300 | 7300   | 140  | 6200  | 300 |

## Table L-3. Monthly Estimates of Uranium Discharged From Manhole 175 to the Great Miami River with Associated Standard Deviations (SD)<sup>a</sup>

<sup>a</sup> From Voillequé 1991; daily measurements for these monthly totals are compiled in Tables L1-6 to L1-8 in the Annex. These tables illustrate the results of the methodology used to determine uranium quantities discharged in liquid wastes to the river for all years.

|        | 1960   |       | 1961   |     | 1962   | ÷            |   |
|--------|--------|-------|--------|-----|--------|--------------|---|
| Month  | Volume | SD    | Volume | SD  | Volume | SD ·         |   |
| Jan    | 35.2   | 1.2   | 47.0   | 0.9 | 34.2   | 1.2          |   |
| Feb    | 32.3   | . 0.8 | 41.9   | 0.8 | 31.9   | 1.2          |   |
| Mar    | 31.5   | 1.0   | 45.9   | 0.8 | 31.8   | 1.1          |   |
| Apr    | 28.8   | 0.5   | 45.1   | 0.8 | 25.2   | <b>0.9</b> . |   |
| May    | 30.1   | 0.7   | 42.0   | 0.8 | 24.6   | 0.9          | • |
| Jun    | 31.1   | 1.1   | · 39.0 | 0.7 | 28.5 · | 1.0          |   |
| Jul    | 28.0   | .0.5  | 47.6   | 0.9 | 29.5   | 1.0          |   |
| Aug    | 29.0   | 0.5   | 46.0   | 1.0 | 31.7   | 1.1          |   |
| Sep    | 30.3   | 0.6   | 28.1   | 1.0 | 28.4   | 1.1          |   |
| Oct    | 40.7   | 0.7   | 24.8   | 0.9 | 23.2   | 0.8          |   |
| Nov    | 38.1   | 0.7   | 28.3   | 1.0 | 23.9   | 0.9          |   |
| Dec    | 42.2   | 0.8   | 29.9   | 1.1 | 30.1 · | 1.1          |   |
| Annual | 397    | 2.7   | 465    | 3.0 | 343    | 3.6          | • |

## Table L-4. Monthly Estimates of Effluent Volume (million gallons) Through Manhole 175 to the Great Miami River With Associated Standard Deviations (SD)<sup>a</sup>

<sup>a</sup> From Voillequé 1991; daily measurements for these monthly totals are compiled in Tables L1-6 to L1-8 in the Annex. These tables illustrate the results of the methodology used to determine the volume of effluent discharged to the river for all years.

Page L-15
| Page I 16                             |                                               |
|---------------------------------------|-----------------------------------------------|
| rage L=10                             | The Fernald Dosimetry Reconstruction Project  |
| · · · · · · · · · · · · · · · · · · · | Tasks 2 and 3. Source Terms and Uncertainties |

| Year              | Total II (k-) | Esh (7:1- | Of the of |                           |
|-------------------|---------------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| 1050              | 2200          |           | 95th '#11e                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Information Sources       |
| 1052              | 2200          | 1000      | 2800                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | a                         |
| 1024              | 2200          | 1600      | 2800                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | · a                       |
| 1994              | 2200          | 1600      | 2800                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | a, b, Table L1-1          |
| 1922              | 2200          | 1900      | 2400                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | b, Table L1-1             |
| 1956              | 2600          | 2300      | 2900                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | b, Table L1-2             |
| 1957              | 3700          | 3400      | .4000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | c, Table L1–3             |
| . 1958            | 3900          | 3700      | 4100                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1–4             |
| 1959              | 2800          | 2500      | 3100                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1-5             |
| 1960              | 5600          | 5100      | 6100                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1–6             |
| 1961              | 7300          | 7100      | 7500                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1-7             |
| 1962              | 6200          | 5700      | 6700                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1–8             |
| 1963              | 4300          | 4000      | 4600                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1-9             |
| 1964              | 5100          | 4700      | 5500                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1–10            |
| 1965              | 3500          | 3200      | 3800                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | d                         |
| 1966              | 4500          | 4000      | 5000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1–11            |
| 1967              | 1890          | 1700      | 2100                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1-12            |
| 1968              | 2400          | 2100      | 2700                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | d                         |
| 1969              | 2300          | 2000      | 2600                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | c, Table L1–13            |
| 1970              | 1500          | 1300      | 1700                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | đ                         |
| 1971 .            | 2200          | (1900)    | 2500                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | d is in the second second |
| 1972 <sup>·</sup> | 1100          | 940       | 1300                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | d -                       |
| 1973              | 1700          | 1500 ·    | 1900                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ď                         |
| 1974              | 720           | 620       | 850                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | d .                       |
| 1975              | 1010          | 860       | 1200                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | -<br>đ                    |
| 1976              | 730           | 640       | 820                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | d                         |
| 1977              | 910           | 780       | 1000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | đ                         |
| 1978              | 850           | 740       | 960                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | đ                         |
| 1979              | 1050          | 960       | 1240                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | d the second              |
| 1980              | 640           | 560       | + 720                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | d en a                    |
| 1981              | 600           | - 530     | 670                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | đ                         |
| 1982              | 750           | 550       | 950                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | đ                         |
| 1983              | 590           | 510       | 670                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | đ                         |
| 1984              | 900           | 770       | 1000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | ď                         |
| 1985              | 610           | 510       | 710                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | u da                      |
| 1986              | 460           | 300       | 550                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | d o                       |
| 1987              | 770           | 650       | 000<br>200                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | u, e<br>d o               |
| 1000              |               |           | DAN                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | u,e                       |

Table L-5. Annual Uranium Losses to the Great Miami River By Way of

a Assume annual totals from 1955.

10 C 10

Sector of the sector

10.2 March 10

 $T_{i+1}$ 

1. -

b Some daily measurements at MH 175 available; NLCO 1954, NLCO 1955, NLCO 1956.

c Based on daily measurements at MH 175, and monthly operating loss reports; NLCO 1957 to 1969. · . . ,

.

d From Schwan 1967 to 1983. 19 2010 20 1000

e. Annual Environmental Monitoring Reports (Aas et al. 1986, Aas et al. 1987, WMCO 1988, WMCO 1989.

ć





**Figure L-6.** Comparison of uranium quantities discharged to the river from Manhole 175 for 1960 and 1967, based on daily measurements reported in analytical data sheets from the Bioassay Department (ADS) and from monthly loss reports (month) (Cuthbert 1960–1961, Schwan 1967–1983).

•

Overall, the quantity of uranium discharged ranged from about 200 kg in October 1961 up to a high of 1480 kg in September 1962. Releases were higher in 1961 than in 1960 or 1962. This is reflected in the annual totals of approximately 5600 kg in 1960, 7300 kg in 1961 and 6200 kg in 1962. These annual totals are 25 to 35% higher than those listed in historic reports from FMPC (Boback et al. 1987). Table L-4 shows the monthly total effluent volumes to the river in 1960, 1961 and 1962. Total flow through MH 175 was higher in 1961, with an average flow rate of 1.3 million gallons per day (MGD), than in either 1960 (average of 1.1 MGD) or 1962 (average of 0.9 MGD).

Uranium releases exceeded 100 kg on at least one day in April 1960 (Table L1-6, annex), August 1961 (Table L1-7, annex), and September and December 1962 (Table L1-8, annex). Losses for the first 9 days of September 1962, which were approximately equal to the total uranium loss for an average month, caused much concern at FMPC (Starkey 1962a). Large releases in 1962 on September 6th (190 kg), 8th (170 kg), and 10th (680 kg), were due to several large accidental releases from Plant 8 during that time. In some months, there was less variation in amounts of uranium discharged per day (for example, December 1960, January 1961), than in other months (for example, September 1960, February 1962). Differences in rainfall patterns and production activities, and the occurrence of spills and unusual releases contribute to the variation. Spills and accidental releases are discussed more thoroughly in an upcoming section.

, e. '

~ . . . . .

:**1**:

1991 N - 1

Sec. S

Very Start

#### **Enrichment Categories for Uranium in Liquid Releases**

The distribution of uranium among the three uranium enrichment categories changed over time at the FMPC. Of the total uranium released to the river, Figure L-7 shows the fraction of the discharges that were normal, enriched and depleted uranium during each year from 1960 to 1984 (Cuthbert 1960-1962, Schwan 1967-1983). Normal uranium represented the greatest fraction of uranium in the releases until 1967, and from 1970 to 1976. Releases of enriched uranium were minor until 1964 when it reached 40% of the total, and fluctuated between 20% and 60% of the total until 1971. Only a small fraction of depleted uranium was released until 1977 when it rose rapidly to 80% to 90% of the total uranium in liquid effluents. No normal uranium was released after 1978. These relationships of the enrichment categories of uranium in liquid effluents released from the site are quite similar to those for uranium receipts and shipments from the site (See Appendix C).



**Figure L-7.** Relative fraction of normal, enriched and depleted uranium released to the Great Miami River Via Manhole 175 From the FMPC from 1960 to 1984.

and the second

ς,

#### ESTIMATES OF URANIUM DISCHARGED TO PADDY'S RUN FROM THE FMPC

n generation

Water collected in the storm sewer system and passed through the storm sewer lift station before being discharged through Manhole 175 to the Great Miami River. A flow meter and continuous sampler monitored the discharges. Since the storm sewer lift station is not connected to any process, all the uranium lost through it was assumed to come from leaks and spills (Ross, 1972). Initially, the storm sewer system had only a detention basin and sump for emptying it when necessary. However, the detention basin was not used, and in July 1955 the storm sewer lift station was installed. Prior to that all runoff from the site went directly to Paddy's Run. The lift station in place in the early sixties was designed to

37

take only the initial runoff during a heavy rain. The pumping capacity of the pumps was approximately 500,000 gallons per day or 350 gallons per minute (DeFazio 1960).

Of the total quantity through the Storm Sewer system, most was discharged through the Lift Station while a percentage overflowed and was discharged through the outfall. Figure L-8 shows the magnitude and variability of the uranium discharges to the storm sewer lift station from 1955 to 1968. The major peaks in September 1962, March 1964 and February 1966 coincide with accidental spills to the storm sewer system, or nonroutine releases of materials (Table L-10). Frequently, uranium concentrations measured at the storm sewer lift station were higher in the late winter or early spring following warmer weather when thawed material in the pipes and on the ground could flow freely. Tables L1-14 to L1-21 in the annex contain the uranium concentrations measured at the storm sewer outfall to Paddy's Run and at the storm sewer lift station from 1954 to 1966. Table L1-23 lists the monthly uranium losses and percentage of total storm water flow that discharged through the outfall and to the lift station for 1960, 1961 and 1962. Clearly, flow to the storm sewer system, and, ultimately to Paddy's Run was quite variable, depending upon total rainfall, and rainfall patterns. Generally, from 2 to over 50% of the flow through the lift station was discharged to Paddy's Run. In some instances, where flow was particularly high, there were reports of up to 80% of the flow being lost to Paddy's Run (Starkey 1964c). Runoff to the storm sewer outfall ditch to Paddy's Run Creek is a major contributor to the uranium contamination in the groundwater to the south of the site. Uranium levels measured in the SSOD and at the lift station are used in Appendix M to develop a source term for groundwater contamination outside of the FMPC.

#### Estimates of Uranium Losses to Paddy's Run

Liquid effluent from the site flowed to Paddy's Run when the capacity of the storm sewer lift station was reached. When the capacity of the storm sewer lift station was reached, water overflowed through the storm sewer outfall to Paddy's Run Creek. The volume of storm water that overflowed the storm sewer lift station to Paddy's Run is related to rainfall amounts and patterns. Storm water flow lags the actual precipitation event by several hours, usually showing an increase in flow the next day (Patton, 1985). Furthermore, contaminants were getting into Paddy's Run from areas other than the storm sewer outfall, perhaps from the vicinity of the Pilot Plant storage pad, from the waste pits, or from the vehicle washing station northwest of Plant 1 (Starkey 1959).

Ground contamination occurred on the west side of the Pilot Plant when the sump overflowed the drain to the southwest corner of the site and into Paddy's Run if the rainfall was sufficient (Flowers 1961, Gessiness 1961). By August 1961, curbing had been installed around the sidewalk between the Pilot Plant Annex and the Pilot Plant to direct some of the contaminated runoff to a catch basin, preventing contamination of the soil (Quigley 1961). Pilot Plant personnel made a survey of the ditches and mud holes west of the Pilot Plant, and made note of several large uranium contaminated ditches running to the southwest, eventually discharging into a large gully due west of the Pilot Plant at the second fence (Shaw 1961). In addition, there was a partially excavated hole on the west side of the Pilot Plant which was usually filled with contaminated water. Memoranda indicate that there were plans to pump out the hole (Shaw 1961, Gessiness 1961). It was reported that surface

| Page 1 | L-20 |
|--------|------|
|--------|------|

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

. . .

and subsurface drainage in the Pilot Plant Area flowed into a manhole on the warehouse storage pad, and then, by gravity, into an open drainage ditch which discharged into Paddy's Run Creek (DeFazio 1962). In addition, it was not unusual in the earlier years to drain water from the fluoride pit (Waste Pit 3) directly to Paddy's Run Creek when heavy rains caused high flow in the stream (Starkey 1956).



Figure L-8. Monthly quantities of uranium to the storm sewer system from runoff at the FMPC from January 1955 through December 1968. These values were reported in routine operating loss reports from the FMPC. The uranium measured in the storm sewer system comes from leaks, accidental spills and ground contamination events. Nonroutine events involving liquid effluents are recorded in Table L-10.

Prior to the late 1960's, there was no continuous metering of the flow of water through the storm sewer to Paddy's Run Creek (Pennack, 1966), although there was discussion on the continuous measurement of the surface flow in Paddy's Run for some time (Jeffers 1962), and on the purchase of a portable flow meter and sampler (Chapman 1959). In 1966 it was proposed to install a 1,000 gallons per minute (gpm) V-notch weir meter and proportional sampler just downstream from the Storm Sewer Lift Station. Prior to that time, Water Treatment department personnel took grab samples and estimated the flow at the weir notch south of the parking lot (Ross, 1965). Depending upon the duration of the flow, a number of other grab samples would be taken at half hour intervals, and composited. A sample of the composite was then sent to the Bioassay Laboratory for analysis. There continued to be concern regarding the significance of grab samples from the storm sewer outfall in representing uranium quantities lost to Paddy's Run (Quigley 1965). On days when there was a storm sewer outfall flow, the uranium concentration of the outfall sample was usually much higher than the 24-hour composite from the lift station. Analytical results suggested that day-to-day differences in uranium concentrations between the Storm Sewer Outfall grab samples and Storm Sewer Lift Station samples could be significant, but that monthly uranium totals were similar (Ross 1965).

- 2

Another source of effluent to Paddy's Run Creek originated as runoff from a portion of the production area near the pilot plant, and as drainage from the waste pit area. In the 1950s, there was a drainage ditch to the south of the waste pits to direct runoff to Paddy's Run (NLCO 1959).

#### Source of Information for Estimates of Uranium to Paddy's Run

For 72 months during the 1960-1966 period, documentation was available that indicated the dates of outfall flows to Paddy's Run, the volume discharged in gallons, and the uranium concentration for each flow to Paddy's Run. Tables L-17 to L-21 in the annex list the losses for those months in 1960-1964 and 1966 where detailed information was located for individual outfall events (Rathgens 1974). The values in the tables come from two types of reports discussed earlier. The first report is "Discharge of Liquid Wastes into the River" (DLW), a monthly report listing the daily discharge of liquid wastes from the Sanitary Sewer, Storm Sewer, Manhole 175, and Storm Sewer Outfall. The Storm Sewer Outfall category lists the dates, volume in gallons, and measured uranium concentration in ppm for each flow to Paddy's Run. For some months, the total number of outfall flows is not known with certainty (e.g., May - Sep 1960), although records of monthly totals of uranium and volume are available for all months (Chapman 1956, Pennack 1973, Rathgens 1974, Bardo 1985, Patton 1985).

The second type of report is the "Measured Losses and Removals of SS Material From the Production Stream" (MLR), a monthly summary of uranium discards to the General Sump and stack losses. Volumes and quantities of normal and enriched uranium discarded as liquid waste from each process area are listed. In addition, the MLR reports give the losses to Paddy's Run, discards to the chemical pit, and "removals" from the pit to the river.

#### Uncertainties of Estimating Uranium Losses to Paddy's Run Creek

The uncertainty associated with estimation of uranium losses to Paddy's Run includes three major components. One area of uncertainty involves unmonitored losses from the site above the point where the storm sewer outfall enters Paddy's Run (where the measured losses were recorded). Records of numerous samples obtained from Paddy's Run indicated that the standards were exceeded in various locations north of where the storm sewer outfall enters Paddy's Run Creek (DeFazio 1960). Quantitative information on the amounts of materials discharged to Paddy's Run from drainage north of the storm sewer outfall location is sparse. One report noted that samples of water in the manhole at the Pilot Plant warehouse showed "uranium contamination but not above what would have been expected normally" (Shaw 1961). The concentration of uranium in the water in the gully was highest at the point due west of Plant 2 and 8 and tapered off at the point west of the Pilot Plant (Shaw 1961). One report noted that the analysis of samples from the open drainage ditch west of the Pilot Plant indicated that uranium concentrations varied from 7 to 28 mg U L<sup>-1</sup> with some flows over 5 gallons per minute (DeFazio 1962).

If these limited data are used to determine whether or not this drainage might be a significant contributor to the total discharges from FMPC to Paddy's Run, then we can calculate the quantity of uranium that would be discharged through this unmonitored

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

NUMBER &

1997.00 A

1-310-1

42.43.53

200

ŝ

drainage ditch if these conditions existed continuously for a month, and compare that value to our monthly estimates. If we assume that a continuous flow of runoff water of 5 gallons per minute (216000 gallons per month) with an average uranium concentration of 28 mg U  $L^{-1}$  occurs for an entire month, then we would expect about 20 to 25 kg of uranium per month from this source. This compares to roughly 100 kg of uranium lost to Paddy's Run through the storm sewer outfall ditch each month. Although this rough calculation is conservative, and based on extremely limited data, it represents one source of material loss to Paddy's Run that was not monitored. It may have been the most significant unmonitored source. Consequently, we assume an additional release of 25% above the monthly effluent volume and uranium quantities reported by the FMPC in analytical data sheets and monthly reports.

A second component of uncertainty surrounding the estimation of discharges to Paddy's Run is associated with the collection of grab samples in the storm sewer outfall ditch prior to its convergence with Paddy's Run, and uranium analysis of the grab samples by the fluorometric method. In our interim source term report (Voillequé et al. 1991), data on the number of outfalls to Paddy's Run per month, the volume of water per outfall event, and the uranium concentration of grab samples taken during the overflow event were available for 17 of 36 months in 1960–1962 (See Tables L1–18 and L1–19). Uranium was analyzed by the fluorometric method similar to MH 175 samples. For the individual outfall events in these months, the limit of error (LE) for the uranium concentration measurement at the 95% confidence level was assumed to be 75%, higher than the LE assumed for the uranium determination at the MH 175 discharge point (50%) because the sampling protocol for Paddy's Run involved intermittent grab sampling rather than continuous sampling (Courtney 1965).

Reports indicated that the accuracy of the V-notch Weir flow station ranged from 8% to 15% for normal to flood condition flows, respectively. (Noyes 1966). For this report, the variation is assumed to be 15% for all events. When these errors associated with volume and uranium concentration measurements for individual outfall events are propagated through the month, the LE on the monthly totals range from 4% to 15% of the monthly totals. Consequently, for months when detailed information on number of outfall events was not available, a LE of 15% was assumed for the monthly totals for these 19 months.

A third component of uncertainty for uranium loss to Paddy's Run Creek involves time periods when rainfall, and consequently runoff, were quite high and the capacity of the storm sewer lift station flow meter and V-notch Weir at Paddy's Run may have been exceeded. The water flowing to Paddy's Run occurred when the capacity of the storm sewer lift station was reached. Of the total quantity through the Storm Sewer system, most was discharged through the Lift Station while a percentage overflowed and was discharged through the outfall. Monthly data on measured outfall volume and total uranium to Paddy's Run from the storm sewer overflow indicate that from 2 to 55% of the total flow passed through the outfall to Paddy's Run, with an average of  $21 \pm 11\%$  (Table L1-23).

The pumping capacity at the lift station was approximately 500,000 gallons per day or about 350 gallons per minute (DeFazio 1960). During this time period (1960-1962), there were an average of 3 to 6 times a month when daily flow through the storm sewer lift station was greater than 600,000 gallons per day, with volumes from 750,000 to 850,000 gallons measured occasionally (Starkey 1960-1961). Without specific rainfall patterns and amounts for those specific days, however, it is difficult to speculate whether the flow was

•••

5.

 $\langle \cdot \rangle$ 

These uncertainty estimates for each of the three sources of error that were discussed (unmeasured losses to Paddy's Run, sampling and analytical, and exceeding the capacity of the storm sewer lift station), were incorporated into our final source term estimates for uranium lost to Paddy's Run. Our release estimates, increased by 25% due to unmonitored losses to Paddy's Run, were multiplied by the combined estimates for analytical error and overflow at lift station (15% plus 20%) to provide a bound around each estimate of uranium discharged to Paddy's Run. To determine the 90% confidence intervals surrounding the estimates, the error was multiplied by 1.645. Tables L-6 and L-7 list the monthly quantities of uranium losses and discharge volumes to Paddy's Run for 1960, 1961 and 1962, as an example of the methodology. The uranium concentration data for the storm sewer outfall ditch from original analytical data sheets for 1954 to 1966 are presented in the annex in Tables L1-14 to L1-21.

| Table L-6. Monthly | Estimates of L | Jranium Losses | ; to Paddy's | Run With | Associated |
|--------------------|----------------|----------------|--------------|----------|------------|
| •                  | Stand          | ard Deviations | (SD)         | •        |            |

|        | 1960  |        | 1961  |        | 1962  | ·      |
|--------|-------|--------|-------|--------|-------|--------|
| Month  | U(kg) | SD(kg) | U(kg) | SD(kg) | U(kg) | SD(kg) |
| Jan    | 160   | 65     | 100   | 40     | 170   | 130    |
| Feb    | 170   | 70     | 100   | 40     | 160   | 130    |
| Mar    | 4     | 2      | 230   | 90     | 390   | 310    |
| Apr    | 40    | 15     | 120   | 50     | 35    | 35     |
| May    | 160   | 60     | . 120 | 50     | 160   | 130    |
| June   | 220   | 130    | 80    | 30     | 90    | 75     |
| July   | 170   | 70     | 120   | 45     | 90    | 75     |
| Aug    | 90    | 10     | 20    | 7      | 60    | 45     |
| Sep    | 90    | 30     | 330   | 100    | 6     | 5      |
| Oct    | 110   | 40     | 60    | 90     | 100   | 80     |
| Nov    | 72    | 30     | 140   | 70     | 75    | 60     |
| Dec    | 50    | 20     | 30    | 90     | 135   | 110    |
|        | ••    | · ·    |       | • •    |       |        |
| Annual | 1300  | 200    | 1400  | 220    | 1500  | 430    |

<sup>a</sup> From Voillequé 1991; measurements for these monthly totals are compiled in Tables L1-18, L1-19 and L1-22 in the Annex. These tables illustrate the results of the methodology used to determine uranium quantities discharged in liquid wastes to Paddy's Run for all years of operations.

For annual losses in the early sixties, the discharges to Paddy's Run were  $1055 \pm 201$  kg in 1960,  $1131 \pm 439$  kg in 1961, and  $1273 \pm 272$  kg in 1962. Few documents listed uranium losses to Paddy's Run routinely, or summarized these losses on a monthly or annual basis. The latest Remedial Investigation / Feasibility Study Groundwater draft report (RIFS 1990), is one of the few documents that lists losses to Paddy's Run. The RIFS report estimates for

| The Fernald Dosimetry Reconstruction Project      |
|---------------------------------------------------|
| <br>Tasks 2 and 3. Source Terms and Uncertainties |

losses to Paddy's Run for 1960, 1961 and 1962 are 910, 1180 and 1190 kg, respectively, Our estimates for these years are listed in Table L-8 along with the estimates for all years. 

| <sup>*</sup> |             | S      | tandard Devia | tions (SD) |             |          |
|--------------|-------------|--------|---------------|------------|-------------|----------|
|              | 1960        |        | 1961          |            | 1962        | · •.     |
|              | Volume      | SD     | Volume        | SD         | Volume      | SD       |
| Month        | (million ga | llonst | (million ga   | lons)      | (million ga | ilons) e |
| Jan          | 0.19        | 0.05   | 3.3           | 0.5        | 8.9         | 2.5      |
| Feb          | 9.5         | 1.6    | 3.4           | · 0.5      | 5.3         | 1.5      |
| Mar          | 0.05        | 0.01   | 11            | 1.5        | 22          | 6.1      |
| Apr          | 0.64        | 0.14   | 4.1           | 0.6        | 1.6         | 0.44     |
| May          | 0.8         | 0.04   | 4.1           | 0.6        | 0.02        | 0.05     |
| Jun          | 4.9         | 1.4    | 1.7           | 0.3        | 1.4         | 0.4      |
| Jul          | · 4.0       | 0.65   | 3.7           | 0.5        | 8.4         | 2.3      |
| Aug .        | 0.8         | 0.15   | 0.35          | 0.05       | 1.2         | 0.33     |
| Sep          | 2.9         | 0.82   | 1.9           | 0.52       | 0.11        | 0.03     |
| Oct          | 1.9         | 0.31   | . 0.95        | 0.26       | 3.3         | 0.94     |
| Nov          | 1.4         | 0.22   | 3.6           | 1.0        | 3.1         | 0.95     |
| Dec          | 21.5        | 0.22   | 3.1 👌 🕴       | 0.9        | 4.6         | 1.3      |
| Annual       | 28          | 2.4    | 42            | 2.5        | 60          | 7.4      |

#### Monthly Estimates of Fff Daddy's Run With A

CHARTER BOOK ON CO

From Voillequé 1991; measurements for these monthly totals are compiled in Tables L1-18, L1-19 and L1-22 in the Annex. These tables illustrate the results of the methodology used to determine the volume of effluent discharged to Paddy's Run for all years.

100 A 10 A

1. N. ...

A. 14.14

10. 10 miles

÷

۰. . Harry 1 Figure L-9 compares monthly uranium losses to Paddy's Run from the Storm Sewer Outfall Ditch for three time periods: 1959 to 1962, 1969 and 1970, and 1979 and 1980. The data show that the quantity of uranium lost to Paddy's Run varied considerably from month to month in the early years, so that an average value over a short period of time may not adequately have described a particular month, or several month period. The figure also shows the gradual decrease in total quantity and in monthly variability of uranium released to Paddy's Run. The decline reflects a decrease in production in the seventies and eighties, along with some improvements in the effluent handling system onsite.  $(g_{ij}, g_{ij})$ 

Annual estimates of uranium released to Paddy's Run are shown in Figure L-2 with those releases directly to the river from the FMPC. In Table L-8, estimates of uranium losses to Paddy's Run are listed for all years of operations, with the associated uncertainties.

ここにはこうい 公司 (記録) (いい)

11

#### NONROUTINE RELEASES TO SURFACE WATER

The State of the residence of the providence of the second second .0 Releases of contaminated liquids from spills, drum ruptures, and overflow of sump ponds have been considered in determining the total quantity of uranium released in liquid effluents from FMPC. Regular ground contamination reports were issued on a regular basis. As early as September 1953, an investigation of contamination of the storm sewer outfall to Paddy's Run was conducted after local residents reported changes in the stream from the previous year (Blase and Starkey 1953). The investigators at the site concluded that the primary source of contamination to Paddy's Run was iron salts in runoff from the coal pile.

Page L-24

· · · ·

10.00

(1, 2, 3, 4, 5)

At that time, all surface drainage from the plant site discharged directly to Paddy's Run via the storm sewer system. During the 1950s, brief "Storm Sewer Contamination" memoranda encouraged plant supervisors to minimize the causes of increased ground contamination and spills (Stewart 1957), but generally no quantitative details of incidents were provided.



Figure L-9. Monthly uranium losses to Paddy's Run Creek by way of the Storm Sewer Outfall Ditch for three time periods: 1959-1962, 1969-1970 and 1979-1980. The gradual decline in uranium releases over the years coincides with improvements in the liquid effluent handling system, and with a decline in production activities.

On June 1, 1959, an external area ground contamination survey program of all production plant was initiated on a weekly schedule to inform plant supervision of existing major ground contamination areas, their sources, remedies, and the effect of ground contamination on the storm sewer system (Dodd 1959). Frequently, spills of contaminated materials were described by thickness, and area of gravel covered. For example, a "quarter inch thick" spill covering one square yard, occurred on the graveled area near Plant 4 in February 1964 (Starkey 1964b). Initially all major contaminated areas of soil were to be removed to the waste pits. By 1961, however, the excavation activity was viewed as "not only ridiculous but also an expensive" practice, because of recurring contamination in some locations of the process area (Flowers 1961). With the emphasis on ground contamination, however, the number and extent of spills did appear to decrease over time, shown in Table L -9, in which we have compiled information on the monthly frequency and general source of spills affecting the storm sewer system from 1959 to 1969.

> Radiological Assessments Corporation "Setting the standard in environmental health"

.

%

0

| Page I | -26 |
|--------|-----|
|--------|-----|

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

1122 200 1

P. CALLY

いれたい

| V      | · · · · · · · · · · · · · · · · · · · |                        |           | Primary Information        |
|--------|---------------------------------------|------------------------|-----------|----------------------------|
| 1ear   | Uranium(kg)                           | <u>5th File</u>        | 95th %ile | Sources                    |
| 1952   | 522                                   | 410                    | 630       | а                          |
| 1953   | 522                                   | 410                    | 630       | a                          |
| 1954   | 522                                   | 410                    | 630       | b, d, Table L1–14          |
| 1955   | - 300                                 | 190                    | 405       | b, d, Table L1–15          |
| 1956   | 270                                   | 210                    | 320       | b, d, Table L1–16          |
| 1957   | 340                                   | 280                    | 410       | b, d, Table L1–17          |
| 1958   | 630                                   | 510                    | 750       | b, d                       |
| 1959   | 840                                   | 640                    | 1000      | c                          |
| 1960   | . 1300                                | 800                    | 1800      | e, Table L1–18, L1–19      |
| 1961   | 1400                                  | 1000                   | 1600      | e, Table L1–19, L1–20      |
| 1962   | 1500                                  | 1100                   | 2100      | d, Tables L1-17 & 11-18    |
| 1963   | 901                                   | 720                    | 1100      | b, Table L1–18             |
| 1964   | 1722                                  | 1260                   | . 2200    | d, e, Tables L1–18 & L1–21 |
| 1965   | 622                                   | 490                    | 760       | Ь                          |
| 1966   | 771                                   | 550                    | . 1000    | d, Table L1–22             |
| 1967   | 753                                   | 560                    | 950       | е                          |
| 1968   | 358                                   | 280                    | 430       | e                          |
| 1969   | 290                                   | 250                    | 340       | e                          |
| 1970   | 349                                   | 300                    | 390       | e                          |
| 1971   | 499                                   | 410                    | 590       | <b>~</b> e                 |
| 1972   | 322                                   | 280                    | 370       | e                          |
| 1973   | 231                                   | 200                    | 265       | e                          |
| 1974   | 255                                   | 210                    | 300       | e                          |
| 1975 ″ | 245                                   | 180                    | .250      | Ъ                          |
| 1976   | 272                                   | 230                    | 310       | · e                        |
| 1977   | 204                                   | 170                    | 230       | e                          |
| 1978   | 68 ·                                  | 60                     | 80        | e                          |
| 1979   | 84                                    | 70                     | 100       | e                          |
| 1980   | 50                                    | 40                     | 60        | e                          |
| 1981   | . 20                                  | 18                     | 22        | • <b>f</b>                 |
| . 1982 | 20                                    | 18                     | 22        | f                          |
| 1983   | 54                                    | 40                     | 70        | е                          |
| 1984   | 57                                    | <b>50</b> <sup>3</sup> | 70        | e                          |
| 1985   | `· <b>39</b>                          | 30                     | 50        | f                          |
| 1986   | 17                                    | 15                     | 20        | f .                        |
| 1987   | <0.5                                  | <b>&lt;0.5</b>         | 0.5       | f                          |
| 1988   | <0.5                                  | <0.5                   | 0.5       | ŕ f                        |

a Assume annual totals from 1954; estimates based on uranium measurements at the storm sewer outfall. the storm sewer lift station not installed until August 1955.

b Based on monthly reports of storm sewer losses; assume 20% to storm sewer outfall ditch.

c Routine monthly reports of operating losses for all months.

d Analytical data sheets for daily losses to storm sewer outfall ditch.

e Monthly records of outfall events to Paddy's Run.

f Annual Environmental Monitoring Reports; assumed uncertainty range of 10%.

· · ·

.

. .

| Table L–9. Monthly Frequency and General Location of Spills Affecting the |
|---------------------------------------------------------------------------|
| Storm Sewer System During 1959 Through 1969 <sup>a</sup>                  |

...

|      |        | Number of Incidents   |                                    |
|------|--------|-----------------------|------------------------------------|
| Year | Date   | Affecting Storm Sewer | Areas Involved                     |
| 1959 | June   | 22                    | All processing areas               |
| 1961 | April  | 12                    | All processing plants              |
| •    | May    | 14                    | All processing plants              |
| •    | June   | 13                    | All processing plants              |
| •    | July   | 10 .                  | All processing plants              |
| •    | August | 8                     | All processing plants              |
|      | Sep    | - 15                  | All processing plants              |
|      | Oct    | 10                    | Plant 2/3, 6, 8, 9, Pilot          |
| 1962 | Sep    | 16                    | Plant 4, 5, 6, 8, 9, Pilot         |
|      | Nov    | 11                    | Plant 1 pad, 4, 5,6, 8, 9, Pilot   |
| 1963 | March  | 16                    | All processing plants              |
|      | June   | 7                     | Plant 2/3, Plant 6, Plant 8, Pilot |
| 1964 | Feb    | 18                    | All processing plants              |
| 1965 | Mar    | 4.                    | Plant 8, roads                     |
| 1000 | Apr    | 1                     | Railway                            |
|      | May    | · 2                   | Plant 2, 4                         |
|      |        |                       |                                    |
| 1966 | Jan    | 9                     | Plant 1 pad, 2/3, 8, 9             |
|      | Feb    | 7                     | Plant 2, 8                         |
|      | Mar    | 16                    | Plant 8, tank farm                 |
|      | Apr    | 10                    | Tank farm, Plant 8, 2/3            |
|      | Мау    | 5.                    | Plant 8, 2/3, tank farm            |
| •    | June   | 4                     | Plant 2/3, 8                       |
|      | July   | 2                     | Plant 1, roads                     |
|      | Aug    | 4                     | Plant 2/3, Lab Bldg.               |
|      | Sep    | 2                     | Roads                              |
|      | Oct    | 1                     | Bldg. 64(Th warehouse)             |
|      | Nov    | 2                     | Plant 9                            |
| •    | Dec    | 3                     | Plant 8, 2                         |

(continued on next page)

| Page | L-28 |
|------|------|
|------|------|

| SI                                | torm Sewer | System During 1959 Throug                                                                                        | h 1969 <sup>a</sup> (continued) |
|-----------------------------------|------------|------------------------------------------------------------------------------------------------------------------|---------------------------------|
| 1967                              | Jan        | <b>12</b> <sub>1121</sub> 20                                                                                     | Plant 8, 4                      |
|                                   | Feb        | · 11 · · · · · · · · · ·                                                                                         | Plant 8                         |
|                                   | Mar        | 3                                                                                                                | Plant 8                         |
|                                   | Apr        | <b></b>                                                                                                          | Plant 8, 1                      |
| · · ·                             | May        | <b>3 1 1</b>                                                                                                     | Plant 8, tank farm              |
|                                   | June       | 10                                                                                                               | Plant 8, 4, tank farm           |
| · · · ·                           | July       | 9                                                                                                                | Plant 8                         |
| •                                 | Aug        | <b>8</b> . Etc.                                                                                                  | Plants 8, 2/3, 4, roads         |
|                                   | Sep        | 1                                                                                                                | Plants 8                        |
|                                   | Oct        |                                                                                                                  | Plant 6, roads                  |
|                                   | Nov        | 1. 1. 1. 1. <b>4</b> 19 1                                                                                        | Plants 2/3, 4, 8, roads         |
|                                   | Dec        | 4                                                                                                                | Plants 2/3, 4, 8                |
|                                   |            |                                                                                                                  | •                               |
| 1968                              | June       | 4                                                                                                                | Plants 8, 2, roads              |
|                                   | July       | <b>4</b> (5) <b>1</b> <i>b</i> (1) <i>b</i> (1)                                                                  | Plants 4, Pilot, roads          |
|                                   | Aug        | 2                                                                                                                | Roads                           |
|                                   | Sep        | 2                                                                                                                | Plant 8, roads                  |
|                                   | Oct        | 4                                                                                                                | Plants 2, 6, 8, roads           |
|                                   | Nov        | 1                                                                                                                | General Sump Area               |
| ,                                 | Dec        | 2.555.55.546.55.55                                                                                               | Plant 8, roads                  |
|                                   |            | and the second |                                 |
| 1969                              | Jan        | i i i                                                                                                            | Plant 8                         |
|                                   | Feb        | 3                                                                                                                | Plant 8                         |
| · · ·                             | Mar        | <b>3</b>                                                                                                         | Plant 8, roads                  |
|                                   | Apr        | 1                                                                                                                | Plant 8                         |
|                                   |            |                                                                                                                  | . •                             |
|                                   | Nov        | ····· <b>1</b> , ······                                                                                          | General Sump                    |
| بر ال <sup>رو</sup> ي المراجع وال | Dec        | <b>2</b> , <b>1</b> , <b>1</b>                                                                                   | Plant 8, roads                  |

#### Table L-9. Monthly Frequency and General Location of Spills Affecting the Storm Sewer System During 1959 Through 1969<sup>a</sup> (continued)

<sup>a</sup> Data were compiled from the monthly reports, "Comments on Ground Contamination in Process Area"(Flowers 1959–1962; Dodd 1958–1959) and "Incidents Affecting the Storm Sewer System"(Riestenberg 1965–1969) that were available for this time period.

From the review of numerous ground contamination reports since 1954, it becomes clear that several locations in the production area continued to be problem areas. These are:

1. 11. 1. 1

100 Jan 1997

. 2

t \*.

Plant 8. Contamination prevalent at the east and west end of the plant. Contamination at the north side was caused by the operation of the box furnace. Some of this contamination was checked with the enlargement of the paved area so that it could be flushed from the pavement to the existing sump and storm sewer system (Chapman 1956). Increase in level of storm sewer losses with initiation of the airport scrap handling operation in April 1960.

• Plant 6. The Machining Area from the east pad near the intersection of First and "E" Streets continued to be contaminated from runoff and underground leakage from acid 4

3. . lines below floor level (Bussert 1956, Tippenhauer 1957). The east pad serves a dual purpose as a plant entrance and a work area, resulting in contamination being spread routinely by vehicles moving through the area (Smith 1961). Although the east pad proper was designed to drain into a sump, "E" street was not so constructed. The lack of curbing on the south end of the pad allowed contamination to drain to the dirt field (Spenceley 1959).

- Plant 2/3. Ore spills common on the SW side. Orange oxide contamination occurs at the SE corner of Plant 2 at the "gulper" station. This problem arose from the muffler discharge connections and from breakage of filter bags in the gulper system (Chapman 1956). Most contamination was restricted to the concrete pad, although the surrounding gravel was replaced after the scrubber system replaced the dry bag collector in late 1956.
- Plant 1 Storage Pad. The area east of the Drum Reconditioning Building usually contained several hundred empty contaminated drums waiting to be baled. Loose contamination fell from the drums onto the pad which flowed into the storm sewer.
- Pilot Plant. The most contaminated areas around the Pilot Plant generally were near the storage pads to the south and west of the Pilot Plant, where the sump overflowed the drain to the SW corner of the facility to Paddy's Run. The small pad near the fence on the west side of the plant was "badly contaminated with piles of  $U_30_8$ " in the mid-1950s (Chenault 1955). Occasionally, equipment that had been inadequately cleaned was stored on the ground near the SW pad the Pilot Plant (Starkey 1958b). On the west side of the Pilot Plant, the principal contamination was from spills of nitric acid wastes with low uranium concentrations around the nitric acid absorber and storage tank (Davis 1957). In August 1957, a large volume of sump liquor with a low uranium concentration was accidentally spilled while loading the sump truck in that area. This action required "moving a lot of dirt" (Davis 1957). Contaminated soil was removed from near these storage pads periodically, but this area was drained by natural seepage and surface runoff into Paddy's Run Creek.

Over the years, several attempts were made to locate, and thereby eliminate, specific sources of the uranium that were found at the Storm Sewer Lift Station (Chapman 1961, Starkey 1969, Riestenberg 1969, Ross 1972, Lenyk 1977). Generally these surveys indicated that, except for the Boiler Plant area, uranium was entering the storm sewer system plantwide by surface drainage (Lenyk 1977). The main sources of contamination appeared to be the transportation and use of dirty drums, dirty pallets, storage on the ground, and redrumming operations at some of the storage pads. Furthermore, the use of contaminated oil as dust palliatives on secondary roads and the fly ash pile near the SE corner of the site between the storm sewer outfall ditch and Paddy's Run Creek contributed to storm sewer contamination for years (Karl 1960; Starkey 1960) (See Figure K-1, Appendix K).

For a significant spill into the storm drain, the flow from the lift station could be directed to the General Sump by reversing the flow from the sump, using an emergency gate or diversion valve installed in the early 1970s (Keller 1978). Contamination of this type would usually be washed into the storm sewer system or into Paddy's Run depending upon the location of the contamination. Contamination in Paddy's Run was the primary result of ground spills at the facility (Starkey et al. 1961). The lift station, installed in June 1955,

Ŧ,

1-10-00

. : . . .

would handle the majority of the flow in the sewers, with the first fifteen minutes of flow going to the river or catch basins, and the rest flowing over to Paddy's Run (Glass 1955a).

To ascertain the significance of contamination incidents and major unplanned releases of liquid on the determination of the surface water source term, we closely examined reports of incidents involving unusual losses of uranium in liquid effluents, and listed them in Table L-10. The data have been taken from various documents to provide as complete a record as possible of the major accidents or unusual events that discharged quantities of uranium and other radionuclides higher than "normally" released on a daily or monthly basis.

"Notice of Contamination Source" forms were prepared for incidents of chemical spills, radioactive spills, and releases of contaminants directly to the storm sewer due to mechanical problems (Flowers 1960a). The most significant incidents that contributed to possible increases in the uranium quantities in liquid effluent were reported in "Comments on Monthly River and Effluent Flow" reports (Fischoff 1960–1962). These events were based on the daily calculated uranium losses in the effluent and on formal incident reports received. As the scope of our investigation expanded for all years of FMPC operation, a somewhat similar procedure was followed with the emphasis on those events which may have caused contamination in the storm sewer greater than would be expected from "routine" operations. Table L-10 summarizes the major unplanned releases and losses of material into the liquid effluent system that were reported or recorded in memoranda, daily log sheets, or various types of reports. It provides a brief description of the event, the date, reference source, and general location of the spill or accidental release. The table includes the detailed summary of events for the 1960-1962 period from the Draft Interim Task 2 and 3 report (Voillequé et al. 1991).

The release points for spills or accidental discharges from the FMPC facility would be the same for unplanned as for "routine" liquid effluent releases, that is, through MH 175 to the Great Miami River, or to Paddy's Run. In many cases, the unplanned releases involved quantities of material that were similar in magnitude to daily discharges through MH 175. For example, the incidents on November 21, 1959 (Beers 1960a), January 28, 1960 (Flowers 1960a), and June 1961 (Cuthbert and Quigley 1961) involved the lost of from 2 to 11 kg U, but the main emphasis of these reports was on equipment failure or the need for better procedures.

Occasionally, unplanned releases involved large quantities that were easily measured at the Storm Sewer Lift Station and Manhole 175 (See Figure L-8). For example, in 1962, the uranium concentration measured at Manhole 175 was 125 mg L<sup>-1</sup> on September 10 (about 25 times the concentration measured for routine releases), and 15 mg L<sup>-1</sup> on September 11, reflecting the release of approximately 1000 pounds (450 kg) of uranium to the storm sewer from a digester filter overflow in Plant 8 on September 10. The unplanned releases of September 4 and September 7, 1962 were monitored at Manhole 175 as higher-than-usual concentrations of 10 mg L<sup>-1</sup> on September 5, 45 mg L<sup>-1</sup> on September 6, and 45 mg L<sup>-1</sup> uranium on September 8. This series of losses of materials to the storm sewer system during September 1962 contributed to the highest estimated monthly release of 1500  $\pm$  240 kg ( $\pm$ standard deviation) of uranium via Manhole 175 (Tables L-3 and L-4), compared to the average monthly discharge of about 350 kg in 33 million gallons of effluent.

1. 121

Page L-31

I

|                             | I                                     | sinuent System    | at the FMPC                                  |
|-----------------------------|---------------------------------------|-------------------|----------------------------------------------|
| Date                        | • •.                                  |                   |                                              |
| (reference)                 | Plant Area                            | Release Amount    | Description of Event or Circumstances        |
| 9 June 1954                 | Roadway                               | 871 lb. South     | Transport trailer broke loose from train,    |
| (Costa 1955)                | storage pad                           | African           | spilling contents of 16 drums; cleaned up    |
|                             | to Plant 2                            | Concentrate       | and drummed.                                 |
| •                           |                                       |                   |                                              |
| 6 Dec 1954                  | Storage pad                           | Unknown           | Diuranate cake and black oxide in dollies    |
| (Harrell 1954)              |                                       |                   | turned over, splitting two drums of          |
| · .                         | н.<br>1                               |                   | diuranate cake                               |
| ·                           | · · · · · · · · · · · · · · · · · · · | 4                 |                                              |
| July 1955                   | Plant 1 pad                           | Unknown           | Scrap material spilled over pad due to poor  |
| (NLCO 1955).                | •                                     |                   | stacking of material and burst drums         |
|                             |                                       |                   | causing greater contamination than           |
|                             |                                       |                   | normal of ground and storm sewers.           |
|                             |                                       |                   |                                              |
| Oct 1955                    | Plant 2/3                             | Varies from 2 to  | NW corner of acid recovery contamination     |
| (Glass 1955a;               | •                                     | 26 x maximum      | by raffinate dumping station to storm        |
| Stewart 1955)               |                                       | allowable conc.   | sewer: ruptured drums on pad lost to         |
|                             |                                       | (MAC) of 0.22     | Paddy's Run at the scrap pit.                |
|                             |                                       | $dpm mL^{-1}$ .   | -                                            |
| 1 Nov 1955                  | Plant 2/3                             | 26 lb. of U in    | Loss due to removal and cleaning of vapor    |
| (Chapman 1955)              |                                       | 195,000 gallons   | lines between denitration and acid           |
|                             |                                       |                   | recovery                                     |
| 9 May 1055                  | Diant C                               |                   |                                              |
| 2 1907 1955<br>(Class 1955) | Conoral                               | 40 lb. from       | Reinery sump surge capacity reached so       |
|                             | sump                                  | river in 20 000   | levels detected in Tank F18-1 Cause          |
|                             |                                       | gallons.          | traced to filter problem in Plant 6.         |
|                             |                                       | •                 |                                              |
| 17 Nov 1955                 | General                               | 19 16.            | Spill of 2000 gallons of calciner feed in    |
| (Chapman 1955)              | Sump                                  |                   | Combined Raffinate Area.                     |
| 23 Nov 1955                 | Plant 2/3                             | 28 0 lb II in     | Condenante france de situation versen line   |
| (Stewart 1955)              | I lance 20                            | 341 000 gallons   | went to general sump prior to analysis:      |
|                             |                                       | e 11,000 Bullions | after analysis $(10 \sigma L^{-1})$ material |
| •.                          |                                       | •                 | drummed and returned to refinery.            |
| 25 January 1956             | K-65 Silo                             | Estimated 1000    | Metal oxide dust blew out between the top    |
| (Strattman 1956)            | Area                                  | lb. of 2700 lb.   | and sidewalk of the first silo, covering     |
|                             | ι.                                    | insoluble metal   | several hundred feet around silo; removed    |
|                             |                                       | Oxide that was    | with snow layer to concrete trench betweer   |
|                             |                                       | sent to the silo. | Plant I and Kellnery.                        |
| 7, 19 Mar 1957              | Storm                                 | 53 lb/day: 10 mg  | Unknown cause: high "II" stream flushed      |
|                             | <b>^</b>                              | - 1               |                                              |

(continued on next page)

Radiological Assessments Corporation "Setting the standard in environmental health"

# 

5

**,** is

2

### Page L-32

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

| Date<br>(reference)            | " Plant Area                        | Release Amount                                                                                                                  | Description of Event or Circumstances                                                                                                                                                                                 |
|--------------------------------|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3 April 1957<br>(DeFazin 1957) | Roadway                             | Spill material<br>12,000 mg U L <sup>-1</sup>                                                                                   | Barrel of material spilled on road at "B"<br>and 2nd Street; material pushed into<br>Storm Sewer manhole.                                                                                                             |
| 22 July 1958<br>(Noyes 1958)   | Drainage<br>system at<br>NE corner  | a di Cara di<br>Cara di Cara di | Proposal to modify and repair drainage<br>system surrounding Production Area to<br>eliminate recurrence of flood condition.                                                                                           |
| 16 Sep 1958<br>(Ross 1958)     | Refinery<br>Area                    | 8.32 mg L <sup>−1</sup> . ∰ to g                                                                                                | Spill of raffinate in refinery area showed a U concentration of 4100 mg $L^{-1}$ ; rain washed spill to storm sewer and Paddy's Run.                                                                                  |
| 23 July 1959<br>(Harr 1959)    | Plant 2/3                           | 1000 lb. U; about<br>400 lb. to storm<br>sewer                                                                                  | Release of hot uranyl nitrate solution from<br>the 8" vent of the #212 sparge tank on to<br>the denitration pad, the roadway east of<br>the Refinery and the gravel area east to<br>Plant 4. Gravel excavated to pit. |
| 21 Nov 1959<br>(Beers 1960a)   | Plant 8<br>Storm<br>Sewer           | 500–750 gallons<br>of 1800 mg L <sup>-1</sup><br>U; 12 lb.                                                                      | Digestion filter pump failure                                                                                                                                                                                         |
| 5 Jan 1960<br>(Flowers 1960a)  | Source<br>unknown                   | 46 kg (101 lb.)                                                                                                                 | Detected in storm sewer and MH 175<br>samples; concentration 12 mg U L <sup>-1</sup> .                                                                                                                                |
| 28 Jan 1960<br>(Flowers 1960a) | Plant 8                             | 11 kg (24 Tb.)                                                                                                                  | Not given                                                                                                                                                                                                             |
| 18 Feb 1960<br>(Flowers 1960b) | Plant 8 to<br>Pit 3                 | "Unknown"<br>(MAC not<br>exceeded in<br>Paddy's Run)                                                                            | Effluent line from Plant 8 broke near entry<br>to Pit 3; flow to Paddy's Run via drainage<br>'ditches                                                                                                                 |
| 29 Aug 1960<br>(Harr 1960)     | General<br>Sump                     | · 111 lb. U to<br>waste pit                                                                                                     | One of tanks (F18E-3) was pumped too pit before analysis.                                                                                                                                                             |
| 1 Oct 1960 (Beers<br>1960b)    | Plant 8<br>Storm<br>Sewer           | <b>70 kg (155 lb.</b><br>(UO <sub>3</sub> ) 20 V love<br>(UO <sub>3</sub> ) 10 V                                                | Not clear; 16.5 mg U L <sup>-1</sup> detected in storm<br>sewer and MH 175 samples.                                                                                                                                   |
| 20 Feb 1961<br>(Starkey 1961a) | Pilot Plant,<br>west side           | Not given in report                                                                                                             | Process and contaminated water pumped<br>onto ground; area "cleaned up".                                                                                                                                              |
| 20 Mar 1961 (Bravard 1961a)    | Sump Area,<br>Plant 9 "D"<br>Street | Spill material<br>had 1 g U L <sup>-1</sup> ; "2<br>-3 mR h <sup>-1</sup> "                                                     | Overflow of sump pit that empties filtrate<br>hold tank diked area to graveled area<br>covering 10' by 40'.                                                                                                           |

#### Table L 10 3.5

(continued on next page)

٠

í.

ŗ

1.....

19.11 al 10

1.1.1

ļ

. بروان بروان .

| Table L-10. Majo | r Unplanned Liquid Releases and Spills to the Onsite Liq | uid |
|------------------|----------------------------------------------------------|-----|
| •                | Effluent System at the FMPC (continued)                  | •   |

| Date                                                   |                              | :/*                                                                |                                                                                                                                                  |
|--------------------------------------------------------|------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| (reference)                                            | Plant Area                   | Release Amount                                                     | Description of Event or Circumstances                                                                                                            |
| 27 Mar 1961<br>(Bravard 1961b)                         | Plant 9, So.<br>gravel area  | 150 kg (330 lb.);<br>10 gal drum<br>black oxide                    | 55–gal drum with 10–gal drum inside<br>failed when burning briquettes added; area<br>cleaned up.                                                 |
| 28 Apr 1961<br>(Beers 1961)                            | Plant 8 UAP<br>Acid Filtrate | 158 kg (347 lb.)<br>U; 830 gal of 50 g<br>U L <sup>-1</sup> .      | Spill contaminated 40–50 yards of gravel;<br>storm sewer was closed and material was<br>drummed                                                  |
| Jun 1961<br>(Cuthbert &<br>Quigley 1961)               | Pilot Plant,<br>outside      | 1.5 kg (3 lb.) U                                                   | Area SW of Pilot Plant; material removed<br>to waste pit.                                                                                        |
| 4 Sep 1962<br>(Gessiness 1962)                         | Plant 1<br>storage pad       | 91 SS kg U (200<br>SS lb.)                                         | Leakage from drums of contaminated solvent being transported to digestion.                                                                       |
| 7 Sep 1962<br>(Gessiness 1962)                         | Plant 1<br>Storage Pad       | 307 SS kg (675<br>SS lb.)                                          | Leakage from drums of contaminated solvent being transported to digestion.                                                                       |
| 10 Sep 1962<br>(Noyes 1962a;<br>Strattman '62;)        | Plant 8<br>Storm<br>Sewer    | 455 kg(1000 lb.)<br>U in 1820 gallons                              | Winlo digestion filter overflow of liquid containing UO <sub>2</sub> Cl <sub>2</sub> .                                                           |
| 13 Dec 1962<br>(Beers 1962;<br>Noyes 1962b &<br>1962c) | Plant 8<br>Storm<br>Sewer    | 70 SS kg (153 lb.)<br>enrich U, 92 SS<br>kg (203 lb.)<br>normal U. | Calculated release based on storm sewer<br>sample from MH 23 and digester sample in<br>Plant 8; due to plugged filtrate line to<br>precipitator. |
| 1–10 Mar 1964<br>(Starkey 1964b)                       | ·                            | 1640 lb. U to<br>Paddy's Run                                       | Not clear; probably involved Plant 8.                                                                                                            |
| 14 Feb 1966<br>(Starkey 1966a)                         | Pilot Plant                  | 1230 lb. U                                                         | UF <sub>6</sub> release.                                                                                                                         |
| 6 Jun 1966<br>(Nelson 1966)                            | Plant 2                      | 900 lb.                                                            | Process "slop" liquor leaked from diked<br>area beneath the NE and SE hold tanks on<br>N side of refinery.                                       |
| 2 Aug 1966<br>(Noyes 1966)                             | Plant 2                      | 600 lb. of U at<br>1.12% <sup>235</sup> U                          | Open nitric acid value to NE hold tank<br>allowed overflow of materials with U<br>concentration of 50–70 g $L^{-1}$ to storm<br>sewer.           |
| 12 Oct 1966<br>(Starkey 1966b)                         | Plant 3                      | 100 lb. U onto<br>graveled area                                    | Leaking overhead line near the SE corner<br>of the plant; some gravel was removed for<br>reprocessing.                                           |

(continued on next page)

Radiological Assessments Corporation "Setting the standard in environmental health"

ļ

| Page 1 | L-34 |
|--------|------|
|--------|------|

۰. بر

.

おとろう

10.00 LA

11.5V124.22

والمستانية

12/11

| Date                                       |                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Date<br>(reference) Pla                    | nt Area Poloaco Amour                                                                                                                                        | · Deseriation of French on Circlemeterson                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| January 1967 Plan                          | t 8 Various and the                                                                                                                                          | Le Description ni Event or Circumstances                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Risetanhorr                                | varinus i i                                                                                                                                                  | OAr filter, filtrate receiver problems                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 10071                                      |                                                                                                                                                              | resulted in 8 contamination notices.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 1907)                                      |                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| March 1967 'Plan<br>(Riestenberg           | t 8 Various                                                                                                                                                  | Sump filter problems: frozen discharge<br>line.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 1967) ···································· | na de la construction de la construction<br>Na construction de la construction d | ng 1997 - Charles Marine, ann an Anna br>Anna anns an Anna an Ann                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 28 Jun 1967 Plan                           | t 2/3 41 to 100 lb. U i                                                                                                                                      | n 👾 Slop Tank F1-25A, located in diked area                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| (Levy 1967)                                | 450,000 gal. (17                                                                                                                                             | 6 of plant, overflowed; most contained, som                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|                                            | g L <sup>-1</sup> ).                                                                                                                                         | leaked via trenches to storm sewer.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 10 Oct 1968 Plan<br>(Starkey 1969)         | t 8 1–2 mR hr <sup>-1</sup><br>reading                                                                                                                       | Liquid material coming from UAP scrubb<br>stack covered ground area of 26' by 15'; no<br>action taken.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|                                            |                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| - 14 Oct 1968<br>(Starkey 1969)            | t 8 5 mR hr <sup>-1</sup> , b<br>reading (6.0, 1),                                                                                                           | Spill covering 4' by 4' area at edge of pad<br>near Bldg. 72 scale area; area cleaned.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Feb 1969 Plan                              | t 8 About 500 lb. in                                                                                                                                         | Trouble with acid filtrate pumps causing                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| (Riestenberg<br>1969a)                     | two weeks                                                                                                                                                    | low pH readings at lift station; two rebuil<br>centrifugal pumps installed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| March 1969                                 | t 2/3 100 mg L-1 at 5                                                                                                                                        | 5 Flushing pad area on west end of Refiner                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| (Riestenberg                               | -65 gpm in stor                                                                                                                                              | n station in the state of the s |
| 1969Ы                                      | sewer                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Dec 1971 Stor<br>(Ross 1972) Sewe          | m Several hundred<br>er lb./mo.                                                                                                                              | Should investigate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 27 Apr, 3 and 8 Plan                       | t 6 Up to 11 mg $L^{-1}$                                                                                                                                     | Briquette processing floor leak, and broke                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| May 1978                                   | U at storm                                                                                                                                                   | storm sewer line; operations stopped unt                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| (Riestenberg                               | sewer: 50 mg L                                                                                                                                               | 1 floor repairs completed; flow to MH 175                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>1978)</b>                               | at MH near Plt                                                                                                                                               | 6. Howas diverted to General Sump.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 18 January 1988 Plan                       | t 2/3 40 lb. (19 kg)                                                                                                                                         | Plant 2/3 roof and ground area NE of pla                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| (WMCO 1989)                                | uranium                                                                                                                                                      | contaminated with uranyl nitrate vented                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                                            | the set block                                                                                                                                                | through stack with water vapor.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                            | <u> </u>                                                                                                                                                     | Habber - The state of the state |
| Spring 1989 Grav<br>(Dugan et al. S of     | vel area 1356 lb. (615 kg<br>Plant 7 – black material;                                                                                                       | )Black material (fly ash) fell from a dump<br>U :                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

### \_..! . -

, •

 A Constant of the state of the · . • • • 200 ••••• . • . . . . •

> . .\*

. . . . . . 

~

1.5

7

Because very little rainfall fell during September 1962 (Table L1-23), the loss of uranium to Paddy's Run Creek was only  $6 \pm 3 \text{ kg}$  ( $\pm$  standard deviation) with an estimated monthly volume loss of 110,000  $\pm$  21,000 gallons ( $\pm$  standard deviation). Although highly dependent on rainfall, the average discharge per month to Paddy's Run Creek during this period was roughly 140 kg in 3 to 5 million gallons of water (Tables L-6 and L-7).

In 1955, daily measurements from September through December indicate quite high uranium concentration measurements at MH 175 on November 2 (7.6 mg  $L^{-1}$ ), and November 30 (6.2 mg  $L^{-1}$ ), compared to an average 4 mg U  $L^{-1}$ . These events were related to filtration problems in Plant 6, and to cleaning the denitration vapor lines when condensate from the line was sent to the General Sump without analysis; respectively (Chapman 1955). The material was drummed and returned to refinery for further processing.

In February, March, and April 1964, more uranium was lost to the storm sewer (over 5000 lb.) than in any other three-month period of operations (Fischoff 1964a, 1964b, 1964c). Although no single cause was given for this high loss of materials, varying factors apparently contributed to it. There were extreme weather conditions over the previous eight months with higher than average rainfall. During this time, additional storage pads were being constructed to prevent further spills onto dirt and graveled areas, and this activity may have loosened dirt as a source of contamination in runoff. Finally, work began on repairing the Plant 8 roof where a chronic ground and storm sewer contamination problem existed. During this repair in February and March, all loose contamination was to be removed from the roof before resurfacing and gutter replacement. This loose contamination may have been a source of storm sewer contamination, although it is not clear from the available documentation how the material was handled. This work was completed by April 1964, when a significant portion of the Plant 8 roof area was connected to down spouts directly to the plant sump system (Starkey 1964c). Interestingly, K.N. Ross, of the Industrial Hygiene and Radiation Department who noted contamination problems in memoranda and reports, was on leave from the site at the Nuclear Metals Division in Albany, NY from January 13, 1964 to May 18, 1964.

What seemed to be more common was the situation where a higher than average uranium concentration was noted at MH 175 alerting personnel that an unplanned release or spill of materials containing uranium had occurred. The origin of these higher releases could not always be traced to a definite source or particular location within the facility. For example, in 1960 higher uranium concentrations were measured on January 5 (12 mg L<sup>-1</sup>), February 9 (10 mg L<sup>-1</sup>), February 18 (13 mg L<sup>-1</sup>), April 11 (30 mg L<sup>-1</sup>), and May 15 (21 mg L<sup>-1</sup>) than the average range of 2 to 6 mg L<sup>-1</sup> uranium (See Table L1-6, annex). Based on these concentration measurements and the corresponding volumes for that day, the probable size of the release or discharge would be calculated (Flowers, 1960a; Beers, 1960b).

On other occasions, situations occurred which did not seem to produce an effect upon the uranium concentration in the effluent at MH 175, such as those in March and April 1961 when an overflow in a sump pit occurred, and Plant 8 UAP acid filtrate spilled and contaminated 40-50 yards of gravel (Table L-10). Furthermore, the addition of contaminated water from extinguishing radioactive fires, or flushing of spill areas into manholes, which were not infrequent events, were not always seen at MH 175 (Fischoff 1961). Such conditions may have been due to closing the storm sewer near the spill until it was cleaned up, or to an insufficient volume of the effluent for proper flow in the lines

#### Page L-36

1999 - L

0.435

1. 1. S. S. S.

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

caused by low rainfall. Another possibility is the occurrence of extreme freezing temperatures during a particular month which would cause accumulation in the lines (Fischoff 1961). Generally, these latter incidents were noted when melting snow or excess rainfall increased the effluent flow through the lines causing a higher-than-usual flow and greater quantities of uranium at MH 175, such as during periods in February and April 1961 when the average volume and uranium concentration were about twice as high as normal (Table L1-7, annex).

Clearly, Manhole 175 sampling, results often did not correlate well with known abnormal releases in the process area. The reverse was also true. In many cases the magnitude of "routine" releases masked the unplanned discharges of some material. On some occasions, excess uranium was noted on the day of an unusual or unplanned occurrence, while other events occurred which did not seem to produce an effect at the sampling location (Fischoff 1961b). It does appear, however, that the major unplanned releases were detected (e.g. September 10, 1962) at the discharge points from the site. The fact that the large increases in uranium concentration in effluent discharged to the storm sewer system (Figure L-8) correspond to documented accidental spills bears this out. Thus, it is probable that unplanned or accidental liquid releases or spills were detected and have been accounted for as additions to the "usual" or "routine" discharges of uranium measured at Manhole 175 and Paddy's Run Creek. The review of incident reports covering all years of operations suggests that major incidents were not missed, and information regarding major and minor incidents of all kinds were communicated rather frequently by memo, report or letter.

#### CHEMICAL AND PHYSICAL FORM OF URANIUM IN LIQUID EFFLUENTS

Several uranium species of both the +4 and +6 oxidation states may have been present in solution in liquid waste streams flowing from the FMPC. The species containing uranium of the +6 oxidation state would probably predominate because most of the uranium discards to the General Sump came from Plant 2/3 (Table L-1), in which the liquid digested material was composed of hexavalent uranium compounds almost exclusively. Uranium in the +4 oxidation state in the form of green salt (UF4) was also discharged from some of the other plants. In addition, some uranium-containing solids which have not been identified specifically were carried in suspension in the liquid waste streams (Alpaugh 1956). There may also have been very small particulates of the insoluble compounds  $U_3O_8$  and  $UO_2$ among the suspended solids.

The species of uranium in the +6 state would include the well-known uranyl ion,  $UO_2^{++}$ , and hydrolytic products such as  $UO_2(OH)^+$ ,  $(UO_2)_2(OH)_2^{++}$ ,  $(UO_2)_3(OH)_4^{++}$ , and others. The very complex hydrolytic reactions involving these species have been described in the literature (Gmelin 1984). The ratios of these various ionic species in waste streams, Paddy's Run Creek, or the Great Miami River would be a function of the pH of the water. Based on the volume of liquid effluent discharged to the river (Tables L-4 and L-7, Figure L-3), most of the UF<sub>4</sub> releases from the plants would have dissolved in the waste streams even though it is not very soluble in water (about 30 mg L<sup>-1</sup>). Hydrolytic reactions of UF<sub>4</sub> probably occurred. Some of the unidentified suspended solids containing uranium that were released in the waste streams might have dissolved during the continued dilution downstream.

The presence of suspended solids in liquid process waste discharged to the Miami River

• •

<u>.</u>

Page L-37

ł

is considered in assessing the relative solubility of uranium in liquid releases. General concern about the level of total suspended solids (TSS) or filterable materials in the liquid effluents to the river was a long-standing issue at the site (Starkey et al. 1962). The primary problem was that "settleability and radioactivity of the solids are such that the State of Ohio pollution standards cannot always be met without serious curtailment of production processes" (Boback and Heatherton 1958). Daily measurements of TSS were made on 24-hour composite effluent samples at MH 175 beginning in 1956 (NLCO 1956). Table L1-24 in the annex lists the daily measurements of TSS to the river in 1957, and shows the extreme fluctuation for that year because no settling occurred before discharge to the river. The annual average value in 1957 was 400 mg  $L^{-1}$ , with a maximum of 4600 mg  $L^{-1}$  measured on October 12, 1957. After April 1958, all solids from the General Sump were sent to Pit 3 for settling, and the liquor pumped to the river via MH 175. This improvement was reflected in the decline of average TSS at MH 175 to less than 100 mg  $L^{-1}$  in the 1960s and early 1970s (Figure L-10). The decline continued to less than 25 mg  $L^{-1}$  since 1975. Table L1-25 summarizes the monthly average TSS concentrations in liquid effluents for 1957 to 1966.

Various chemicals and coagulants were tested to assess their effectiveness in removing these solids. In a series of twelve tests in 1958 on effluent samples from around the site, Separan 210, a Dow Chemical Company flocculating agent, reduced the TSS by approximately 70%, beta activity by 90% and alpha activity by 74%. Based on these tests, a TSS concentration of 25 parts per million (ppm) was suggested as a design criterion for wastes released to the river (Boback & Heatherton 1958). After 1958, the TSS in effluents dropped significantly with the transfer of material to the General Sump for settling before release to the river. In the seventies, the U.S. EPA National Pollutant Discharge Elimination System (NPDES) permit for TSS was set at 100 mg L<sup>-1</sup> (Boback et al. 1977).

Similarly, methods were assessed for their usefulness in removing soluble uranium from the liquid effluent (Dugan 1971). In 1971, tests results showed that the addition of lime slurry decreased the soluble uranium concentration of storm sewer effluent. However, the addition of lime to the storm sewer to neutralize acid spills and to prevent corrosion at the lift station was usually associated with higher TSS levels in effluents to the river (Boback 1971b). Other causes of TSS exceeding the limit were related to runoff from the coal pile (Starkey 1968b) and variable pH of the effluent (Boback 1971c).

In summary, the ratios of various ionic species of uranium compounds in waste streams, Paddy's Run Creek, or the Great Miami River is a function of the pH of the water. Based on the high volume of liquid effluent released, many of the uranium species released from the plants would have dissolved in the waste streams, although suspended solids were prevalent in the effluent. Among the suspended solids may have been very small particulates of the insoluble compounds  $U_3O_8$  and  $UO_2$ . It is clear that not all the suspended solids measured on a daily basis were uranium, but the average monthly values may provide an upper bound for the amount of insoluble uranium released in liquid effluent.



 $\overline{\phantom{a}}$ 

No.

1.1.1.1.1.1.1

5.000

なもうこと

Į,

×

Figure L-10. Annual average concentration of total suspended solids in liquid effluents released at MH 175 to the river. Daily measurements were made beginning in 1956 at MH 175. Major improvements in the liquid effluent treatment in 1958 lead to a significant decrease in TSS.

#### RADIONUCLIDES OTHER THAN URANIUM

Uranium was the primary material processed at the FMPC with some thorium processing occurring at various times. Most of the feed material had previously been separated chemically from the naturally occurring daughter radionuclides. Consequently, most effluents from the facility consisted primarily of uranium and, when it was being processed, thorium. Beginning in 1953, thorium operations were performed in the Metals Fabrication Plant (Plant 6), Recovery Plant (Plant 8), Special Products Plant (Plant 9) and the Pilot Plant. Thorium oxide for thorium metal conversion was made during the period of 1954 to 1956 by aqueous precipitation of thorium fluoride from an aqueous hydrofluoric acid solution (Jester 1964). Severe corrosion problems, caused by hot nitric-hydrofluoric acid mixtures, forced a change to the more expensive oxalate process in Plant 9. Appendix D in this report, and Appendix C in the Task 4 report, Environmental Pathways - Models and Validation, describe the products of radioactive decay of uranium and thorium. Four isotopes of radium naturally occur as decay products of thorium and uranium. Two of these, <sup>228</sup>Ra and <sup>224</sup>Ra, are decay products of thorium. Radium-223 is a decay product of <sup>235</sup>U, and  $^{226}$ Ra is a decay product of  $^{238}$ U. When the relative importance of releases of these radionuclides to water was assessed for the 1960 to 1962 period, it was found that the radium isotopes were of primary importance (Appendix C, Killough et al. 1993).

Appendix D also describes other radionuclides that were released during FMPC operations from the processing of recycled uranium, that is, uranium that was not completely separated from fission and activation products before it was returned to the FMPC as feed material. Recycled uranium was processed at the FMPC beginning in the fall of 1962 (Voillequé et al. 1991). When recycled uranium was processed, some fission and

| Liq                 | uid Effluents Fro | m the FMPC   |             |
|---------------------|-------------------|--------------|-------------|
| Materials in Liquid | Releases Began    | Measurements | Information |
| Effluents           |                   | Began        | Source      |
| Decay Products      |                   |              |             |
| Total Thorium       | 1954              | 1956         | a, b, c     |
| Total Radium        | 1952              | 1955         | а           |
| <sup>226</sup> Ra   | 1952 ·            | 1968         | a, b, c     |
| <sup>228</sup> Ra   | 1954              | - 1968       | a, b, c     |
| Fission Products    |                   |              |             |
| <sup>90</sup> Sr    | Fall 1962         | 1976         | d           |
| <sup>99</sup> Tc    | Fall 1962         | 1969         | b, d        |
| <sup>106</sup> Ru   | Fall 1962         | 1976         | b, d        |
| <sup>137</sup> Cs   | Fall 1962         | .1976        | d           |
| Activation Products |                   |              |             |
| <sup>237</sup> Np   | Fall 1962         | 1976         | đ           |
| <sup>238</sup> Pu   | Fall 1962         | 1976         | d           |
| 239,240Pu           | Fall 1962         | 1976         | d           |

| Table L-11. Decay, Fission and Activation Products Released in |
|----------------------------------------------------------------|
| Liquid Effluents From the FMPC                                 |

<sup>a</sup> Original analytical data sheets for some periods; NLCO 1955b, NLCO 1956, NLCO 1957, NLCO 1969, NLCO 1970, NLCO 1971, NLCO 1972, NLCO 1973, NLCO 1974.

<sup>b</sup> Various monthly reports including routine operating loss reports, Industrial Hygiene and Radiation Department reports and Aquifer Contamination Reports.

<sup>c</sup> Based on correlations between releases of uranium and other radionuclides when measurements were made; see Table L-13.

<sup>d</sup> Based on correlations between releases of uranium and other radionuclides when measurements were made; see Table L-12.

Thorium and radium were measured in liquid effluents beginning in the early 1950s, and original analytical data sheets for radium measurements were located for 1955, 1956, 1957, 1969 and 1970–1974 (Tables L1–25 to L1–32), and for thorium for 1956 and 1957 (Tables L1–33 and L1–34). Measurements were made on weekly or biweekly composites for radium, and monthly composites for thorium. A regular sampling program for <sup>226</sup>Ra and <sup>228</sup>Ra was begun in 1968, for <sup>99</sup>Tc in 1969, and for all other radionuclides of interest in 1976 (Boback et al. 1987, NLCO 1975). Periodic monthly composite samples from MH 175 were analyzed for <sup>99</sup>Tc (technetium) and <sup>106</sup>Ru-<sup>106</sup>Rh (ruthenium-rhodium) activity beginning in the late 1960s when higher levels of beta activity were measured in effluents sent to Waste Pit 3 (Starkey 1968a, NLCO 1971, NLCO 1974). However, the bioassay lab procedure for <sup>106</sup>Ru was not documented for those years (Berger et al. 1985). Routinely, monthly composites of the daily samples from MH 175 were analyzed for <sup>226</sup>Ra, <sup>228</sup>Ra, <sup>106</sup>Ru and thorium with annual composites analyzed for the other radionuclides through the mid-1980s. Analysis of <sup>232</sup>Th in liquid wastes to the river replaced total thorium measurements in 1984 (Facemire et al. 1985).

1. N. W. S.

1.00

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

Release estimates of these other radionuclides are based on correlations between the total annual releases of uranium and those of the other radionuclides. These ratios of releases, computed for years when measurements were made, provide a basis for estimating the release of the other radionuclides for years when they were not measured. This methodology is described in Appendix D in the present report, and in Appendix C of Task 4 (Killough et al. 1993). Ratios of the annual average activity of a radionuclide (or, quantity of thorium) to the annual uranium quantity were calculated for years when data were available. The measured concentrations at MH 175 reported in analytical data sheets were used to calculate the ratio for some years (NLCO 1955b, NLCO 1956, NLCO 1957, NLCO 1969, NLCO 1970, NLCO 1971, NLCO 1972, NLCO 1973, NLCO 1974). Annual average concentrations of radium, thorium and the fission and activation products in liquid effluents were reported by the FMPC in historic release reports (Boback et al. 1987), and in annual environmental monitoring reports (Boback et al. 1977, Boback et al. 1978, Boback & Ross 1979, Boback & Ross 1980, Boback & Ross 1981, Fleming et al. 1982, Fleming & Ross 1983. Fleming & Ross 1984, Facemire et al. 1985, Aas et al. 1986, Aas et al. 1987, WMCO 1988, WMCO 1989). The annual average uranium concentration at MH 175, or total quantity of uranium to the river was used for these correlations depending upon the source of data (analytical data sheets or total release estimates, respectively). The variability of the release ratio from year to year was considered in deriving the uncertainty associated with the estimated releases of these other radionuclides. The release estimates and uncertainty analysis were computed using Monte Carlo techniques in the Crystal Ball' program (Decisioneering 1993), assuming a lognormal distribution for the ratios of the radionuclide of interest to uranium.

Table L-12 shows the relative concentrations of activation and fission products relative to uranium,  $\mu$ Ci (kg U)<sup>-1</sup>, based on thirteen years of measurements. For radium and thorium, the ratios are based on a somewhat longer measurement history. Table L-13 shows that the ratios of releases are based on measurements as early as 1956 for thorium, and 1968 for <sup>226</sup>Ra and <sup>228</sup>Ra. Measurements of total radium, made in the early 1950s (NLCO 1955b, NLCO 1956, NLCO 1957), were used to calculate a ratio of <sup>226</sup>Ra activity (assuming a specific activity of 0.99 µCi per µg Ra) to uranium, which was used to estimate 226Ra releases in the 1950s. During the 1950s, the <sup>226</sup>Ra concentrations are higher than in later years because, from October 1955 to August 1958, some of the uranium ore processed was pitchblende, which had very high uranium (and thus decay product) concentrations (See Appendix J). For later years, a second  $^{226}$ Ra ratio (50 ± 80 µCi (kg U)<sup>-1</sup>) based on measurements made from 1968-1988; was used to calculate releases estimates. A single ratio for  $^{228}$ Ra to uranium (90 ± 80 µCi (kg U)<sup>-1</sup>), based on measurements made from 1968-1988, was used to calculate <sup>228</sup>Ra releases. These estimates were calculated for years when thorium processing occurred, because <sup>228</sup>Ra is a decay product of thorium (See Appendix D).

Relative concentrations of thorium with respect to uranium are reported as kilograms of thorium per kilogram of uranium, (kg Th) (kg U)<sup>-1</sup>. Because thorium processing occurred only during specific years, release estimates are calculated for 1954 to 1957, and for 1968-1988. Ratios of thorium to uranium quantities were calculated for two periods: the 1950s and 1964-1988. The ratio for the early time  $[0.41 \pm 0.04 \text{ kg Th (kg U)}^{-1}]$  is based on concentrations of thorium to uranium measured at MH 175 in 1956 and 1957 (NLCO 1956, NLCO 1957). For later years, the ratio  $[0.013 \pm 0.015 \text{ kg Th} (\text{kg U})^{-1}]$  is based on measurements from 1967-1988.

. . .

: .

.

4

| (90          | Sr, <sup>99</sup> Tc, <sup>10</sup> | <sup>6</sup> Ru, <sup>137</sup> Cs) | Measured in       | Liquid Was         | ste Discha          | rges, µCi (k            | g U) <sup>-1</sup> a |
|--------------|-------------------------------------|-------------------------------------|-------------------|--------------------|---------------------|-------------------------|----------------------|
| Year         | <sup>239,240</sup> Pu               | <sup>238</sup> Pu                   | <sup>237</sup> Np | 1.47Cs             | [1 <sup>Ki</sup> Ru | 99 <b>T</b> c           | <sup>90</sup> Sr     |
| 1976         | 0.00024                             | 0.00049                             | 0.00024           | 24                 | 3.7                 | 1.1 x 10 <sup>4</sup>   | no data              |
| 1977         | <0.053                              | <0.024                              | <0.48             | 80                 | 7.8                 | 9.5 x 10 <sup>1</sup>   | 71                   |
| 1978         | <0.038                              | <0.027                              | 0.036             | 17                 | 1.2                 | $1.1 \ge 10^2$          | 7.8                  |
| 1979         | 0.024                               | 0.0082                              | 0.16              | 5.                 | 1.5                 | 2.8 x 10 <sup>3</sup>   | 2.6                  |
| 1980         | 2.2                                 | 0.006                               | <0.16             | <b>16</b> .        | 1.4                 | 1.4 x 10 <sup>3</sup>   | 4.1                  |
| 198 <u>1</u> | 0.05                                | 0.0088                              | <0.24             | 4 .                | 1.2                 | . 7.3 x 10 <sup>3</sup> | 4.3                  |
| 1982         | 0.02                                | 0.0065                              | 0.4               | 3.7                | 0.045               | 1.3 x 10 <sup>4</sup>   | 4.2                  |
| 1983         | 0.13                                | 0.0085                              | <0.30             | 9.3                | 0.51                | 3.5 x 10 <sup>4</sup>   | 9.8                  |
| 1984         | 0.049                               | 0.029                               | 0.20              | 17                 | 0.49                | 1.9 x 10 <sup>4</sup>   | 12                   |
| 1985         | 0.024                               | 0.012                               | <0.27             | 16                 | <0.68               | 1.3 x 10 <sup>4</sup>   | 8.5                  |
| 1986         | <0.022                              | <0.022                              | <0.022            | <2.2               | <22                 | 3.3 x 10 <sup>3</sup>   | 2                    |
| 1987         | <0.073                              | <0.072                              | <0.31             | <b>&lt;9.7</b> , j | <43                 | 3.5 x 10 <sup>3</sup>   | 2.9                  |
| 1988         | <0.028                              | <0.02                               | <0.04             | <6                 | <39                 | 7.3 x 10 <sup>3</sup>   | 1.5                  |
|              |                                     |                                     |                   | • .                |                     |                         |                      |
| Mean         | 0.31                                | 0.01                                | 0.16              | 19                 | 2.0                 | $8.9 \times 10^3$       | 11                   |
| StdDev       | 0.76                                | 0.01                                | 0.16              | 22                 | 2.4                 | 9.7 x 10 <sup>3</sup>   | 19                   |

Table L-12. Relative Concentrations of Activation (Pu, Np) and Fission Products

<sup>a</sup> Data for these ratios of activity ( $\mu$ Ci) to quantity (kg) of uranium are taken from Annual Environmental Monitoring Reports (Boback et al. 1977, Boback et al. 1978, Boback & Ross 1979, Boback & Ross 1980, Boback & Ross 1981, Fleming et al. 1982, Fleming & Ross 1983, Fleming & Ross 1984, Facemire et al. 1985, Aas et al. 1986, Aas et al. 1987, WMCO 1988, WMCO 1989).

The result of these computations for thorium are shown in Figure L-11, where the relative quantities of total thorium are compared to the total quantity of uranium discharged in liquid effluents for those years when thorium was processed. The higher thorium releases in the 1950s were related to the fact that thorium oxide for thorium metal conversion was made during the period of 1954 to 1956 by aqueous precipitation of thorium fluoride from an aqueous hydrofluoric acid solution (Jester 1964). This process caused severe corrosion problems, caused by hot nitric-hydrofluoric acid mixtures. For later thorium operations, a change to the more expensive oxalate process in Plant 9 occurred. After 1964, the quantities of thorium discharged to the river were approximately two orders of magnitude less than the quantities of uranium. The thorium releases in the mid-1950s were substantially higher. Similarly, the relative changes in activity of <sup>228</sup>Ra and <sup>226</sup>Ra in liquid effluents from the FMPC with time, shown in Figure L-12, are similar to the pattern of thorium releases. The highest releases occurred during the 1950s and 1960s, with a gradual decrease in activity in the 1970s and 1980s. Tables L-14 and L-15 show the annual estimates for thorium, <sup>228</sup>Ra, and <sup>226</sup>Ra, discharged in liquid effluents from the FMPC, along with the uncertainty estimates for each measurement.

Figure L-13 displays the total release estimates for the radionuclides, <sup>239,240</sup>Pu, <sup>238</sup>Pu. <sup>237</sup>Np, <sup>137</sup>Cs, <sup>106</sup>Ru, <sup>99</sup>Tc, and <sup>90</sup>Sr, for all years of operations. Table L-16 provides the annual estimates of fission and activation products discharged in liquid effluents from the FMPC for each year from 1962 to 1988. Because the processing of recycled uranium at the

#### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

FMPC did not begin until October 1962, values for 1962 are based on only three months of operation. Since 1962, total releases of <sup>99</sup>Tc were approximately 300,000 mCi (300 Ci), with an uncertainty range of 100,000 to 800,000 mCi (100 to 800 Ci). The best estimate for releases of <sup>239,240</sup>Pu since 1962 is 8.8 mCi, with an uncertainty range of 1.9 to about 30 mCi.

Page L-42

|                                          |            | <sup>226</sup> Ra        | <sup>228</sup> Ra               | Thorium                    |
|------------------------------------------|------------|--------------------------|---------------------------------|----------------------------|
|                                          | Year       | μCi (kg U) <sup>-1</sup> | $\mu$ Ci (kg U) <sup>-1 a</sup> | kg Th (kg U) <sup>-1</sup> |
|                                          | 1955       | 1600 <sup>h</sup>        |                                 | ······                     |
|                                          | 1956       | 220 <sup>b</sup>         | •                               | 0.44                       |
|                                          | 1957       | 530 <sup>h</sup>         |                                 | 0.37                       |
| Me                                       | an (1950s) | 780                      |                                 | 0.41                       |
| Std                                      | ev (1950s) | 590                      |                                 | 0.04                       |
|                                          | 1967       | м                        | •                               | 0.012                      |
|                                          | 1968       | <b>270</b> · · ·         | . 590                           | 0.069                      |
| na tra construction<br>Second            | 1969       | 250                      | 390                             | 0.028                      |
| n an | 1970.      | 104 · · · ·              | 260                             | 0.015                      |
|                                          | 1971       | 1                        | 24                              | 0.018                      |
| •                                        | 1972 ·     | 48                       | 13                              | 0.016                      |
|                                          | 1973       | 21                       | 5.30                            | 0.008                      |
|                                          | 1974       | 7.50                     | 5.60                            | 0.017                      |
|                                          | 1975       | 7.02                     | 8.60                            | 0.0035                     |
| ·                                        | 1976       | 9.72                     | 11 •                            | 0.0076                     |
| •                                        | 1977       | 8.00                     | 77                              | 0.0057                     |
|                                          | 1978       | 3.81                     | 5.10                            | 0.0065 -                   |
|                                          | 1979       | 0.68                     | 8.20                            | 0.0061                     |
|                                          | 1980       | 0.56                     | 5.20                            | 0.0033                     |
|                                          | 1981       | 19                       | 12                              | 0.0053                     |
|                                          | 1982       | 4.03                     | 17                              | 0.0052                     |
|                                          | 1983       | 2.40 .                   | 11                              | 0.0035                     |
|                                          | 1984       | <17                      | <14                             | 0.0044                     |
|                                          | Moon       | 50                       |                                 | 0.013                      |
|                                          | mean       | 50                       | 30                              | 0.010                      |

Table L-13. Relative Concentrations of Radium and Thorium

Values are derived from the following sources: routine analytical data sheets for uranium,  $^{226}$ Ra and thorium in the 1950s (see Tables L1-1 to L1-13, L1-26 to L1-28 and L1-34 and L1-36), and <sup>228</sup>Ra in 1969, 1967–1975, Boback et al. 1987; 1976–1988, Annual

Environmental Monitoring Reports (Boback et al. 1977, Boback et al. 1978, Boback & Ross 1979, Boback & Ross 1980, Boback & Ross 1981, Fleming et al. 1982, Fleming & Ross 1983, Fleming & Ross 1984, Facemire et al. 1985, Aas et al. 1986, Aas et al. 1987, WMCO 1988, WMCO 1989). 1851 A. 19 20 Ĩ.

<sup>b</sup> For 1955, 1956 and 1957, the ratio is derived from total radium measurements of µµg per mL (Tables L1-26 to L1-28), assuming a specific activity of 0.99 µCi per µg Ra.



**Figure L-11.** Relative annual estimates for uranium and thorium released in liquid effluents from the FMPC. Thorium processing occurred from 1954 to 1957 and from 1964 through 1988. The uranium values represent total uranium quantities released to both the Great Miami River and to Paddy's Run Creek. Figure L-2 shows the uranium releases individually to the river and to Paddy's Run.



Figure L-12. Annual estimates of  $^{226}$ Ra and  $^{228}$ Ra releases in liquid effluents from the FMPC. Release estimates for  $^{228}$ Ra, a decay product of thorium, are given for 1954-1957, and 1964-1988, the years when thorium processing occurred (see Table L-15).

Radiological Assessments Corporation "Setting the standard in environmental health"

•

S

2



The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

5

いたの

CONTRACT NORT

÷



**Figure L-13.** Estimates of total activity of radium, fission and activation products released from the FMPC in liquid effluents. For radium, the values represent releases from 1952 to 1988; for the other radionuclides, releases occurred from 1962 onward. The uncertainty of each estimate is shown as the 95th and 5th percentiles.

Tables L-14 to L-16 also show the gradual decrease in release estimates in the 1970s and 1980s. These decreases over time for all radioactive materials are related to a general reduction in production activities from the higher levels observed in the fifties and sixties, as well as to a number of changes in liquid effluent handling and treatment at the site, including

- major improvements in the General Sump area for waste effluent processing in 1968, and the
- construction of new wet chemical Waste Pit 5 by 1969.

By 1967, Waste Pit 3 was nearly at its capacity. At the same time, the General Sump was processing large volumes of soluble high beta activity material from a variety of processing campaigns. However, the General Sump was in more frequent need of repairs by the mid-1960s. When holding tanks in the General Sump were being repaired, virtually all effluent from the General Sump was pumped to Waste Pit 3 before proper precipitation and settling could occur. To make more room in the pit, pumping from the waste pit clearwell was increased prior to complete settling of the material. A consequence of this was higher discharges of radionuclides to the river during the sixties.

In 1969, two new 15,000 gallon and a new 50,000 gallon sludge settling tanks in the General Sump area were installed, and a new head tank for regulating continuous discharge to the river was operational (OHIO 1968). Most importantly, the construction of the new wet chemical pit began on July 15, 1968, and was receiving material by the end of that year (Starkey 1968c). The first effluent from the new pit was pumped to the river on January 6, 1969 (Starkey 1969a).

. . .

| Table L-14. An   | nual Estimat<br>d Effluents F | es of Thoriun | n Discharged in<br>C (kg) <sup>a</sup> |
|------------------|-------------------------------|---------------|----------------------------------------|
| Diqui            | Median                        | tom the FML   |                                        |
| Year             | Estimate                      | 5th 77ile     | 95th %ile                              |
| 1954             | 1100                          | 800           | 1500                                   |
| 1955             | 1100                          | 830           | 1400                                   |
| 1956             | 1200                          | 910           | 1500                                   |
| 1957             | 1600                          | 1300          | 2100                                   |
| 1964             | 58                            | 11            | 280                                    |
| 1965             | 34                            | 8             | 150                                    |
| 1966             | 43                            | 9             | 190                                    |
| 1967             | 22                            | 5             | 100                                    |
| 1968             | 24                            | 5             | 110                                    |
| 196 <del>9</del> | 22                            | 5             | 110                                    |
| 1970             | 14                            | 3             | 63                                     |
| 1971             | 24                            | 5             | . 110                                  |
| 1972             | 13                            | 3             | 50                                     |
| 1973             | 16                            | 3             | 67                                     |
| 1974             | 11                            | 2             | 48                                     |
| 1975             | 10                            | 2             | 48                                     |
| 1976             | 9                             | 2             | 43                                     |
| . 1977           | 9                             | 2             | 44                                     |
| 1978             | 8                             | 2             | 41                                     |
| 1979             | . 10                          | 2             | 51                                     |
| 1980             | 6                             | 1             | 28                                     |
| 1981             | · 5                           | 1             | 24                                     |
| 1982             | 7                             | 1             | 30                                     |
| 1983             | 6                             | 1             | 26                                     |
| 1984             | 8                             | 2             | 37                                     |
| 1985             | 6                             | 1             | <b>25</b> ·                            |
| 1986             | 4                             | 1             | 20                                     |
| <b>1987</b>      | 7                             | 1 /           | 33                                     |
| <b>1988</b>      | .7                            | 1             | 35                                     |
| Total all years  | 5800                          | 3800          | 9400                                   |

а Estimates and uncertainties were calculated with CrystalBall Version 3.0 (Decisioneering 1993). No thorium processing occurred in 1952, 1953, or 1958-1963 (see Appendix C).

In the sixties, unusually high soluble beta activity, measured in the General Sump and the waste pits, was attributed to <sup>106</sup>Ru and <sup>99</sup>Tc from various processing campaigns such as the processing of NFS feed material which contained <sup>106</sup>Ru , or to high <sup>236</sup>U refinery runs (Starkey 1967b). In the oxidized state, both are soluble in basic and acidic solutions, so that they were not effectively removed by passage through the General Sump. By 1970, the beta activity attributed to soluble <sup>106</sup>Ru and <sup>99</sup>Tc had gradually decreased from the levels seen previously (Boback 1969).

> Radiological Assessments Corporation "Setting the standard in environmental health"

<u>;</u>

 $\dot{\mathbf{z}}$ 

. . , 1 .

5.1

|   |          | Radium-228  |                 | Radium-226                            |                  |             |           |
|---|----------|-------------|-----------------|---------------------------------------|------------------|-------------|-----------|
|   | •        | Median      | ·               | • • • • • • • • • • • • • • • • • • • | Median           |             |           |
|   | Year     | Estimate    | <u>5th %ile</u> | 95th %ile                             | Estimate         | 5th File    | 95th %ile |
|   | 1952     |             |                 |                                       | 1900             | 616         | 5300      |
|   | 1953     |             |                 |                                       | : 1700           | 535         | 4800      |
|   | 1954     | 110         | 14              | 930                                   | 1700             | 584         | 5300      |
|   | 1955     | 100         | 12              | 710                                   | 1700             | 622         | 5200      |
|   | 1956     | 130         | 17              | 1200                                  | . 1800           | 623         | 5400      |
|   | 1957 🕖   | -180        | · <b>2</b> 5    | 1300                                  | 2600             | 907         | 7700      |
|   | 1958 - j |             | :               | , <del>.</del> .                      | 2900             | 1105        | 8500      |
|   | 1959     |             |                 |                                       | 2200             | 822         | - 6400    |
|   | 1960     |             | •               | S. 6. 11.                             | 480              | 46          | . 3300    |
|   | 1961     |             |                 |                                       | 600              | 54          | 6300      |
|   | 1962     | -           | - *             | • •                                   | 540              | 52          | 5400      |
| • | 1963     |             |                 |                                       | <sup>-</sup> 130 | 21          | 870       |
|   | 1964     | 250         | 36              | 2000                                  | 180              | 27          | 1100      |
|   | 1965     | 170         | 23              | 1400                                  | 110              | 17          | 680       |
|   | 1966     | 200         | <b>2</b> 5      | 1600                                  | 130              | 21          | 830       |
|   | 1967     | 96          | 13              | 820                                   | 72               | 10          | 460       |
|   | 1968     | 120         | 15              | 1050                                  | 69               | 13          | 460       |
|   | 1969     | 110         | 11              | 880                                   | 68               | 11          | 490       |
|   | 1970     | 74          | 9               | 670                                   | : 50             | . 7         | 320       |
|   | 1971     | 95          | 13              | 800                                   | 72               | . 12 -      | 500       |
|   | 1972     | 53          | 7               | 450                                   | 36               | 5           | 240       |
|   | 1973     | 82          | 10              | 690                                   | 49               | 8           | 360       |
|   | 1974     | 38          | . 5             | 340                                   | 32               | 5           | 200       |
|   | 1975     | 48          | 6               | 440                                   | 31               | 5           | 200       |
|   | 1976     | 34          | 4 .             | 320                                   | 25               | 4           | 170       |
|   | 1977     | <b>48</b> · | 6               | 370                                   | 29               | 5           | 179       |
|   | 1978     | 42          | 5               | 300                                   | 25               | . 4         | 150       |
|   | 1979     | 63          | 6               | 500                                   | 31               | ST <b>4</b> | 200       |
|   | 1980 ·   | 33          | . 4             | 250                                   | 17               | 3           | 120       |
|   | 1981 - 1 | 29          | • 4             | 280 ·                                 | 15               | 2           | 100       |
|   | 1982     | . 33        | 5               | 260                                   | 20               | 3           | 120       |
|   | 1983 :   | 28          | 4               | 250                                   | 18               | 2           | 110       |
| • | 1984     | 41          | 5               | - 370                                 | 27               | - 4         | 180       |
|   | 1985 😒   | 32          | 4               | 280                                   | 17               | 3.03        | 100       |
|   | 1986     | 21          | · 3 ·           | 180                                   | 13               | 2           | 83        |
|   | 1987     | 40          | 5 5             | b 18 300                              | 23               | 3           | 130       |
|   | 1988     | 37          | 4               | 260                                   | 21               | 3           | 140       |
|   |          |             |                 |                                       |                  |             | •         |

#### 11.11 - 224743 Table L-15. Annual Estimates of <sup>228</sup>Ra and <sup>226</sup>Ra Discharged in

<sup>a</sup> Estimates and uncertainties were calculated with CrystalBall Version 3.0 (Decisioneering 1993). <sup>b</sup> Radium-228 is a decay product of thorium; estimates of <sup>228</sup>Ra releases are given for 1954-

1957, and 1964–1988, the years when thorium processing occurred. •

. ..

s and the later set of in des transmission

. . .

· •

| Year <sup>h</sup> | <sup>239,240</sup> Pu | <sup>238</sup> Pu | <sup>237</sup> Np | <sup>137</sup> Cs | <sup>106</sup> Ru | <sup>99</sup> Tc  | <sup>90</sup> Sr |
|-------------------|-----------------------|-------------------|-------------------|-------------------|-------------------|-------------------|------------------|
| 1962              | 0.39                  | 0.01              | 0.21              | 25                | 2.6               | 11000             | 270              |
| 1963              | 1.29                  | 0.04              | 0.69              | . 82              | 8.6               | . 38000           | 900              |
| 1964              | 1.23                  | 0.04              | 0.66              | 78                | 8.2               | 36000             | 860              |
| 1965              | 0.87                  | 0.03              | 0.46              | 55                | 5.8               | 26000             | 610              |
| 1966              | 1.35                  | 0.05              | 0.72              | 86                | 9.0               | 39600             | 940              |
| 1967              | 0.57                  | 0.02              | 0.30              | 36                | 3.8               | 16600             | 390              |
| 1968              | 0.72                  | 0.02              | 0.38              | · 46              | 4.8               | 21000             | 500              |
| 1969              | 0.69                  | 0.02              | 0.37              | 44                | 4.6               | 20200             | 480              |
| 1970              | 0.45                  | 0.02              | 0.24              | 29                | 3.0               | 13000             | 310              |
| 1971              | 0.66                  | 0.02              | 0.35              | 42                | 4.4               | 19000             | 460              |
| 1972              | 0.33                  | 0.01              | 0.18              | 21                | 2.2               | 9700              | 230              |
| 1973              | 0.51                  | 0.02              | 0.27              | 32                | 3.4               | 15000             | 360              |
| 1974              | 0.22                  | 0.01              | 0.12              | 14                | 1.4               | 6300              | 150 ·            |
| 1975              | 0.30                  | · 0.01            | 0.16              | 19                | 2.0               | <sup>-</sup> 8900 | 210              |
| 1976              | 0.22                  | 0.01              | 0.12              | 14 "              | 1.5               | 6400              | 150              |
| 1977              | 0.27                  | 0.01              | 0.15              | 17 -              | 1.8               | 8000              | 190              |
| 1978              | 0.26                  | 0.01              | 0.14              | 16                | 1.7               | 7500.             | 180              |
| 1979              | 0.32                  | 0.01              | 0.17              | 20                | 2.1               | 9200              | 220              |
| 1980              | 0.19                  | 0.01              | 0.10              | 12                | 1.3               | 5600              | 130              |
| 1981              | 0.18                  | 0.01              | 0.10              | 11                | 1.2               | 5300              | 130              |
| 1982              | 0.23                  | 0.01              | 0.12              | 14                | 1.5               | 6600              | 160              |
| 1983              | 0.18                  | 0.01              | 0.09              | 11                | 1.2               | 5200              | 120              |
| 1984              | 0.27                  | 0.01              | 0.14              | 17                | 1.8               | 7900              | 190              |
| 1985              | 0.17                  | 0.01              | 0.09              | 10                | 1.1               | 4800              | 120              |
| 1986              | 0.13                  | 0.00              | 0.07              | · 8               | 0.84              | 3700              | 88               |
| 1987              | 0.21                  | 0.01              | 0.11              | 13                | 1.4               | 6200              | 150              |
| 1988              | 0.22                  | 0.01              | 0.12              | 14                | 1.5               | 6500              | 160              |
| Fotal: all years  | 8.8                   | 0.28              | 4.4               | 540               | 56                | 300000            | 600              |
| 5th–95th %ile)    | (1.9–33)              | (0.16-3.4)        | (1.1–18)          | (140–1900)        | (14-220)          | (110000-          | (1500-<br>24000) |

Table L-16. Annual Activity Estimates of Fission and Activation Products
Discharged in Liquid Effluents From the FMPC (mCi)<sup>a</sup>

<sup>a</sup> The median estimates are based on the average ratio of measured activity of these radionuclides to the quantity of uranium released in liquid effluent from 1976 onward. The values are reported in millicuries (mCi); one mCi is equal to 1000 microcuries (µCi) or 0.001 curie (Ci).

<sup>b</sup> Processing of recycled uranium at the FMPC did not begin until October 1962. Consequently, values for 1962 are based on only three months of processing.

By 1969, when the average concentration of  $^{228}$ Ra in the plant effluent was about 1.8 disintegrations per minute per milliliter (d/m/mL) (Table L1-29, annex), the Oak Ridge Operations Atomic Energy Commission requested the concentration of  $^{228}$ Ra in the wastes discharged to the river be reduced (Boback 1969). At that time, the Pilot Plant thorium extraction process was the major source of this radionuclide. A barium sulfate precipitation at the Pilot Plant and additional treatment at the General Sump were intended to reduce

| Page L-48 | The Fernald Dosimetry Reconstruction Project  |
|-----------|-----------------------------------------------|
|           | Tasks 2 and 3. Source Terms and Uncertainties |

the <sup>228</sup>Ra in the extraction waste stream before being pumped to Waste Pit 5. Beginning the oxalate process for thorium recovery in Plant 8 in 1969, however, prevented lowering the concentrations quickly. By mid-1970, work at the General Sump had increased as a result of processing thorium scrap in Plant 8. The clear liquid from this process was pumped to the Chemical Waste Pit 5 and the solids were reprocessed through Plant 8. The reduction in average <sup>228</sup>Ra concentration at MH 175 from 3.2 d/m/mL in December 1969 to 1.6 d/m/mL in March 1970 (Table L1-29) occurred when there were no thorium extraction operations in the Pilot Plant during that period. Even though all thorium effluent from both Plant 8 and the Pilot Plant was pumped to Pit 5, <sup>228</sup>Ra in the effluent from the General Sump to the river still averaged 5.0 d/m/mL in August 1970, and was attributed to incoming effluents from various plants (Boback 1970). By the end of 1970, the concentration of <sup>228</sup>Ra had declined. In 1971, the General Sump began solidifying certain <sup>228</sup>Ra-bearing wastes from Plant 8 for shipment and burial offsite (Pennack 1971).

0.14

÷.

Ц. S.

A. Walter

1999 Sec. 199

N. 1000

#### SUMMARY AND CONCLUSIONS

· · · · · · · · · ·

•• • • • • •

Liquid wastes at the FMPC came from three main sources: (1) process water from the production area via the General Sump and clearwell portion of the waste pits, (2) from the sanitary sewer treatment plant, and (3) from the storm sewer system. The facilities for handling liquid wastes from the process areas included collection sumps and treatment equipment at each plant to remove uranium from process waste water before it was pumped to the General Sump. From the General Sump, the effluent was pumped to the waste pits where settling occurred, after which the liquid was decanted to the clearwell portion of the pit. Key improvements in the liquid handling system at the FMPC, especially in 1958, 1968 and 1985, were reflected in noticeable declines in concentrations of uranium, thorium and other radionuclides, as well as in total suspended solids measured at the discharge point to the river.

Liquid effluent left the FMPC site at two locations. The main pipeline exited via Manhole 175 (MH 175) into the Great Miami River at a point almost directly east of the plant site. Liquid waste water also left the site via the storm sewer outfall ditch and runoff into Paddy's Run Creek, when the storm sewer lift station could not handle the runoff volume. Effluent volume and total uranium concentration were measured routinely at both locations (MH 175 and the storm sewer outfall ditch). Daily analytical data sheets, and monthly reports of effluent volume and uranium discharged form the basis of our source term computations.

Table L-17 summarizes our estimates for releases of materials in liquid effluents from the FMPC for all years of operation. Our best estimate of uranium released to the Great Miami River for all years is 82,000 kg. The 5th to 95th percentile uncertainty range is 71,000 to 94,000 kg of uranium. The sources of uncertainty for losses through MH 175 to the Great Miami River come primarily from the analytical errors in the daily measurements of water flow, and in sampling and determination of uranium concentration in the water. Some estimates of uranium in liquid wastes have been made by others on an annual basis (Boback 1971a), or in summary reports evaluating the past discharge history of the facility (Rathgens 1977, Boback et al., 1985). These estimates of uranium to surface water from 1951 through 1984 range from 74,000 to 77,000 kg (Boback et al. 1987, Galper 1988) and fall

.

....

. .

Г<u>а</u>

within the uncertainty range of our estimates. Revisions to historic discharge reports generally focused on amending estimates of uranium loss to airborne effluents, and did not include updated figures for liquid effluents (Boback et al. 1985, Boback et al. 1987).

| Material Released to Great              |               | Uncertainty Range       |
|-----------------------------------------|---------------|-------------------------|
| Miami River                             | Median Value  | (5th %ile to 95th %ile) |
| . • • • • • • • • • • • • • • • • • • • | Quantity (kg) | Quantity (kg)           |
| Uranium                                 | 82,000        | 71,000 to 94,000        |
| Uranium (To Paddy's Run)                | 17,000        | 14,000 to 20,000        |
| Thorium                                 | 5,800         | 3800 to 9400            |
|                                         | •             |                         |
|                                         | Activity (Ci) | Activity (Ci)           |
| <sup>228</sup> Ra                       | 2.7           | 0.33 to 20              |
| <sup>226</sup> Ra                       | 18            | 15 to 22                |
| <sup>239,240</sup> Pu                   | 0.0088        | 0.0019 to 0.033         |
| <sup>2;38</sup> Pu                      | 0.00028       | 0.00016 to 0.0034       |
| <sup>237</sup> Np                       | 0.0044        | 0.0011 to 0.018         |
| <sup>137</sup> Cs                       | 0.54          | _ 0.14 to 1.9           |
| <sup>106</sup> Ru                       | 0.056         | 0.014 to 0.22           |
| <sup>99</sup> Tc                        | 300           | 110 to 800              |
| <sup>90</sup> Sr                        | 6.0           | 1.5 to 24               |

#### Table L-17. Summary of Total Estimates of Radioactive Materials Released From the FMPC in Liquid Effluents For All Years of Operation

The total release estimate for uranium to Paddy's Run via the storm sewer outfall ditch and runoff is 17,000 kg of uranium. The 5th to 95th percentile uncertainty range is 14,000 to 20,000 kg of uranium. In addition to analytical errors, sources of uncertainty included overflow at the flow meter stations when rainfall, and consequently runoff, were quite high and unmeasured uranium losses through runoff from the west side of the facility directly into Paddy's Run. These latter two, undocumented sources of uranium to Paddy's Run are incorporated into our final release estimates.

Losses to Paddy's Run show much more month to month variation than do the uranium loss estimates to the Great Miami River. The highest annual releases of uranium occurred from 1960 to 1964, when the average quantity of uranium discharged through MH 175 to the river was approximately 500 kg each month, about 3 to 4 times greater than the average quantity of uranium lost to Paddy's Run each month.

The other materials released at various times over the years include decay, fission and activation products of uranium, thorium and recycled uranium. Recycled uranium was not processed until late 1962, so releases of fission and activation products began at that time. Releases of thorium, and one of its decay products, <sup>228</sup>Ra, occurred when thorium was processed at the site: 1954–1957, and 1964–1988. Releases of <sup>226</sup>Ra occurred throughout the history of the site, and the total release is estimated at 18,000 mCi or 18 Ci, with

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

uncertainty range of 15 to 22 Ci. These values will be used to calculate radiation doses to the population in the vicinity of the FMPC, which will be reported in our final task report.

The chemical form of uranium in liquid effluents is not known with certainty, but several uranium species of both the +4 and +6 oxidation states may have been present in solution in liquid waste streams during this period. The ratios of these various ionic species in the process waste streams, in Paddy's Run Creek, or in the main effluent pipeline to the river, would be a function of the pH of the water. Some uranium-containing suspended solids that were released into the waste streams might have dissolved during dilution downstream from the FMPC.

al inna colo

and the

#### REFERENCES

ALCON ...

Aas, C.A., D.L. Jones and R.W. Keys. FMPC Environmental Monitoring Report for 1985. FMPC-2047, Special. Westinghouse Materials Company of Ohio; 30 May 1986.

Aas, C.A., S.J. Clement, G.L. Gels & C.A. Lojek. FMPC Environmental Monitoring Annual Report for 1986. FMPC-2076, Westinghouse Materials Company of Ohio; 30 April 1987.

Alpaugh, E.L. Information Report - Ground Contamination As Reported by L. Williams. Report to R.C. Heatherton. Cincinnati; OH: National Lead Company of Ohio; 5 April 1956.

Bardo, R.W. Storm Sewer Losses to Great Miami River. Cincinnati, OH: National Lead Company of Ohio; June 1985.

Beers, H.M. Storm Sewer Losses — Plant 8, Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 2 November 1960.

<sup>4</sup> Beers, H.M. Ground contamination incident—Plant 8, Report to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 2 May 1961.

Beers, H.M. Slightly enriched (300 Series) uranium loss to the storm sewer, Report to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 17 December 1962.

Beers, H.M. Reported storm sewer uranium loss from Plant 8. Memorandum to C.R. Chapman. Cincinnati; OH: National Lead Company of Ohio; 6 January 1960 (1960a).

Beers, H.M. Storm sewer losses — Plant 8, Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 2 November 1960 (1960b).

Beers, H.M. Ground Contamination Incident-Plant 8, Report to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 2 May 1961.

Beers, H.M. Slightly enriched (300 Series) Uranium Loss to the Storm Sewer, Report to C. R. Chapman. Cincinnati, OH: National Lead Company of Ohio; 17 December 1962.

Beers H.M. Storm Sewer Losses — Plant 8. Memorandum to R. H. Starkey. National Lead Company of Ohio. 2 November 1960.

.

.

- Berger, J.D., G.S. Gist, C.M. Morrow, D.J. Niederkorn, D.T. Robinson. Environmental Program Review of the Feed Materials Production Center Fernald, Ohio. Oak Ridge, TN: Radiological Site Assessment Program. Oak Ridge Associated Universities. October 1985.
- Blase, E.F. and R.H. Starkey. Pollution Studies at Paddy's Run. Cincinnati, OH: National Lead Company of Ohio; 14 September 1953.
- Boback, M.W. and R.C. Heatherton. Laboratory Tests for Flocculation and Removal of Suspended Solids in Process Wastes. Cincinnati, OH: National Lead Commune of Ohio. 10 February 1958.
- Boback, M.W. Radioactivity in airborne and liquid effluents calendar 1970. Cincinnati, OH: National Lead Company of Ohio. 21 June 1971 (1971a).
- Boback, M.W. Aquifer Contamination Control Report to the Manager. Cincinnati, OH: National Lead Company of Ohio. 24 August 1971 (1971b).
- Boback, M. W. Aquifer Contamination Control Report to the Manager. Cincinnati, OH: National Lead Company of Ohio. 13 December 1971 (1971c).
- Boback, M.W. and K.N. Ross. Feed Materials Production Center Environmental Monitoring Annual Report for 1978 NLCO-1159. Cincinnati, OH: National Lead Company of Ohio. May 1979.
- Boback, M.W. and K.N. Ross. Feed Materials Production Center Environmental Monitoring Annual Report for 1979 NLCO-1164. Cincinnati, OH: National Lead Company of Ohio. April 1980.
- Boback, M.W.; D.A. Fleming; T.A. Dugan; R.W. Keys; R.B. Grant. History of FMPC radionuclide discharges. Cincinnati, OH: National Lead Company of Ohio; NLCO-2039; November 1985.
- Boback, M.W.; T.A. Dugan; D.A. Fleming; R.B. Grant; R.W. Keys. History of FMPC radionuclide discharges. Cincinnati, OH: Westinghouse Materials Company of Ohio; FMPC-2082, Revision to FMPC-2058; May 1987.
- Boback, M.W. Aquifer Contamination Control Report to the Manager. Cincinnati, OH: National Lead Company of Ohio; 30 December 1969.
- Boback, M.W. Aquifer Contamination Control Report to the Manager. Cincinnati, OH: National Lead Company of Ohio; 23 April 1970.
- Boback, M.W. Aquifer Contamination Control Report to the Manager. Cincinnati, OH: National Lead Company of Ohio; 24 August 1971.
- Boback. M.W., K.N. Ross, and D.A. Fuchs. Feed Materials Production Center Environmental Monitoring Annual Report for 1976. NLCO-1142. Cincinnati, OH: National Lead Company of Ohio; April 1977.
CASE OF

- Boback. M.W., K.N. Ross, and D.A. Fuchs. Feed Materials Production Center Environmental Monitoring Annual Report for 1977. NLCO-1151. Cincinnati, OH: National Lead Company of Ohio. April 1978.
- Boback. M.W., and K.N. Ross. Feed Materials Production Center Environmental Monitoring Annual Report for 1980. NLCO-1168. Cincinnati, OH: National Lead Company of Ohio; April 1981.
- Bogar, L.C. Trends in Effluent Water Quality. Report to J.A. Reafsnyder, Department of Energy. Cincinnati, OH: Westinghouse Materials Company of Ohio; 28 September 1987.

Bogar, L.C. Trends in Effluent Water Quality-Source of Increased Gross Beta Activity. Report to J.A. Reafsnyder, Department of Energy. Cincinnati, OH: Westinghouse Materials Company of Ohio; 4 November 1987.

Bravard, R.F. Contaminated spill in graveled area, west side of Plant 9, 3/20/61, Report to L. M. Levy. Cincinnati, OH: National Lead Company of Ohio; 23 March 1961a.

Bravard, R.F. Incident report of ground contamination of gravel area south of Plant 9, Report to L. M. Levy. Cincinnati, OH: National Lead Company of Ohio; 30 March 1961b.

Bravard, R.F. Machining area dust collector failure on 8/25/61, Memorandum to L. M. Levy. Cincinnati, OH: National Lead Company of Ohio; 11 September 1961c.

Brown, E.A. Laboratory Quality Control Report for the Period November 11, 1966 Through December 9, 1966. Report to J.W. Robinson. Cincinnati, OH: National Lead Company of Ohio. 11 January 1967.

Bussert, C.E. Plant 6 Material Losses From Faulty Process Lines. Memorandum to C.H. Walden. Cincinnati, OH: National Lead Company of Ohio; 8 May 1956.

Cahalane, R.W. The operation of the General Sump System, FMPC Manufacturing Standards. Cincinnati, OH: National Lead Company of Ohio; SOP 3C-501; 24 March 1961.

Carr, D.E. Monthly Report of Industrial Wastes. Report to B. McDill, Ohio Department of Health. Cincinnati, OH: National Lead Company of Ohio; 8 August 1955.

Chapman, C.R. Uranium Losses From the General Sump in November. Report to A. Stewart., Jr. Cincinnati, OH: National Lead Company of Ohio; 19 December 1955.

Chapman, C.R. Idea Letter — Portable flow meter and sampler, Memorandum to P. G. DeFazio. Cincinnati, OH: National Lead Company of Ohio. 16 July 1959.

Chapman, C.R. Uranium Losses From the General Sump in November. Report to A. Stewart, Jr. Cincinnati, OH: National Lead Company of Ohio; 19 December 1955.

Chapman, C.R. Ground Contamination. Report to A. Stewart, Jr. Cincinnati, OH: National Lead Company of Ohio; 27 March 1956.

Chapman, C.R. Storm Sewer Losses. Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 10 February 1961.

51

- Costa, J.J. Spillage of South African Concentrates Lot 247. Memorandum to C.H. Walden. Cincinnati, OH: National Lead Company of Ohio; 9 June 1954.
- Courtney, D.L. Balance Around Manhole 175, Memorandum to B. Gessiness. Cincinnati, OH: National Lead Company of Ohio; 12 April 1965.
- Cuthbert, F.L. Measured Losses and Removals of SS Material From the Production Stream, Monthly report to J. H. Noyes. Cincinnati, OH: January 1960 - September 1961 (1960-1961).
- Cuthbert, F.L and J. A. Quigley. Ground contamination Pilot Plant, Report to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 18 July 1961.
- Davis, J.O. Ground Contamination, Pilot Plant Area. Memorandum to F.L. Cuthbert. Cincinnati, OH: National Lead Company of Ohio; 18 September 1957.
- Decisioneering. 1993. Crystal Ball<sup>\*</sup> Version 3.0 for Windows. User's Manual. Decisioneering, Inc., Denver, Colorado.
- DeFazio, P.G. Comments on monthly river and effluent flow for November 1959, Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 14 January 1960.
- DeFazio, P.G. Idea Letter Revision of drainage system in Pilot Plant Area, Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 29 November 1962.
- DeFazio, F.G. Storm Sewer Contamination. Memorandum to A. Stewart, Jr. Cincinnati, OH: National Lead Company of Ohio; 22 April 1957.
- Dodd, A.O. Summary of Ground Contamination Survey Program. Report to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 15 July, 1959.
- Dodd, A.O. Comments on Monthly River and Effluent Flow. Cincinnati, OH: National Lead Company of Ohio; (1958-1959).
- Dugan, T.A. Removal of Uranium From Storm Sewer Effluent. Report to M.W. Boback. Cincinnati, OH: National Lead Company of Ohio; 20 December 1971.
- Dugan, T.A., G.L. Gels, J.S. Oberjohn and L.K. Rogers. Feed Materials Production Center Annual Environmental Report for Calendar Year 1989. Cincinnati, OH: Westinghouse Materials Company of Ohio. October 1990.
- Facemire, C.F., D.L. Jones and R.W. Keys, FMPC Environmental Monitoring Annual Report for 1984, NLCO-2028, Special. National Lead of Ohio, 1985; 15 July 1985.
- Fischoff, R.L. Comments on monthly river and effluent flow for January 1961, Report to R.H. Starkey, Cincinnati, OH: National Lead Company of Ohio; 23 February 1961.
- Fischoff, R. L. Comments on monthly river and effluent flow for December 1960, Monthly report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; January 1960 -August 1961 (1960-1961).

٠.

2

. .

1-110-10

175.14

- Fischoff, R.L. High Uranium Concentration in Plant 6 Water Seepage Pit. Memorandum to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 5 February 1963.
- Fischoff, R.L. Comments on Monthly River and Effluent Flow for December 1960. Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 17 January 1961.
- ET. Fischoff, R.L. Monthly Report for February 1964 Radiation & Effluent Control Section. Report to R. H. Starkey, Cincinnati, OH: National Lead Company of Ohio: 2 March 1964a.
  - Fischoff, R.L. Monthly Report for March 1964 Radiation & Effluent Control Section. . Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 31 March 1964b.

BUT THE ALL STREET يماء (17 - مور المرز) Fischoff, R.L. Monthly Report for April 1964 - Radiation & Effluent Control Section. Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 1 May 1964c.

[13] W. H. M. Martin, A. Starter, M. Satzlinski, "Phys. Rev. Lett. 149 (1974). Fleming, D.A, M.W. Boback. and K.N. Ross. Feed Materials Production Center Environmental Monitoring Annual Report for 1981. NLCO-1180, Special, UC-41, Cincinnati, OH: National Lead Company of Ohio. May 1982.

the second s Fleming, D.A. and K.N. Ross. Feed Materials Production Center Environmental Monitoring Annual Report for 1923. NLCO-1187, Special, UC-41, Cincinnati, OH: National Lead .\*\* Company of Ohio; May 1983.

Fleming, D.A. and K.N. Ross. Feed Materials Production Center Environmental Monitoring He Annual Report for 1983. NLCO-2018, Special, UC-41, Cincinnati, OH: National Lead Company of Ohio: 1984.

Flowers, D.L. Ground contamination, Memorandum to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 21 June 1961.

Flowers, D.L. Monthly Report of Industrial Wastes, Monthly Report to Bruce McDill, Department of Health, State of Ohio; Cincinnati, OH: National Lead Company of Ohio; 1960-1961. 

Flowers, D.L. Comments on Monthly River and Effluent Flow for January 1960. Cincinnati, OH: National Lead Company of Ohio; 16 February 1960 (1960a).

and the domain of the second of the Flowers, D.L. Comments on Monthly River and Effluent Flow for February 1960. Cincinnati, OH: National Lead Company of Ohio; 8 March 1960 (1960b).

 A state of the sta Flowers, D.L. Comments on Monthly River and Effluent Flow. Cincinnati, OH: National Lead Company of Ohio; (1959-1962). Suff transformers

Galper, M. Tabulation of data on historical emissions from FMPC. Memorandum to B. Speicher and L. Elikan. Cincinnati, OH: National Lead Company of Ohio; 27 October 1988. The standard the second second

Gessiness, B. Inspection Report - Technical Division ground contamination committee, Report to W. E. Shaw. Cincinnati, OH: National Lead Company of Ohio; 9 June 1961.

1.1.1

5

÷

0

.

- Gessiness, B. Excessive Storm Sewer Losses. Memorandum to M.S. Nelson. Cincinnati, OH: National Lead Company of Ohio; 13 September 1962.
- Glass, D.W. Radium Losses to Miami River. Memorandum to C.H. Walden. Cincinnati, OH: National Lead Company of Ohio. 19 April 1954.
- Glass, D.W. Activities of storm sewer effluent to Paddy's Run and Manhole 175. Handwritten notes from report to staff. Cincinnati, OH: National Lead Company of Ohio: 25 October 1955a.
- Glass, D.W. Incident High Uranium In General Sump–November 2, 1955. Report to A. Stewart, Jr. Cincinnati, OH: National Lead Company of Ohio; 7 November 1955b.
- Harr, G.R. Uranyl Nitrate Release. Memorandum to J.H. Noyes. Cincinnati, OH: National Lead Company of Ohio; 23 July 1959.
- Harr, G.R. Explanation of General Sump Uranium Loss of 111.4 lbs. "U" on 8/29/60. Cincinnati, OH: National Lead Company of Ohio; 2 September 1960.
- Harrell, E.M. Spillage of SF Material. Memorandum to C.R. Chapman. Cincinnati, OH: National Lead Company of Ohio. 8 December 1954.
- Harries, R.W. Report on uranium content of the laboratory sump for the month of July, Memorandum to C. H. Walden. Cincinnati, OH: National Lead Company of Ohio; 11 August 1953.
- Jeffers, O.H. Inspection of Paddy's Run Creek. Letter to J.A. Quigley. Columbus, OH: U.S. Department of the Interior, Geological Survey; 1 May 1962.
- Jester, H.L. 16 January 1964. Thorium Oxide by the Oxalate Precipitation Process Current Status. Memorandum to C.W. Huntington. Cincinnati, OH: National Lead Company of Ohio.
- Karl, C.L. Field Tests on Utilization of Contaminated Oils as Dust Palliatives: Letter to J.H. Noyes. Cincinnati, OH: United States Atomic Energy Commission; 14 June 1960.
- Keller, C.A. Feed Materials Production Center, Fernald, Ohio: NPDES Permit No. OH009580, Order No. V-M-78-AO-16. Letter to D.S. Bryson, U.S. EPA. Cincinnati, OH: National Lead Company of Ohio; 1 March 1978.
- Killough, G.G.; Case, M.J.; Meyer, K.R.; Moore, R.E.; Rogers, J.F.; Rope, S.K.; Schmidt, D.W.; Shleien, B.; Till, J.E.; Voillequé, P.G. The Fernald Dosimetry Reconstruction Project Task 4 Environmental Pathways—Models and Validation. Draft interim report for comment. Neeses, South Carolina: Radiological Assessments Corporation; Rep. CDC-3; March 1993.
- Lenyk, R.G. Storm Sewer Survey at FMPC. Memorandum to A.F. Pennack. Cincinnati, OH: National Lead Company of Ohio; 14 April 1977.
- Levy, L.M. Incident Report U Loss to Storm Sewer on 6-28-67. Report to S.F. Audia. Cincinnati, OH: National Lead Company of Ohio; 11 July 1967.

•.;

ý.

5

- Marshall, S. Measured Losses and Removals of SS Material From the Production Stream, Monthly report to J. H. Noyes. Cincinnati, OH: March, October, November, December 1963.
- McCreery, P. N. Specifications for plant effluents pumped to the General Sump, Memorandum for general distribution. Cincinnati, OH: National Lead Company of Ohio; 23 August 1965.
- Nelson, M.S. Uranium Loss From Plant 2 to the Storm Sewer. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 14 June 1966.
- NLCO (National Lead Company of Ohio). Summary of Ground Contamination Surveys for Months of September, October 1955.Cincinnati, OH: National Lead Company of Ohio; 1955.

NLCO (National Lead Company of Ohio). Analytical data sheets for analysis of uranium, radium, thorium and total suspended solids in effluent at MH 175. Cincinnati, OH: National Lead Company of Ohio. 1954, 1955. (1955b).

NLCO (National Lead Company of Ohio). Analytical data sheets for analysis of uranium, radium, thorium and total suspended solids in effluent at MH 175. Cincinnati, OH: National Lead Company of Ohio. 1956.

- NLCO (National Lead Company of Ohio). Analytical data sheets for analysis of uranium, radium, thorium and total suspended solids in effluent at MH 175. Cincinnati, OH: National Lead Company of Ohio. 1957.
- NLCO (National Lead Company of Ohio). Analytical data sheets for analysis of uranium, radium, thorium and total suspended solids in effluent at MH 175. Cincinnati, OH: National Lead Company of Ohio. 1960-1962.
- NLCO (National Lead Company of Ohio). Contaminated Oil in Storm Sewer System. Cincinnati, OH: National Lead Company of Ohio; 23 February 1962.

- NLCO (National Lead Company Of Ohio). Engineering drawing of scrap pit area, pit disposal area. Drawing No. 8-4269. Cincinnati, OH: National Lead Company of Ohio; 24 July 1959.
- NLCO (National Lead Company Of Ohio). Environmental assessment for wet chemical waste pit No. 6 for Construction Proposal (CP-74-5). Cincinnati, OH: National Lead Company of Ohio; 24 October 1974.
- NLCO (National Lead Company of Ohio). Radioactivity in Airborne and Liquid Effluents Calendar Year 1970. Cincinnati, OH. 21 June 1971.
- NLCO (National Lead Company of Ohio). Standard Operating Procedure The Neutralizing System - Refinery Sump, Plants 2 and 3; SOP 3A-206; Cincinnati, OH: National Lead Company of Ohio; 1 May 1957.
- NLCO (National Lead Company of Ohio). Standard Operating Procedure -The Refinery Sump Operations, Production - Plants 2 & 3; SOP 3C-206; Cincinnati, OH: National Lead Company of Ohio; 10 April 1961.

÷., .

÷.,

- NLCO (National Lead Company of Ohio). Analytical data sheets for analysis of uranium, radium, thorium and total suspended solids in effluent at MH 175. Cincinnati, OH: National Lead Company of Ohio. 1969.
- NLCO (National Lead Company of Ohio). Analytical data sheets for analysis of uranium, radium in effluent at MH 175. Cincinnati, OH: National Lead Company of Ohio. 1970.
- NLCO (National Lead Company of Ohio). Analytical data sheets for analysis of uranium, radium in effluent at MH 175. Cincinnati, OH: National Lead Company of Ohio. 1971.
- NLCO (National Lead Company of Ohio). Analytical data sheets for analysis of uranium, radium in effluent at MH 175. Cincinnati, OH: National Lead Company of Ohio. 1972.
- NLCO (National Lead Company of Ohio). Analytical data sheets for analysis of uranium, radium in effluent at MH 175. Cincinnati, OH: National Lead Company of Ohio. 1973.
- NLCO (National Lead Company of Ohio). Work Sheets for 1973 Environmental Monitoring Report, Radioactive Effluent Report and Onsite Discharge Report. Cincinnati, OH. 1974.
- NLCO (National Lead Company of Ohio). Work Sheets for 1974 Radioactive Effluent Report and Onsite Discharge Data Report. Cincinnati, OH. 1975.
- Noyes, J.H. Preliminary tests on the recovery of uranium from Fernald sump liquors, Letter to C.K. McArthur. Cincinnati, OH: National Lead Company of Ohio; 27 March 1958.
- Noyes, J.H. Storm Sewer Losses During September. Letter to C. L. Karl. Cincinnati, OH: National Lead Company of Ohio; 24 September 1962a.
- Noyes, J.H. Supplementary Report Storm Sewer Loss in Plant 8. Letter to C. L. Karl. Cincinnati, OH: National Lead Company of Ohio; 18 December 1962b.
- Noyes, J.H. Final Report Storm Sewer Loss in Plant 8. Letter to C. L. Karl. Cincinnati, OH: National Lead Company of Ohio; 31 December 1962c.
- Noyes J.H. Idea letter storm sewer sampler. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 21 March 1966.
- Noyes J.H. Remedial Work on Drainage system to Handle Surface Runoff. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 15 August 1958.
- Noyes J.H. Uranium Loss to Storm Sewer on August 2, 1966. Letter to C.L. Karl. Cincinnati, OH: National Lead Company of Ohio; 12 August 1966.
- OHIO (State of Ohio Department of Health). Report on Detail Plans of Proposed Sewage Treatment Plant for Fernald Plant of the U.S. Atomic Energy Commission. Crosby Township, Hamilton County. Columbus, OH: State of Ohio Department of Health; 24 October 1955.
- OHIO (State of Ohio Department of Health). Report on Improved Waste Effluent Processing Facilities National Lead Company of Ohio-Feed Materials Production Center, Crosby Township, Hamilton County. Columbus, OH: State of Ohio Department of Health; 9 December 1968.

Sec. 1.

P&G (Proctor & Gamble Company). Monthly Reports of Samples Taken at the FMPC Prior to Discharge to Great Miami River. Reports to Ohio EPA. January 1983 to December 1985. 1985.

Patton, J.B. Study of precipitation/stormwater flow of FMPC - 1978, Memorandum report to N. R. Leist and D. P. Cooper. Cincinnati, OH: National Lead Company of Ohio; 14 July 1985.

Pennack, S. Liquid effluent review. Cincinnati, OH: National Lead Company of Ohio; 14 August 1973.

Pennack, A.F. Reduction of <sup>228</sup>Ra in Plant Effluent, Report to the Manager. Cincinnati, OH: National Lead Company of Ohio. 20 August 1971.

Quigley, J.A. Recommended NCG values for the storm sewer outfall and Paddy's Run.. Cincinnati, OH: National Lead Company of Ohio; 2 September 1965.

Rathgens, L. H & S Request, Tabulation of volume and uranium quantities to MH 175 and Paddy's Run prior to CY 1963. Inter-office memorandum to M. Boback. Cincinnati, OH: National Lead Company of Ohio; 19 April 1974.

Rathgens, L. Over-all accountability analyses report, Plant startup Through September 30, 1976, Letter to H. D. Fletcher. Cincinnati, OH: National Lead Company of Ohio; 25 August 1977.

Reafsnyder, J.A. Radioactivity and uranium in the Liquid Effluent-Feed Materials Production Center-June, August September, 1987. Report to T.A. Winston, Ohio EPA. Oak Ridge, TN: Department of Energy. 1987.

Riestenberg, E.B. Incidents Affecting Storm Sewer System. Report to H. Martin. Cincinnati, OH: National Lead Company of Ohio; 25 February 1966.

Riestenberg, E.B. Incidents Affecting Storm Sewer System. Report to H. Martin. Cincinnati, OH: National Lead Company of Ohio; 25 November 1966.

Riestenberg, E.B. Incidents Affecting Storm Sewer System. Report to H. Martin. Cincinnati, OH: National Lead Company of Ohio; 21 March 1967.

Riestenberg, E.B. Incidents Affecting Storm Sewer System. Report to H. Martin. Cincinnati, OH: National Lead Company of Ohio; (1965–1969).

Riestenberg, E.B. Storm Sewer Incidents And Sampling. Report to P.G. DeFazio. Cincinnati, OH: National Lead Company of Ohio: March 1969a.

Riestenberg, E.B. Storm Sewer Incidents And Sampling. Report to P.G. DeFazio. Cincinnati, OH: National Lead Company of Ohio; 3 April 1969b.

Riestenberg, E.B. Storm Sewer Contamination. Report to A.F. Pennack. Cincinnati, OH: National Lead Company of Ohio; 8 May 1978.

an director of the second s

- RIFS (Remedial Investigation/Feasibility Study). Groundwater Report, draft prepared for U.S. Department of Energy, Oak Ridge Operations Office; FMPC-0004-2. Cincinnati, OH: Westinghouse Materials Company of Ohio; December 1990.
- Ross, K.N. Comments on River and Effluent For October 1958. Report to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 19 November 1958.
- Ross, K.N. Sampling of the storm sewer outfall, Handwritten memorandum to R. H. Starkey. Cincinnati, OH: National Lead Company of Ohio; June 1965.
- Ross, K.N. Uranium losses in the Storm Sewer System, Memorandum to M. W. Boback. Cincinnati, OH: National Lead of Ohio; 5 January 1972.
- Ross, K.N, L. Williams, and E.V. Barry. Recommendations Requiring Immediate Action to Abate and Control Contamination. Report to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 24 February 1954.
- Ross, K.N. Comments on River and Effluent for Month of September 1958. Report to R.H. Starkey. Cincinnati, OH: National Lead Company of Ohio; 15 October 1958.
- Ross, K.N. Uranium Losses in the Storm Sewer System. Memorandum to M.W. Boback. Cincinnati, OH: National Lead Company of Ohio; 5 January 1972.
- Schwan, C.A. Routine Operating Losses of SS Materials From the Production Stream. Monthly reports to J.H. Noyes and M.S. Nelson. 1967-1983.
- Seidel, R.D. Report on Improved Waste Effluent Processing Facilities National Lead Company of Ohio-Feed materials Production Center, Crosby Township-Hamilton County. Columbus, OH: State of Ohio Department of Health. 9 December 1968.
- Shaw, W.E. Ground contamination in process areas, Memorandum to F. L. Cuthbert. Cincinnati, OH: National Lead Company of Ohio; 23 June 1961.
- Smith, W.A. Ground Contamination. Memorandum to C.R. Chapman. Cincinnati, OH: National Lead Commune of Ohio. 9 February 1961.
- Spenceley, R.M. Joint Task Force on recycle material processing, Letter to J. A. Reafsnyder. Cincinnati, OH: National Lead Company of Ohio; 1 May 1985.
- Spenceley, R.M. Ground Contamination Survey Machining Area Report to G.C. Coon. Cincinnati, OH: National Lead Company of Ohio; 8 June 1959.
- Spieker, A. M.; S. E. Norris. Groundwater movement and contamination at the AEC Feed Materials Production Center located near Fernald, Ohio, Report to the U.S. Atomic Energy Commission. Columbus, OH: U. S. Geological Survey; September 1962.
- Starkey, R.H. Annual Report for the Calendar Year 1957—IH&R Department to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 21 February 1958 (1958a).
- Starkey, R.H. Discharge of Liquid Wastes Into the River, Monthly Report for August, September, October, November, December to J. E. Hart. Cincinnati, OH: National Lead Company of Ohio; September 1958-December 1958. (1958b).

Radiological Assessments Corporation "Setting the standard in environmental health"

Starkey, R.H. Ground contamination of area around vehicle washing station, Memorandum to G. J. Nowlin. Cincinnati, OH: National Lead Company of Ohio; 3 August 1959.

Starkey, R.H. Ground Contamination Around Pilot Plant. Report to J. O. Davis. Cincinnati, OH: National Lead Company of Ohio; 26 May 1958.

Starkey, R. H. IH&R Department Monthly Report for March, 1960. Report to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 5 April 1960.

Starkey, R.H. FMPC Ground Contamination. Report to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 1 February 1961.

Starkey, R.H. Industrial Hygiene & Radiation Department monthly report for February 1961, Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 8 March 1961 (1961a).

Starkey, R. H. Contamination in Paddy's Run Creek, Memorandum to E. B. Riestenberg. Cincinnati, OH: National Lead Company of Ohio. 18 July 1961 (1961b).

Starkey, R.H. Comments on ground contamination in process areas, Memorandum to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 22 August 1961 (1961 c).

Starkey, R.H. Comments on Ground Contamination in Process Areas, Memorandum to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 25 October 1961 (1961d).

Starkey, R.H. Discharge of Liquid Wastes Into the River. Monthly Report to J. E. Hart. Cincinnati, OH: National Lead Company of Ohio; February 1960 – August 1961. (1960– 1961).

Starkey, R.H. IH & R Department Monthly Report for August, 1962, Report to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 14 September 1962 (1962a).

Starkey, R.H. Comments on Ground Contamination in Process Areas. Report to J. A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 22 October 1962 (1962b).

Starkey, R.H., C. Watson, R.C. Coates, E.B. Riestenberg and J.W. Robinson. Report of FMPC Ground Contamination Study Committee. Cincinnati, OH: National Lead Company of Ohio. 30 September 1962.

Starkey, R.H. IH&R Department Accomplishments, Calendar Year 1963. Report to R.C. Heatherton. Cincinnati, OH: National Lead Company of Ohio. 22 January 1964a.

Starkey, R.H. Comments on Ground Contamination in Process Areas. Report to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 19 March 1964b.

Starkey, R.H. IH&R Department Monthly Report for June, 1964. Report J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio; 8 July 1964c.

Starkey, R.H. Aquifer Contamination Control. Report to the Manager on December 15, 1965. National Lead Company of Ohio, Cincinnati, Ohio; 1965a.

÷.,

.....

- Starkey, R. H. Aquifer Contamination Control. Report to the manager on September 17, 1965. National Lead Company of Ohio, Cincinnati, Ohio; 1965b.
- Starkey, R.H. Minutes of Informal Meeting on Liquid Effluent. Report to E.B. Riestenberg. National Lead Company of Ohio, Cincinnati, Ohio: 9 November 1965 (1965c).
- Starkey, R.H. Aquifer Contamination Control. Report to the Manager. National Lead Company of Ohio, Cincinnati, Ohio; 21 March 1966a.
- Starkey, R.H. Aquifer Contamination Control. Report to the Manager. Cincinnati, OH: National Lead Company of Ohio; 23 September 1966b.
- Starkey, R. H. Aquifer Contamination Control. Report to the Manager. Cincinnati, OH: National Lead Company of Ohio; 22 December 1966c.
- Starkey, R.H. Aquifer Contamination Control Report to the Manager. Cincinnati, OH: National Lead Company of Ohio. 10 August 1967a.
- Starkey, R.H. Aquifer Contamination Control Report to the Manager. Cincinnati, OH: National Lead Company of Ohio. 20 December 1967b.
- Starkey, R.H. High Activity to the Pit during the NFS UNH Campaign of January 22-26, 1968. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 9 February 1968a.
- Starkey, R.H. Aquifer Contamination Control. Report to the Manager. Cincinnati, OH: National Lead Company of Ohio. 25 April 1968b.
- Starkey, R.H. Aquifer Contamination Control Report to the Manager. Cincinnati, OH: National Lead Company of Ohio. 22 August 1968c.
- Starkey, R. H. High Uranium Losses Via the Storm Sewer. Internal memorandum to J.A. Quigley on February 28, 1969. National Lead Company of Ohio, Cincinnati, Ohio; 1969a.
- Starkey, R.H. Aquifer Contamination Control Report to the Manager. Cincinnati, OH: National Lead Company of Ohio. 25 April 1969b.
- Stewart, A., Jr. Sources of Contamination on Site. Report to P.G. DeFazio. Cincinnati, OH: National Lead Company of Ohio; 2 November 1955.
- Stewart, A., Jr. Contamination Storm Sewer System. Report to C.R. Chapman, S.F. Audia and H. Martin. Cincinnati, OH: National Lead Company of Ohio; 2 April 1957.
- Strattman, W. J.; H.M. Beers; B. Gessiness; R.H. Starkey; W.J. Adams; E. Mode. Report of investigation storm sewer loss in the Recovery Plant (Plant 8) on September 10, 1962. Cincinnati, OH: National Lead Company of Ohio; 1962.
- Strattman, W.J. Metal Oxide Spillage Silo Area. Memorandum to A. Stewart, Jr. Cincinnati, OH: National Lead Company of Ohio; 30 January 1956.

. 1

· .i.

1

į,

Theis, C.V. Visit to Atomic Energy Commission's Fernald, Ohio Area, September 26, 1955. Report to A.E. Gorman, Atomic Energy Commission, Washington, C.D. Albuquerque, NM: United States Department of the Interior Geological Survey. 31 October 1955.

Tippenhauer, D.A. Underground SS Material Loss. Production Engineering Department Completion Report. Cincinnati, OH: National Lead Company of Ohio; 9 April 1957.

Voillequé, P.G.; Meyer, K.R.; Schmidt, D.W.; Killough G.G.; Moore, R.E., Ichimura, V.I., Rope, S.K.; Shleien, B.; Till, J.E. The Fernald Dosimetry Reconstruction Project Tasks 2 and 3 Radionuclide Source Terms and Uncertainties — 1960-1962. Neeses, S.C.: Radiological Assessments Corporation. December 1991.

Walden, C.H. Sewer Losses for February 1957. Memorandum to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 19 March 1957.

WMCO (Westinghouse Materials Company of Ohio). Feed Materials Production Center Environmental Monitoring Annual Report for 1988. Cincinnati, OH: Westinghouse Materials Company of Ohio. June 1989.

Yoder, J.D. Comments on River Chart For Month of May, June, July, August 1955. Report to J.A. Quigley. Cincinnati, OH: National Lead Company of Ohio. 21 June 1955.

. . .

(4) Construction (44)
 (4) Construction (44)
 (4) Construction (44)
 (4) Fill (4

antese u Si Torres Nationalese a

- 11 B.4

with iteration

the second of the state of the

### ANNEX

#### DATA TABULATIONS

### MANHOLE 175 VOLUME AND URANIUM CONCENTRATION

Tables L1-1 to L1-13 contain daily uranium concentration measurements at Manhole 175 for 1954-1964, 1966, 1967 and 1969, with effluent volume data for 1960, 1961 and 1962 in Tables L1-6, L1-7, and L1-8. The uranium concentration (mg  $L^{-1}$ ) was determined on 24-hour composite samples. From these measurements, daily and monthly estimates of uranium lost to the river were calculated.

### **OUTFALL TO PADDY'S RUN**

Tables L1-14 to L1-22 contain data on the overflow of effluent to the Storm Sewer Outfall Ditch and Paddy's Run for 1954-1957, 1960-1964, and 1966. The tables list the uranium concentrations measured in grab samples taken periodically during the outfall events, and, for some years, the dates of the overflow (outfall) of the storm sewer lift station to Paddy's Run and the effluent volume measured at the V-notch weir station.

Table L1-23 reports the quantities of uranium in the storm sewer system that are released to the river via the storm sewer lift station, or through the storm sewer outfall ditch to Paddy's Run. Monthly rainfall amounts are also given.

### TOTAL SUSPENDED SOLIDS

Table L1-24 lists the daily measurements of total suspended solids (TSS) in liquid effluents discharged to the river in 1957. Table L1-25 provides monthly averages for TSS measured at MH 175 before discharge to the river. The monthly averages are based on daily measurements reported in analytical data sheets from the Bioassay Department at FMPC.

### **RELEASE OF OTHER RADIONUCLIDES**

Tables L1-26 to L1-33 present data on the concentrations of total radium (Tables L1-26 to L1-28),  $^{228}$ Ra and  $^{226}$ Ra (Tables L1-29 to L1-33) released in liquid effluents from the FMPC for various times from 1955 to 1974. Tables L1-34 to L1-35 show the concentration of thorium measured at MH 175 in 1956 and 1957.

#### **VOLUME OF EFFLUENT**

Table L1–36 lists the annual volume of effluent discharged to the Great Miami River Via Manhole 175, and to Paddy's Run through the storm sewer outfall ditch.

 $\sim$ 

3

Page L--64

; :

.: ï ;

141 Y 141

• .

;

A ALWAY AREAL

1.00

S. S. Market

| 1954         (mg L <sup>-1</sup> )           10-Aug         5.35           2-Sep         1.41           9-Sep         3.10           9-Sep         1.95           Average         2.95 | (kg)<br>22.<br>6<br>13<br>8<br>12 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| 10-Aug         5.35           2-Sep         1.41           9-Sep         3.10           9-Sep         1.95           Average         2.95                                              | 22.<br>6<br>13<br>8<br>12         |
| 2-Sep         1.41           9-Sep         3.10           9-Sep         1.95           Average         2.95                                                                            | 6<br>13<br>8<br>12                |
| 9-Sep 3.10<br>9-Sep 1.95<br>Average 2.95                                                                                                                                               | 13<br>8<br>12                     |
| 9-Sep 1.95<br>Average 2.95                                                                                                                                                             | 8<br>12                           |
| Average 2.95                                                                                                                                                                           | 12                                |
|                                                                                                                                                                                        |                                   |
| Date Uranium <sup>a</sup>                                                                                                                                                              | Total U                           |
| 1955 $(mg L^{-1})$                                                                                                                                                                     | (kg)                              |
| 21-Sep 0.31                                                                                                                                                                            | 1 r                               |
| 24-Sep 2.27                                                                                                                                                                            | · 9                               |
| 27-Sep 0.87                                                                                                                                                                            | , <b>4</b>                        |
| 3-Oct 0.82                                                                                                                                                                             | <b>3</b>                          |
| 6-Oct 2.16                                                                                                                                                                             | <b>9</b> ·                        |
| 9-Oct 0.41                                                                                                                                                                             | 2                                 |
| 12-Oct 2.37                                                                                                                                                                            | 10                                |
| 18-Oct 0.82                                                                                                                                                                            | 3                                 |
| 21-Oct 1.13                                                                                                                                                                            | 5                                 |
| 24-Oct 1.24                                                                                                                                                                            | 5                                 |
| 27-Oct 0.89                                                                                                                                                                            | 4                                 |
| 30-Oct 1.34                                                                                                                                                                            | ·6                                |
| 2-Nov 7.62                                                                                                                                                                             | 32                                |
| 5-Nov 0.81                                                                                                                                                                             | 3                                 |
| 9-Nov 2.06                                                                                                                                                                             | 9                                 |
| 12-Nov 0.83                                                                                                                                                                            | 3                                 |
| 15-Nov 0.82                                                                                                                                                                            | 3                                 |
| 18-Nov 0.68                                                                                                                                                                            | · 3                               |
| 21-Nov 1.20                                                                                                                                                                            | 5.                                |
| 24-Nov 0.37                                                                                                                                                                            | 2                                 |
| 27-Nov 0.81                                                                                                                                                                            | 3                                 |
| 30-Nov 6.18                                                                                                                                                                            | 26                                |
| 3-Dec 1.79                                                                                                                                                                             | 7                                 |
| 6-Dec 0.67                                                                                                                                                                             | <b>3</b> ·                        |
| 9-Dec 0.60                                                                                                                                                                             | 2                                 |
| 12-Dec 0.80                                                                                                                                                                            | 3                                 |
| 15-Dec 0.60                                                                                                                                                                            | · _ 2                             |
| 18-Dec 1.00                                                                                                                                                                            | 4                                 |
| 21-Dec 2.13                                                                                                                                                                            | 9                                 |
| 24-Dec 0.77                                                                                                                                                                            | 3                                 |
| 28-Dec 0.87                                                                                                                                                                            | 4                                 |
| Totals                                                                                                                                                                                 | 190                               |
| Average app 1.4                                                                                                                                                                        | 5.9                               |
| StdDev 1.6                                                                                                                                                                             | 6.5                               |

<sup>a</sup> From NLCO 1955; original analytical data sheets from the Bioassay Department at FMPC.

| Appendi | ix L 👘 |           | · |
|---------|--------|-----------|---|
| Surface | Water  | Discharge | s |

**...** 

. .

6

| Page L | -65 |
|--------|-----|
|--------|-----|

| Table I  | LI-2. Meas    | sured Cor     | icentrati<br>Man | ions and C<br>hole 175 ii | alculated  | i Quantit | ies of Ura    | nium at    |
|----------|---------------|---------------|------------------|---------------------------|------------|-----------|---------------|------------|
| 1956     | Ua            | Total U       | 1956             | Ua                        | Total U    | 1956      | Ua            | Total U    |
| Date     | $(mg L^{-1})$ | (kg)          | Date             | $(mg L^{-1})$             | (kg)       | Date      | $(mg L^{-1})$ | (kg)       |
| 1-Jan    | 1.26          | 1             | 16-May           | 0.70                      | 3          | 26-Jun    | 0.61          | 3          |
| 7-Jan    | 0.25          | 2             | 17-May           | 0.78                      | 2          | 27-Jun    | 0.82          | 9          |
| 10-Jan   | 0.58          | 9             | 18-May           | 0.59                      | 27         | 28-Jun    | 2.24          | 3          |
| 13-Jan   | 2.13          | 1             | 19-May           | 6.44                      | 6          | 29-Jun    | 0.61          | 2          |
| 16-Jan   | 0.23          | · 3           | 20-May           | 1.37                      | 9          | 30-Jun    | 0.41          | 4          |
| 19-Jan   | 0.77          | 1             | 21-May           | 2.15                      | 4          | 1-Jul     | 1.02          | 5          |
| 22-Jan - | 0.30          | 2             | 22-May           | 1.01                      | 5          | 2-Jul     | 1.22          | 7          |
| 25-Jan   | 0.58          | 7             | 23-May           | 1.17                      | 10         | 3-Jul     | 1.63          | 6          |
| 28-Jan   | 1.74          | 7             | 24-May           | 2.44                      | 5          | 4-Jul     | 1.43          | . 4        |
| 1-Feb    | 1.74          | 6             | 25-May           | 1.27                      | 9          | 5-Jul     | 1.02          | 6          |
| 4-Feb    | 1.55          | 13            | 26-May           | 2.15                      | 4          | 6-Jul     | 1.33          | 3          |
| 15-Apr   | 3.16          | 4             | 27-May           | 0.98                      | 5          | 7-Jul     | 0.82          | 4          |
| 17-Apr   | 0.99          | . 4           | 28-May           | 1.17                      | 12         | 8-Jul     | 1.02          | 6          |
| 18-Apr   | 0.99          | 9             | 29-May           | 2.93                      | 9          | 9-Jul     | 1.47          | 5          |
| 19-Apr   | 2.17          | 8             | 30-May           | 2.15                      | 3          | 10-Jul    | 1.26          | . 1        |
| 20-Apr   | 1.95          | 6             | 31-May           | 0.78                      | 44         | 11-Jul    | 0.35          | 3          |
| 21-Apr   | 1.37          | 3             | 1-Jun            | 10.54                     | 6          | 12-Jul    | 0.84          | 3          |
| 22-Apr   | 0.78          | 10            | 2-Jun            | 1.37                      | 6          | · 13-Jul  | 0.84          | 2          |
| 23-Apr   | 2.34          | 8             | 3-Jun            | 1.56                      | 8          | 14-Jul    | 0.36          | 5          |
| 24-Apr   | 1.95          | 39            | 4-Jun            | 2.04                      | 10         | 15-Jul    | 1.26          | 3          |
| 25-Apr   | 9.47          | 10            | 5-Jun            | 2.45                      | . 4        | 16-Jul    | 0.84          | 9          |
| 26-Apr   | 2.44          | 23            | 6-Jun            | 0.92                      | 3          | 17-Jul    | 2.10          | 2          |
| 27-Apr   | 5.47          | · 3           | 7-Jun            | 0.82                      | 8          | 18-Jul    | 0.48          | 8          |
| 28-Apr   | 0.68          | 8             | 8-Jun            | 1.84                      | · <b>3</b> | 19-Jul    | 1.89          | 5          |
| 29-Apr   | . 1.95        | 3             | 9-Jun            | 0.61                      | 2          | 20-Jul    | 1.26          | 2          |
| 30-Apr   | 0.78          | 4             | 10-Jun           | 0.41                      | 2          | 21-Jul    | 0.55          | 3          |
| 1-May    | 1.01          | 18            | 11-Jun           | 0.48                      | 3          | 22-Jul    | 0.63          | 6          |
| 2-May    | 4.29          | 4             | 12-Jun           | 0.70                      | 5          | 23-Jul    | 1.47          | 3          |
| 3-May    | 0.97          | 15            | 13-Jun           | 1.22                      | 8          | 24-Jul    | 0.74          | 3          |
| 4-May    | 3.51          | 11            | 14-Jun           | · 1.94                    | 3          | 25-Jul    | 0.84          | 3          |
| 5-May    | 2.54          | 6 .           | 15-Jun           | 0.82                      | 3          | 26-Jul    | 0.84          | <b>3</b> . |
| 6-May    | 1.36          | 4             | 16-Jun           | 0.79                      | 3          | 27-Jul    | 0.74          | 4          |
| 7-May    | 0.98          | 3             | 17-Jun           | 0.82                      | 1          | 28-Jul    | 0.94          | 8          |
| 8-May    | 0.73          | 8             | 18-Jun           | 0.30                      | 3          | 29-Jul    | 1.89          | 6          |
| 9-May    | · 1.95        | 6             | 19-Jun           | 0.61                      | 5          | 30-Jul    | 1.47          | 8          |
| 10-May   | 1.37          | 4             | 20-Jun           | 1.12                      | 5          | 31-Jul    | 1.89          | 7          |
| 11-May   | 1.07          | 5             | 21-Jun           | 1.22                      | 16         |           |               |            |
| 12-May   | 1.17          | 3             | 22-Jun           | 3.88                      | 8          | Totals    |               | 770        |
| 13-May   | 0.78          | 12            | 23-Jun           | 2.04                      | 3          | Average   | 1.57          | 7          |
| 14-May   | 2.93          | <b>22</b> · · | 24-Jun           | 0.82                      | 3          | StdDev    | 1.52          | 6          |
| 15-May   | 5.37          | . 3           | 25-Jun           | 0.72                      | . 3        | Max       | 10.54         | 44         |
|          |               |               | 1                |                           | 7          | 1 Min     | 0.23          | 1          |

12

<sup>a</sup> From NLCO 1956; original analytical data sheets from the Bioassay Department at FMPC.

### Page L-66

A MARK -

and the second

| The Fernald   | Dosimetry   | Reconstruct | tion Project |
|---------------|-------------|-------------|--------------|
| Tasks 2 and 3 | , Source Te | rms and Ur  | ncertainties |

•

|                 | Manhole 175 in 1957 |             |                     |         |          |                           |             |  |
|-----------------|---------------------|-------------|---------------------|---------|----------|---------------------------|-------------|--|
| 1957            | . Ua                | Total U     | 1957 U <sup>a</sup> | Total U | 1957     | Ua                        | Total U     |  |
| Date            | $(mg L^{-1})$       | (kg)        | Date (mg L-1)       | (kg)    | Date     | $(mg L^{-1})$             | (kg)        |  |
| 1-Jan           | 3.42                | 14          | 11-Feb 11.64        | 48      | 23-Mar   | 2.72                      | 11          |  |
| 2-Jan           | 1.90                | <b>8</b> ·  | 12-Feb 1 15.52      | 65      | 24-Mar   | 2.38                      | 10          |  |
| 3-Jan           | 3.99                | 17          | 13-Feb 17.46        | 73      | 25-Mar   | 2.38 ·                    | 10          |  |
| 4-Jan           | 6.65                | <b>28</b> · | 14-Feb 9.70         | 40      | 26-Mar   | 19.40                     | .81         |  |
| 5-Jan           | 1.71                | 7           | 15-Feb 10.96        | 46      | 27-Mar   | 2.94                      | 12          |  |
| 6-Jan           | 1.33                | 6           | 16-Feb 5.82         | 24      | 28-Mar   | 6.62                      | 28          |  |
| 7-Jan           | 1.33                | 6           | 17-Feb 9.70         | 40      | 29-Mar   | 4.24                      | ′ 18        |  |
| 8-Jan           | 3.61                | 15          | 18-Feb 5.96         | 25      | 30-Mar ' | 1.48                      | 6           |  |
| 9-Jan           | 8.74                | 36          | 19-Feb 5.62         | 23      | 31-Mar   | 1.48                      | 6           |  |
| 10-Jan          | 3.61                | 15          | 20-Feb 1.70         | 7       | 1-Apr    | 2.20                      | . <b>9</b>  |  |
| 11 <b>-J</b> an | 1.33                | 6           | 21-Feb 2.56         | 11      | 2-Apr    | 2.40                      | 10          |  |
| 12-Jan          | 2.76                | 11          | 22-Feb 1.88         | 8       | 3-Apr    | 2.38                      | 10          |  |
| .13-Jan         | 2.28                | 9           | 23-Feb 1.20         | · 5     | 4-Apr    | 2.94                      | 12          |  |
| 14-Jan          | 6.46                | 27          | 24-Feb 4.26         | 18      | 5-Apr    | 3.68                      | 15          |  |
| 15-Jan          | 4.18                | 17          | 25-Feb 4.26         | 18      | 6-Apr    | 5.16                      | 21          |  |
| 16-Jan          | 5.51                | 23          | 26-Feb 3.92         | 16      | · 7-Apr  | 1.84                      | 8           |  |
| 17-Jan          | 2.09                | 9           | 27-Feb 5.28         | 22      | 8-Apr    | 3.50                      | . 15        |  |
| 18-Jan          | 5.78                | 24          | 28-Feb 7.14         | 30      | 9-Apr    | 4.42                      | . 18        |  |
| 19-Jan          | 2.66                | . 11        | 1-Mar 2.38          | 10      | 10-Apr   | 28.40                     | . 118       |  |
| 20-Jan          | <b>5.82</b> ÷       | 24          | 2-Mar 8.34          | 35      | 11-Apr   | 2.58                      | 11          |  |
| 21-Jan          | 3.10                | 13          | 3-Mar 1.02          | · 4     | 12-Apr   | 2.02                      | 8           |  |
| 22-Jan          | 5.82                | 24          | 4-Mar 0.86          | 4       | 13-Apr   | 0.84                      | 3           |  |
| 23-Jan          | 5.28                | 22          | 5-Mar 0.80          | 3       | 14-Apr   | 2.02                      | 8           |  |
| 24-Jan          | 5.82                | 24          | 6-Mar 2.04          | · 8     | 15-Apr   | <b>2.</b> 94 <sub>.</sub> | . <b>12</b> |  |
| 25-Jan          | 1.54                | 6           | 7-Mar 1.54          | 6       | 16-Apr   | 4.42                      | 18          |  |
| 26-Jan          | 2.12                | 9           | 8-Mar 4.08          | 17      | 17-Apr   | 3.50                      | 15          |  |
| 27-Jan          | 4.42                | 18          | 9-Mar 7.76          | · 32    | 18-Apr   | 1,84                      | 8           |  |
| 28-Jan          | 9.18                | 38          | 10-Mar 5.78         | 24      | 19-Apr   | 4.04                      | 17          |  |
| 29-Jan          | 15.52               | 65          | 11-Mar 3.24         | 13      | 20-Apr   | 5.88                      | 24          |  |
| 30-Jan          | 7.76                | 32          | 12-Mar 13.58        | 56      | 21-Apr   | 1.10                      | 5           |  |
| · 31-Jan        | 7.76                | 32          | 13-Mar 5.82         | 24      | 22-Apr   | 0.74 \cdots               | 3           |  |
| 1-Feb           | 7.82                | . 0         | 14-Mar 1.96         | . 8     | 23-Apr   | 1.24                      | 5.          |  |
| 2-Feb           | 2.56                | 33          | 15-Mar 3.92         | 16      | 24-Apr   | 0.76                      | . 3         |  |
| 3-Feb           | 2.38                | 11          | 16-Mar 8.74         | 36      | 25-Apr   | 1.10                      | 5           |  |
| 4-Feb           | 2.38                | 10          | 17-Mar 6.46         | . 27    | 26-Apr   | 0.54                      | 2           |  |
| 5-Feb           | 5.52                | 10          | 18-Mar 1.54         | 6       | 27-Apr 🤅 | 0.24                      | 1           |  |
| 6-Feb           | 3.58                | 23          | 19-Mar 7.98         | 33      | 28-Apr   | 1.26                      | 5           |  |
| 7-Feb           | 4.42                | 15          | 20-Mar 1.36         | 6       | 29-Apr   | 2.02                      | 8           |  |
| 8-Feb           | 5.62                | 18          | 21-Mar : 1.02       | 4       | 30-Apr   | 3.50                      | 15          |  |
| 9-Feb           | 7.74                | 23          | 22-Mar 3.82         | 16      | 1-May    | 2.20                      | 9           |  |
| 10-Feb          | 3.58                | · 32        | L 23-Mar 272        | 11      | 2-Mav    | 1.10                      | 5           |  |

. a de la des antes de la desta de la de la de la de la de la de La desta de la d Table L1-3A. Measu • .....

(Continued on next page)

| Table L1–3B. Measured | <b>Concentrations and Calculated</b> | Quanti | ties of Uranium a | at |
|-----------------------|--------------------------------------|--------|-------------------|----|
| a ta t                | Manhole 175 in 1957                  | ,      |                   |    |

|               |               |            | iiau   |                       | 1 1007     |          |               |         |   |
|---------------|---------------|------------|--------|-----------------------|------------|----------|---------------|---------|---|
| 1957 .        | Ua            | Total U    | 1957   | Ua                    | Total U    | 1957     | Ua            | Total U |   |
| Date          | $(mg L^{-1})$ | (kg).      | Date   | (mg L <sup>-1</sup> ) | (kg)       | Date     | $(mg L^{-1})$ | (kg)    | Ň |
| 3-May         | 0.36          | 1          | 14-Jun | 0.54                  | 2          | 25-Jul   | 0.94          | 4       |   |
| 4-May         | 0.44          | 2          | 15-Jun | 0.98                  | 4          | 26-Jul   | 1.02          | 4       |   |
| 5-May         | 1.20          | 5          | 16-Jun | 2.00                  | 8          | 27-Jul   | 2.52          | 10      |   |
| 6-May         | 0.70          | 3          | 17-Jun | 1.54                  | <b>6</b> . | 28-Jul   | 0.70          | 3       | • |
| 7-May         | 1.48          | 6          | 18-Jun | 3.82                  | 16         | 29-Jul   | . 0.80        | 3       |   |
| 8-May         | 0.92          | 4          | 19-Jun | 1.28                  | 5          | 30-Jul   | 1.08          | 4       |   |
| 9-May         | 0.74          | 3          | 20-Jun | 2.18                  | 9          | 31-Jul   | 1.68          | 7       |   |
| 11-May        | 1.20          | 5          | 21-Jun | 0.72                  | 3          | 1-Aug    | 1.28          | 5       |   |
| 12-May        | 1.60          | 7          | 22-Jun | 0.72                  | 3          | 2-Aug    | 0.68          | 3       |   |
| 13-May        | 1.48          | 6          | 23-Jun | 0.86                  | 4          | 3-Aug    | 0.86          | 4       |   |
| 14-May        | 3.72          | 15         | 24-Jun | 1.10                  | 5 ·        | 4-Aug    | 1.48          | 6       |   |
| 15-May        | 1.08          | 4          | 25-Jun | 1.60                  | 7          | 5-Aug    | 2.52          | 10      |   |
| 16-May        | 1.10          | -5         | 26-Jun | 0.86                  | 4          | 6-Aug    | 0.60          | 2       |   |
| 17-May        | 0.94          | 4          | 27-Jun | 8.94                  | 37         | 7-Aug    | 1.78          | 7       |   |
| 18-May        | 1.20          | 5          | 28-Jun | 1.54                  | 6          | 8-Aug    | 2.10          | 9       |   |
| 19-May        | 0.72          | 3          | 29-Jun | 0.90                  | 4          | 9-Aug    | 2.32          | 10      |   |
| 20-May        | 2.54          | 11         | 30-Jun | 1.14                  | 5          | 10-Aug   | 1.90          | 8       |   |
| 21-May        | 16.32         | 68         | 1-Jul  | 0.62                  | 3          | 11-Aug   | 6.72          | 28      |   |
| 22-May        | 8.20          | 34         | 2-Jul  | 1.90                  | 8          | 12-Aug   | 0.24          | 1       |   |
| 23-May        | 1.82          | 8          | 3-Jul  | 1.06                  | 4.         | 13-Aug   | 3.84          | 16      |   |
| 24-May        | 1.82          | 8          | 4-Jul  | 1.14                  | 5          | 14-Aug   | 1.34          | 6 ·     |   |
| 25-May        | 1.70          | . 7        | 5-Jul  | 0.34                  | 1          | 15-Aug   | 1.54          | 6       |   |
| 26-May        | 9.64          | 40         | 6-Jul  | 0.94                  | 4          | 16-Aug   | 0.80          | 3       |   |
| 27-May        | 0.92          | 4          | 7-Jul  | 1.22                  | 5          | 17-Aug   | 1.48          | 6       |   |
| 28-May        | 0.54          | 2          | 8-Jul  | 0.82                  | 3          | 18-Aug   | 1.26          | . 5     |   |
| 29-May        | 1.10          | 5          | 9-Jul  | 0.72                  | 3          | 19-Aug   | 1.44          | 6       |   |
| 30-May        | 0.72          | 3          | 10-Jul | 1.26                  | 5          | 20-Aug - | 0.66          | 3       |   |
| 31-May        | 0.72          | 3          | 11-Jul | 2.10                  | 9          | 21-Aug   | 0.78          | . 3     |   |
| 1-Jun         | 0.82          | 3          | 12-Jul | 1.18                  | 5          | 22-Aug   | 0.60          | 2       | • |
| 2-Jun         | 1.10          | 5          | 13-Jul | 0.86                  | 4          | 23-Aug   | 0.44          | 2       | • |
| 3-Jun         | 0.72          | <b>3</b> · | 14-Jul | 1.14                  | 5          | 24-Aug   | 1.34          | 6       |   |
| 4-Jun         | 1.10          | 5 ·        | 15-Jul | 0.34                  | 1          | 25-Aug   | 2.88          | 12      |   |
| 5-Jun         | 0.74          | 3          | 16-Jul | 2.66                  | 11         | 26-Aug   | 0.96          | 4       |   |
| 6-Jun         | 1.44          | · · 6      | 17-Jul | 1.42                  | 6          | 27-Aug   | 0.96          | 4       |   |
| 7-Jun         | 0.90          | 4          | 18-Jul | 2.28                  | · 9        | 28-Aug   | 0.36          | 1       |   |
| 8-Jun         | 1.14          | 5          | 19-Jul | 3.16                  | 13         | 29-Aug   | 0.96          | 4       |   |
| 9-Jun         | 0.54          | 2          | 20-Jul | 1.26                  | 5          | 30-Aug   | 0.42          | 2       |   |
| 10-Jun        | 1.26          | 5          | 21-Jul | 0.64                  | 3          | 31-Aug   | 1.16          | 5       |   |
| 11-Jun        | 0.92          | 4          | 22-Jul | 3.58                  | 15         | 1-Sep    | 0.54          | 2       |   |
| 12-Jun        | 2.36          | 10         | 23-Jul | 0.94                  | 4          | 2-Sep    | 1.02          | 4       |   |
| <u>13-Jun</u> | 0.88          | • 4        | 24-Jul | 1.48                  | 6          | 3-Sep    | 1.16          | 5       |   |

(Continued on next page)

### Page L-68

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

ç,

22

5 . . J.

1010311-01

È

• . :

|          | Manhole 175 in 1957 (cont'd) |         |                     |                       |                   |         |                    |                  |
|----------|------------------------------|---------|---------------------|-----------------------|-------------------|---------|--------------------|------------------|
| 1957     | Uª                           | Total U | 1957                | · Ua                  | Total U           | 1957    | Ua                 | Total U          |
| Date     | (mg L <sup>-1</sup> )        | (kg)    | Date                | $(mg L^{-1})$         | (kg)              | Date    | $(mg L^{-1})$      | (kg)             |
| 4-Sep    | 0.96                         | 4       | 16-Oct              | 1.70                  | 7                 | 26-Nov  | 0.76               | 3                |
| 5-Sep    | 0.75                         | 3       | 17-Oct              | 2.44                  | 10                | 27-Nov  | 1.24               | 5                |
| 6-Sep    | 0.60                         | 2       | 18-Oct              | 2.06                  | ··· 9             | 28-Nov  | 2.14               | 9                |
| 7-Sep    | .0.48                        | 2.      | 19-Oct              | 0.82                  | 3                 | 29-Nov  | 0.90               | 4                |
| 8-Sep    | 0.58                         | 2       | <sup>-</sup> 20-Oct | 1.32                  | 5                 | 30-Nov  | 0.86               | 4                |
| g-Sep    | 0.60                         | 2       | 21-Oct              | 1.12                  | · · · 5           | 1-Dec   | 1.48               | .6               |
| 10-Sep   | 1.76                         | 7       | 22-Oct              | 0.56                  | 2                 | 2-Dec   | 0.82               | 3                |
| 11-Sep   | 1.56                         | 6       | 23-Oct              | 2.26                  | · 9               | 3-Dec   | 2.62               | 11               |
| 12-Sep   | 1.38                         | 6       | 24-Oct              | 1.50                  | · · 6             | 4-Dec   | 0.98               | · 4              |
| 13-Sep   | 1.52                         | .6      | 25-Oct              | <sup>≏.(</sup> 1.64 ∶ | 7                 | 5-Dec   | 0.66               | 3                |
| 14-Sep   | 0.52                         | 2       | 26-Oct              | 1.12                  | 5                 | 6-Dec   | 2.14               | 9                |
| 15-Sep   | 0.60                         | 2       | 27-Oct              | 1.38                  | 6                 | 7-Dec   | 1.14               | 5                |
| 16-Sep   | 0.92                         | 4       | 28-Oct              | 0.84                  | 3                 | 8-Dec   | 1.48               | · 6              |
| · 17-Sep | 3.52                         | 15      | 29-Oct              | <sup>12</sup> 0.36    | ` 1               | 9-Dec   | 1.48               | 6                |
| 18-Sep   | 0.96                         | 4       | 30-Oct              | 4.14                  | 17                | 10-Dec  | 1.32               | 5                |
| 19-Sep   | 0.66                         | · 3     | 31-Oct              | 1.50                  | 6                 | 11-Dec  | 2.78 <sup>11</sup> | <b>12</b>        |
| 20-Sep   | 0.58                         | 2       | 1-Nov               | 1.08                  | 4                 | 12-Dec  | 1.96               | 8                |
| 21-Sep   | 1.58                         | • 7     | 2-Nov               | 0.60                  | 2                 | 13-Dec  | 1.92               | · 8              |
| -22-Sep  | 0.98                         | 4       | 3-Nov               | 1.02                  | · 4               | 14-Dec  | 0.76               | · 3              |
| 23-Sep   | 1.10                         | 5       | 4-Nov               | 0.96                  | ·· 4              | 15-Dec  | 3.26               | 14               |
| 24-Sep   | 0.38                         | · · 2 · | 5-Nov               | 4.88                  | 20                | 16-Dec  | 0.56               | 2                |
| 25-Sep   | 0.52                         | 2       | 6-Nov               | 2.64                  | 11                | 17-Dec  | 0.58               | 2                |
| 26-Sep   | 3.34                         | 14      | 7-Nov               | 0.44                  | <sup>9214</sup> 2 | 18-Dec  | 2.68               | 11               |
| 27-Sep   | 0.42                         | 2       | -8-Nov              | 0.98                  | • 4               | 19-Dec  | 1.92               | <sup>1</sup> . 8 |
| 28-Sep   | 0.82                         | 3       | 9-Nov               | 0.98                  | 1 4               | 20-Dec  | 0.96               | ·· 4             |
| -29-Sep  | 0.56                         | 2       | 10-Nov              | 0.84                  | 3                 | 21-Dec  | 0.62               | <sup>1</sup> 3   |
| 30-Sep   | 0.50                         | 2       | 11-Nov              | 0.56                  | 2                 | 22-Dec  | 0.76               | 3                |
| 1-Oct    | 0.34                         | 1       | 12-Nov              | 1.16                  | · 5               | 23-Dec  | 0.34               | 1                |
| 2-Oct    | 1.56                         | 6       | 13-Nov              | 1.36                  | 6                 | 24-Dec  | 0.76               | 3                |
| 3-Oct    | 1.76                         | 7       | 14-Nov              | <sup>5</sup> ·1.64    | i 7               | 25-Dec  | 0.52               | <sup>***</sup> 2 |
| 4-Oct    | 0.70                         | 3       | 15-Nov              | 0.80                  | ି 3               | 26-Dec  | 0.58               | 2                |
| 5-Oct    | 0.40                         | 2       | 16-Nov              | <sup>3</sup> 0.46     | 2                 | 27-Dec  | 0.38               | 2                |
| 6-Oct    | 0.50                         | 2       | 17-Nov              | 0.82                  | 3                 | 28-Dec  | 0.46               | 2                |
| 7-Oct    | 0.86                         | 4       | 18-Nov              | 1.96                  | 8                 | 29-Dec  | 0.66               | • 3              |
| 9-Oct    | 1.32                         | 5       | 19-Nov              | - <b>1.54</b> 👎       | 6                 | 30-Dec  | 0.90               | 4.               |
| . 10-Oct | 1.88                         | 8       | 20-Nov              | 1.46                  | 6                 | 31-Dec  | 1.08               | 4                |
| 11-Oct   | 0.76                         | 3       | 21-Nov              | · 1.24                | 5                 | Total   | · · · ·            | 3700             |
| 12-Oct   | 0.18                         | 1       | 22-Nov              | 0.66                  | 3                 | Average | 2.5                | 10               |
| 13-Oct   | 0.38                         | 2       | 23-Nov              | <sup>0.98</sup>       | 4                 | StdDev  | 3.1                | 13               |
| 14-Oct   | 0.86                         | 4       | 24-Nov              | 😳 <b>(1.18</b> 🕐      | 5                 | Max     | 28                 | 118              |
| 15-Oct   | 1.00                         | 4       | 25-Nov              | 1.10                  | 5                 | Min     | 0.18               | 0.75             |

Table I 0 .

.

<sup>a</sup> From NLCO 1957; original analytical data sheets from the Bioassay Department at FMPC.

. 1.

<u>481 | 1</u> - 005 5 20 - 1000 ÷

| Annondi | а <b>.</b> г | • • |       | • • • |
|---------|--------------|-----|-------|-------|
| Surface | Water        | D   | ischa | irges |

- -

| Page | L-69 |
|------|------|
|------|------|

| 1958               | U <sup>a</sup> | Total U       | 1958           | Ua        | Total U   | 1958             | Ua          | Total II        |
|--------------------|----------------|---------------|----------------|-----------|-----------|------------------|-------------|-----------------|
| Date               | $(mg L^{-1})$  | (kg)          | Date           | (mg L=1). | (kg)      | Date             | (mg Ih      | Local U<br>(ko) |
| 1-Jan              | 1.46           | 6             | 16-Feb         | 0.88      | 4         | 4-Jul            | 0.94        |                 |
| 2-Jan              | 0.94           | 4             | 17-Feb         | 3.78      | 16        | 5-Jul            | 14          | 5               |
| 3-Jan              | 0.96           | 4             | 18-Feb         | 3.22      | 13        | 6-Jul            | 1.7         |                 |
| 4-Jan              | 1.92           | 8             | 19-Feb         | 1 20      | 5         | 7.101            |             | 1               |
| 5-Jan              | 0.76           | 3             | 20-Feb         | 0.96      | -A        | 8.101            | 1.79        | 0<br>7          |
| 6-Jan              | 0.84           | 3             | 21.Feb         | 3.86      | 16        | 0.1.1            | 1.12        | 10              |
| 7-Jan              | 0.58           | 2             | 22.Feb         | 3.42      | 14        | 10. [1]          | 4.0         | 10              |
| 8-Jan              | 0.68           | 3             | 23-Feb         | 1.08      | 14<br>A   | 11.701           | 1.2         | 21              |
| 9-Jan              | 0.76           | 3             | 24-Feb         | 0.66      |           | 12.101           | 1.92        | 1               |
| 10-Jan             | 0.56           | 2             | 25-Feb         | 0.00      | 3         | 12-001           | 0.00        | 3               |
| 11-Jan             | 0.32           | 1             | 26-Feb         | 1 1 4     | 3         | 14 5.1           | 0.94        | . 4.            |
| 12-Jan             | 1.18           | . <b>1</b>    | 27.Fah         | 9.79      | 11        | 15.1.1           | 1 4 4       | J<br>E          |
| 13-Jan             | 0.76           | 3             | 28-Fah         | 2.70      | 11        | 16.1.1           | 7 0<br>1-44 | 0<br>00         |
| 14-Ian             | 2.5            | , o           | 1.Mor          | 2.10      | 1.1       | 17.1.1           | 4.5         | ·· 20           |
| 15-Ian             | 2.68           | . 10          | 2-Mar          | 2.00      | · 11<br>2 | 10 1.1           | 3.0<br>0.0  | 14              |
| 16-Jan             | 0.74           | 3             | 2-Mar          | 1.20      | ວ<br>=    | 10-301           | 2.9         | 11              |
| 17-Jan             | 0.02           | ຸ ບ<br>ວ      | 4 Mar          | 1.20      | . 0.      | 19-Jul           | 2.6         | 10              |
| 18.Jan             | 0.52           | о<br>О        | 4-Mar<br>5 Mar | 0.08      |           | 20-501           | 1.60        | 6               |
| 10-0an<br>19-Jan   | 1.04           | о.<br>А       | 5-Mar          | 0.00      | 2         | 21-JUI           | 1.53        | 7               |
| 20-Tan             | 0.84           | 4             | o-Mar<br>7 Mor | 2.00      | 10        | 22-JUI           | 2.2         | 8               |
| 21-Tan             | 1.5            | 5             | 9 Mar          | 1.00      | 7         | 23-301           | 3.4         | 14              |
| 22-1an             | 5.78           | - ; U<br>- 00 | 0 Mar          | 1.00      | 7         | 24~JUI<br>05 I.J | 1.3         | 5               |
| 22-0411<br>22. Ian | 0.10           | 22            | 9-Mar          | 1.00      | 07        | 25-Jul           | 1.22        | 5               |
| 20-0411<br>94-10-0 | 1.50           | о<br>С        | 10-mar         | 7.00      | 21        | 25-JUI           | 0.74        | 3               |
| 24-Jan<br>95-Ian   | 1.00           | <b>0</b>      | 11-Mar         | 3.50      | 14        | 27-Jul           | 2.2         | 8               |
| 20-0an<br>26-10-   | 1.54           |               | 12-Mar         | 1.24      | 5         | 28-Jul           | 2.28        | 9               |
| 20-0 an<br>97. Ion | 2.5            | 10            |                | 4.32      | 17        | 29-JUI           | 3.22        | 12              |
| 27-Jan<br>28-Jan   | 2.30           | . 10          | 14-Mar         | 2.88      | - 12      | 30-Jul           | 3.55        | 13              |
| 20-Jan<br>20-Jan   | 2.00           | 20            | 10-Mar         | 1.64      | 6         | 31-Jul           | 6.7         | 25              |
| 30-Jan             | 1.4            | 50<br>E       | 10-Mar         | 1.24      | . 5       | I-Aug            | 12.3        | . 59            |
| 31. Inn            | 1.4            | 5             | 10 Mar         | 1.86      |           | 2-Aug            | 1.62        | 7               |
| 1.Eve              | 1.00           | 4             | 10 Mar         | . 0.47    | 2         | 4-Aug            | 3.36        | 15              |
| J-L 6D             | V.12           | 3<br>         | 19-Mar         | 0.86      | 3         | 5-Aug            | 2.72        | 14              |
| 2.F.h              | 1.20           | 5             | 20-Mar         | 0.54      | 2         | 7-Aug            | 4.28        | 19              |
| 097-C              | V.80           | 3             | 21-Mar         | 1.72      | 7         | 8-Aug            | 1.22        | 5               |
| 4•5 60<br>5 17-1   | U.14           | 3             | 22-Mar         | 1.36      | 5         | 9-Aug            | 2.10        | 8               |
| 0.5.60<br>C D-F    | . 1.40         | . 6           | 23-Mar         | 1.44      | 5.        | 10-Aug           | 1.22        | 5               |
| 0-1 60<br>0 17-1   | 1.5            | . 6           | 24-Mar         | 2.7       | 10        | 11-Aug           | 1.30        | 6               |
| 0-1 6D             | 0.9            | 3             | 25-Mar         | 2.08      | · 8       | 12-Aug           | 2.26        | 11              |
| J-Fed              | 0.82           | 3             | 26-Mar         | 0.68      | 3         | 13-Aug           | 1.70        | 7               |
| 11-Feb             | 0.56           | 2             | 28-Mar         | 0.68      | 3         | 14-Aug           | 3.50        | 16              |
| 11-Feb             | 2.04           | 8             | 29-Mar         | 0.98      | 4         | 15-Aug           | 2.34        | . 11            |
| 12-Feb             | 1.50           | 6             | 30-Mar         | 1.2       | 5.        | 16-Aug           | 2.34        | 10 .            |
| 13-Feb             | 1.40           | 5             | I-Jul          | 2.6       | 10        | 17-Aug           | 1.70        | 7               |
| 14-Feb             | 1.08           | 4             | 2-Jul          | 2.3       | 9         | 18-Aug           | 1.62        | 7               |
| 12-Feb             | 1.40           | 5 i           | 3-Jul          | 1.28      | 5         | 19.Ano           | 0.82        | 4               |

(Continued on next page)

| Page : | L-70 |
|--------|------|
|--------|------|

1988 Sty

 $\sum_{i=1}^{n}$ 

¢

ţ

| _ ·      | <u></u>        | <u></u> . | Manhole   | 175 in 195    | 8 (cont'd  | ) . •    |                  |                |
|----------|----------------|-----------|-----------|---------------|------------|----------|------------------|----------------|
| 1958     | Ua             | Total U   | 1958 💬    | No Ua         | Total U    | 1958     | Ua               | Total U        |
| Date     | $(mg L^{-1})$  | (kg)      | Date      | $(mg L^{-1})$ | (kg)       | Date     | $(mg L^{-1})$    | (kg)           |
| 20-Aug   | 0.66           | 2 .       | 5-Oct     | 2.58          | 10         | 21-Nov   | 0.47             | 2              |
| 21-Aug   | 1.14           | 0 ·       | 6-Oct     | 2.4           | 10         | 22-Nov   | 0.47             | 2              |
| 22-Aug   | 1.30           | 5         | 7-Oct .   | 2.02          | 8          | 23-Nov   | 0.56             | 2              |
| 23-Aug   | 0.98           | 4         | 8-Oct :   | 6.06          | · 23       | 24-Nov   | 1.03 .           | 4              |
| 24-Aug : | 2.10           | 10        | 9-Oct ;   | 4.04          | 15         | 25-Nov . | 1.6              | . 6            |
| 25-Aug   | 2.04           | 7         | 10-Oct :  | 2.4           | 9          | 26-Nov   | 1.5              | 6              |
| 26-Aug   | 3.34           | 15        | 11-Oct    | 2.58          | 9          | 27-Nov   | 0.66             | 2              |
| 27-Aug   | 2.04           | 9 :       | 12-Oct    | 1.48          | 5          | 28-Nov   | 2.44             | 9              |
| 28-Aug   | 0.74           | 3         | 13-Oct :  | 1.48          | 5          | 29-Nov   | 3.01.            | 12             |
| 29-Aug   | 2.80           | 13        | 14-Oct -  | 3.86 ,        | 15         | 30-Nov   | 2.07             | 9              |
| 30-Aug   | 1.48           | 7         | 15-Oct -  | 1.84          | 6          | 1-Dec    | 1.29             | 5              |
| 31-Aug   | 5.20           | 25        | 16-Oct -  | 1.1           | 4          | 2-Dec    | 1.97             | 8              |
| 1-Sep    | 3.54           | 16        | 17-Oct :- | 3.12          | 12         | 3-Dec    | 1.97             | 7              |
| 2-Sep    | 1.30           | 6         | 18-Oct    | 1.54          | 5          | 4-Dec    | . 2.44           | 9              |
| 3-Sep    | 3.16           | 15        | 19-Oct    | 1.1           | 4 (        | 6-Dec    | <b>2.54</b>      | 10             |
| 4-Sep    | 1.86           | 9         | 20-Oct    | 0.92          | 3          | 7-Dec    | 2.16             | · 8            |
| 5-Sep    | 1.68           | · 9       | 21-Oct    | 1.5           | 5          | 8-Dec    | 2.63 ·           | 10 ·           |
| 7-Sep    | 0.94           | 4         | 23-Oct    | 5.35          | 19         | 10-Dec   | 1.22             | 5              |
| 8-Sep    | 3.34           | 15        | 24-Oct    | 4.28          | 15         | 11-Dec   | 1.03             | 4              |
| 9-Sep    | 6.24           | 31        | 25-Oct    | 1.93          | 7          | 12-Dec   | 0.94             | 4 <sup>·</sup> |
| 10-Sep   | 4.46           | 20        | 26-Oct :  | 5.78          | 13         | 13-Dec   | 1.41             | 5              |
| 11-Sep   | 2.80           | 13,       | 28-Oct    | 2.16          | <b>9</b> . | 14-Dec   | 1.5              | 6              |
| 12-Sep   | 3.54           | 16 •      | 29-Oct    | 0.93          | ·· 4 :     | 15-Dec   | 2.2              | 8              |
| 13-Sep   | 4.10           | 18        | 30-Oct    | 1.13          | 5          | 16-Dec   | 0.83             | 3              |
| 14-Sep   | 1.30           | 5         | 31-Oct    | 0.93          | 6          | 17-Dec   | 6.44             | 24             |
| 14-Sep 1 | 1.3            | 5         | 1-Nov     | 16.48         | 108        | 18-Dec   | 1.47             | 6              |
| 15-Sep   | 1.3 😳          | 6         | 2-Nov     | 3.07          | 11         | 19-Dec   | 1.38 ;           | 5              |
| 16-Sep   | 4.46           | 18        | 3-Nov     | 1.34          | 5          | 20-Dec   | 0.64             | 2              |
| 17-Sep   | <b>8.32</b>    | 38        | 4-Nov     | 1.34          | 5          | 21-Dec   | 0.92             | 4              |
| 18-Sep   | 2.98           | 12        | 5-Nov     | <b>5.15</b>   | 22         | 22-Dec   | 0.39             | 2              |
| 19-Sep   | 4.24           | 33        | 6-Nov     | 8.24          | 38         | 23-Dec   | 1.66             | 6              |
| 20-Sep   | 5.52           | 22        | 7-Nov     | 14.42         | 64         | 24-Dec   | 1.84             | 7              |
| 21-Sep   | 1.86           | <b>7</b>  | 8-Nov     | 5.36          | 25         | 25-Dec   | 0.92             | <b>3</b> .     |
| 22-Sep   | 1.48           | 7.        | 9-Nov     | 4.94          | 22         | 26-Dec   | 0.67             | 2              |
| 23-Sep   | 2.76           | 10        | 10-Nov    | 1.88          | 8          | 27-Dec   | 0.58             | 2              |
| 24-Sep   | 1.3            | 5         | 11-Nov.   | 0.94          | 5          | 28-Dec   | 3.68             | 12             |
| 25-Sep   | 1.68           | 7         | 12-Nov    | 1.13          | 4          | 29-Dec   | 7.91             | 28             |
| 26-Sep   | 3.21           | : 14      | 13-Nov    | 0.85          | 3          | 30-Dec   | 2.21             | 10             |
| 27-Sep   | 2.58           | 10        | 14-Nov    | 0.75          | 3          | 31-Dec   | 1.1              | 4              |
| 28-Sep   | 1.48           | 5         | 15-Nov    | 1.79          | 8.         |          | 6. <b>.</b> * 15 |                |
| 30-Sep   | 2.51           | 9_        | 16-Nov    | 1.6           | 6          | Total    |                  | 2600           |
| 1-Oct    | <b>3.5</b> t j | , 14      | 17-Nov    | 1.79          | 6          | Average  | 2.3              | , 9.4          |
| 2-Oct    | 1.28           | 6         | 18-Nov    | <b>6.79</b> 🦵 | 33         | StdDev   | 2.0              | 8.4            |
| 3-Oct    | 4.78           | 19        | 19-Nov    | 0.94          | 6          | Max      | 17               | 69             |
| 4-Oct    | 2.94           | 11        | 20-Nov    | 0.52          | . 3        | Min      | 0.32             | 1.3            |

 Table L1-4B. Measured Concentrations and Calculated Quantities of Uranium at

 Manhole 175 in 1958 (cont'd)

<sup>a</sup> From NLCO 1958.

÷.

11-Feb

1.07

4

.

n\_

| Table L | 1-5A. Meas            | sured Co   | ncentrát | ions and (    | Calculate     | ed Quant | ities of Ura          | anium at |  |
|---------|-----------------------|------------|----------|---------------|---------------|----------|-----------------------|----------|--|
|         |                       |            | Man      | hole 175 ir   | <u>n 1959</u> |          | ·                     |          |  |
| 1959    | Ua                    | U          | 1959     | Uª            | U             | 1959     | .04                   | Ŭ        |  |
| Date    | (mg L <sup>-1</sup> ) | (kg)       | Date     | $(mg L^{-1})$ | (kg)          | Date     | (mg L <sup>-1</sup> ) | (kg)     |  |
| 1-Jan   | 1.20                  | 5          | 12-Feb   | 0.68          | 3             | 30-Mar   | , <b>3.92</b>         | 16       |  |
| 2-Jan   | 1.01                  | · 4        | 13-Feb   | 2.43          | 10            | 31-Mar   | 1.21                  | 5        |  |
| 3-Jan   | 1.10                  | <b>5</b> · | 14-Feb   | 2.81          | 12            | 1-Apr    | 1.67                  | 7        |  |
| 4-Jan   | 2.94                  | 12         | 15-Feb   | 1.26          | 5             | 2-Apr    | 1.02 <sup>.</sup>     | 4        |  |
| 5-Jan   | 2.30                  | 10         | 16-Feb   | 0.78          | 3             | 6-Apr    | 1.95                  | 8        |  |
| 6-Jan   | 1.47                  | 6          | 17-Feb   | 1.07          | .4 ·          | 7-Apr    | 1.77                  | 7        |  |
| 7-Jan   | 1.10                  | 5          | 18-Feb   | 1.65          | 7             | 8-Apr    | 0.93                  | 4        |  |
| 8-Jan ' | 1.47                  | 6          | 19-Feb   | 0.78          | 3             | 9-Apr    | 1.40                  | • 6      |  |
| 9-Jan   | 0.50                  | 2          | 24-Feb   | 0.59          | 2             | 10-Apr   | 0.56                  | 2        |  |
| 10-Jan  | 0.56                  | 2          | 25-Feb   | 0.78          | 3             | 11-Apr   | 0.93                  | 4        |  |
| 11-Jan  | 0.43                  | 2          | 26-Feb   | 0.68          | 3             | 12-Apr   | 1.40                  | 6        |  |
| 12-Jan  | 0.50                  | 2 '        | 27-Feb   | 0.49          | 2             | 13-Apr   | 0.88                  | 4        |  |
| 13-Jan  | 2.91                  | 12         | 28-Feb   | 0.78          | 3             | 14-Apr   | 0.56                  | 2        |  |
| 14-Jan  | 3.68                  | 15         | 1-Mar    | 1.07          | 4             | 15-Apr   | 0.84                  | 3        |  |
| 15-Jan  | 1.16                  | 5          | 2-Mar    | 0.58          | 2             | 16-Apr   | 0.74                  | 3        |  |
| 16-Jan  | 1.07                  | 4          | 3-Mar    | 0.67          | <b>`3</b>     | 17-Apr   | 0.93                  | 4        |  |
| 17-Jan  | 0.97                  | 4          | 4-Mar    | 2.85          | 12            | 18-Apr   | 0.84                  | 3        |  |
| 18-Jan  | 0.58                  | 2          | 5-Mar    | <b>1.52</b>   | 6             | 19-Apr   | 2.94                  | 12       |  |
| 19-Jan  | 0.50                  | 2          | 6-Mar    | 1.33          | 6             | 20-Apr   | 1.30                  | 5        |  |
| 20-Jan  | 1.94                  | 8          | 7-Mar    | 1.24          | 5             | 21-Apr   | 0.78                  | 3        |  |
| 21-Jan  | 3.01                  | 13         | 8-Mar    | 0.86          | 4 ·           | 22-Apr - | 0.68                  | 3        |  |
| 22-Jan  | 2.52                  | 10         | 9-Mar .  | 0.86          | 4             | 23-Apr   | 0.68                  | 3        |  |
| 23-Jan  | 0.68                  | 3          | 10-Mar   | 1.71          | 7             | 24-Apr   | 0.49                  | 2        |  |
| 24-Jan  | 0.87                  | 4          | 11-Mar   | 1.81          | 8             | 25-Apr   | 1.46                  | 6        |  |
| 25-Jan  | 0.78                  | 3.         | 12-Mar   | 1.52          | · 6           | 26-Apr   | 2.85                  | 12       |  |
| 26-Jan  | 1.65                  | 7          | 13-Mar   | 1.81          | . 8           | 27-Apr   | 1.84                  | 8        |  |
| 27-Jan  | 2.04                  | . 8        | 14-Mar   | 1.24          | 5             | 28-Apr   | 2.62                  | 11       |  |
| 28-Jan  | 2.04                  | 8          | 15-Mar   | 1.33          | 6             | 29-Apr   | 1.16                  | 5        |  |
| 29-Jan  | 1.75                  | 7          | 16-Mar   | 2.76          | 11            | 30-Apr   | 0.87                  | 4        |  |
| 30-Jan  | 1.46                  | 6          | 17-Mar   | 1.24          | 5             | 1-May    | 0.58                  | 2        |  |
| 31-Jan  | 1.26                  | 5          | 18-Mar   | 3.88          | 16            | 2-May    | 0.49                  | 2        |  |
| 1-Feb   | 0.97                  | 4          | 19-Mar   | 0.76          | 3             | 3-May    | 0.49                  | 2        |  |
| 2-Feb   | 0.87                  | 4          | 20-Mar   | 1.24          | 5             | 4-May    | 1.07                  | ·4       |  |
| 3-Feb   | 1.84                  | 8          | 21-Mar   | 0.95          | 4             | 5-May    | D.52                  | 2        |  |
| 4-Feb   | 1.94                  | 8          | 22-Mar   | · 0.76        | 3             | 6-May    | 0.34                  | 1        |  |
| 5-Feb   | 1.65                  | 7          | 23-Mar   | 1.62          | 7             | 7-May    | 0.87                  | 4        |  |
| 6-Feb   | 1.55                  | 6          | 24-Mar   | 2.57          | 11            | 9-May    | 0.97                  | 4        |  |
| 7-Feb   | 1.84                  | 8          | 25-Mar   | 0.84          | · · 3         | 10-May   | 3.80                  | 16       |  |
| 8-Feb   | 1.16                  | 5          | 26-Mar   | 1.21          | 5             | 11-May   | 1.84                  | 8        |  |
| 9-Feb   | 1.56                  | 6          | 27-Mar   | 0.74          | 3             | 12-May   | 1.82                  | 8        |  |
| 10-Feb  | 2.23                  | 9          | 28-Mar   | 0.84          | · 3           | 13-May   | 1.75                  | 7        |  |

0.74 (Continued on next page)

3

29-Mar

### **Radiological Assessments Corporation**

14-May

0.67 -

3

"Setting the standard in environmental health"

| Page L-72 | The Fernald Desimetry Reconstruction Project  |
|-----------|-----------------------------------------------|
|           | The remain Dosimetry neconstruction roject    |
|           | Tasks 2 and 3 Source Terms and Uncertainties  |
|           | Tasks 2 and 0, oburte Terms and Oncertainties |
|           |                                               |

| 1959                | · U <sup>a</sup>          | U        | 1959     | · · · · · · · · · · · · · · · · · · · | 5 U          | 1959     | Ua      | U        |
|---------------------|---------------------------|----------|----------|---------------------------------------|--------------|----------|---------|----------|
| Date                | (mg L-l)                  | (kg)     | Date     | (mg I-h                               | (kg)         | Date     | (mg I-h | (kg)     |
| 15-May              | 0.95                      | 4        | 27-Jun   | 0.97                                  | 4            | 8-Ang    | 0.86    | - 4      |
| 16-May              | 0.67                      | 3        | 28-Jun   | 2.96                                  | 12           | 9-Aug    | 1.33    | 6.       |
| 17-May              | 0.53                      | 2        | 29-Jun   | ÷€5.94 × ·                            | 25           | 10-Aug   | 0.48    | 2        |
| 18 May              | 1.71                      | 7        | 30-Jun   | 0.97                                  | 4            | 11-Aug   | 1.81    | 8        |
| 19-May              | 1.14                      | 5        | 1-Jul    | - 0.78                                | 3            | 12-Aug   | 3.92    | 16       |
| 20-May              | 1.52                      | 6        | 2-Jul    | 0.78                                  | 3            | 13-Aug   | 1.62    | . 7      |
| 21-May              | 1.05                      | . 4      | 3-Jul    | 1.84                                  | · 8          | 14-Aug   | 0.54    | ່ 2      |
| 22-May              | 13.72                     | 57       | 4-Jul    | 0.39                                  | - 2          | 15-Aug   | 1.71    | 7        |
| 23-May              | 1.05                      | 4        | 5-Jul    | 2.23                                  | 9            | 16-Aug   | 2.00    | 8        |
| 24-May              | 0.38                      | 2        | 6-Jul    | 3.49                                  | 15           | 17-Aug   | 3.92    | 16       |
| 25-May              | 1.05                      | 4        | 7-Jul    | 1.07                                  | 4            | 18-Aug   | 2.02    | · 8      |
| 26-May              | 1.05                      | 4        | 8-Jul    | 0.97                                  | 4            | 19-Aug   | 1.25    | 5        |
| 28-May              | 0.95                      | : 4      | - 9-Jul  | 0.87                                  | 4            | 20-Aug   | 1.15    | 5        |
| 29-May              | 1.71                      | 7        | 10-Ju]   | 0.97                                  | 4            | 21-Aug   | 1.15    | 5        |
| 30-May              | 0.76                      | 3        | 11-Jul - | 1.65                                  | 7            | 22-Aug   | 0.67    | 3        |
| 31-May              | 0.57                      | 2        | 12-Jul   | 1.26                                  | 5            | 23-Aug   | 0.48    | 2        |
| J-Jun               | 0.57                      | 2        | 13-Jul   | ં <b>1.75</b> ં                       | ··· <b>7</b> | 24-Aug   | 2.40    | . 10     |
| - 2-Jun             | 2.00                      | 8        | 14-Jul   | ·1.07                                 | 4            | 25-Aug   | 1.96    | 8        |
| 3-Jun               | 0.86                      | 4        | 15-Jul   | 1.52                                  | 6            | 26-Aug   | 1.05    | 4        |
| : 4-Jun             | 2.38                      | - 10     | 16-Jul   | 0.95                                  | 4            | 27-Aug   | 2.11    | 9        |
| 5-Jun               | 0.95                      | 4        | 17-Jul   | 1.14                                  | 5            | 28-Aug   | 1.82    | 8        |
| 6-Jun               | 0.71                      | 3        | 18-Jul   | 3.52                                  | 15           | 29-Aug   | 1.54    | 6        |
| 🕆 7-Jun             | 0.38                      | <b>2</b> | 19-Jul   | 2.19                                  | 9            | 30-Aug   | 1.06    | <b>4</b> |
| 8-Jun               | 0.57                      | 2        | 20-Jul   | 1.43                                  | 6            | 31-Aug - | 0.86    | · 4      |
| 9-Jun               | 0.67                      | 3        | 21-Jul   | 0.67                                  | · 3          | 1-Sep    | 3.36    | 14       |
| ' 10-Jun            | ° 1.14                    | 5        | 22-Jul   | 0.95                                  | 4            | 2-Sep    | 2.21    | ́ 9      |
| 11-Jun              | 2.72                      | ູ11      | 23-Jul   | 3.92                                  | 16           | 3-Sep    | 1.34    | 6        |
| 12-Jun_             | 1.75                      | · 7      | 24-Jul   | 2.38                                  | 10           | 4-Sep    | 0.86    | 4        |
| 13-Jun              | 1.07                      | 4        | 25-Jul   | 0.29                                  | 1            | 5-Sep    | 0.67    | 3        |
| 14-Jun              | 0.49                      | 2        | 26-Jul   | 0.37                                  | 2            | 6-Sep    | 1.06    | 4        |
| 15-Jun              | <b>3.4</b> 0 <sup>-</sup> | . 14     | 27-Jul   | 1.14                                  | 5            | 7-Sep    | 0.67    | 3        |
| . 16-Jun            | 0.68                      | · 3      | 28-Jul   | 2.09                                  | 9            | 8-Sep    | 1.15    | 5        |
| 17-Jun <sub>.</sub> | 0.68                      | 3        | 29-Jul   | 1.52                                  | 6            | 9-Sep    | 2.50    | 10       |
| 18-Jun              | 0.58                      | 2        | 30-Jul   | 0.56                                  | 2            | 10-Sep   | 2.98    | • 12     |
| 19-Jun              | 0.39                      | 2        | 31-Jul   | 0.86                                  | 4            | 11-Sep   | 0.86    | 4        |
| 20-Jun              | 0.68                      | 3        | 1-Aug    | 1.62                                  | 7            | 12-Sep   | 1.25    | 5        |
| 21-Jun              | 1.55                      | 6        | 2-Aug    | 0.86                                  | 4            | 13-Sep   | 1.06    | 4        |
| 22-Jun              | 0.87                      | 4        | 3-Aug    | 0.67                                  | 3            | I4-Sep   | 1.73    | • 7      |
| 23-Jun              | 2.04                      | 8        | 4-Aug    | 2.94                                  | 12           | 15-Sep   | 0.86    | 4        |
| 24-Jun              | 1.26                      | 5        | 5-Aug    | 1.62                                  | 7            | 16-Sep   | 3.26    | 14       |
| 25-Jun              | 2.97                      | 12       | 6-Aug    | 1.14                                  | 5            | 17-Sep   | 1.92    | 8        |
|                     | 0.40                      | 10       |          | 1.14                                  | -            | 1        | 0.06    |          |

File C

in the second 
er Michies

•

(Continued on next page)

-

Page L-73

| Table L | 1-5C. Meas            | sured Co | oncentrai | tions and (   | Calculat   | ed Quanti | ities of Ur           | anium at   |
|---------|-----------------------|----------|-----------|---------------|------------|-----------|-----------------------|------------|
|         |                       |          | Manhole   | 175 in 195    | 9 (cont'   | d)        |                       |            |
| 1959    | Ua                    | U        | 1959      | Ua            | U          | 1959      | Ua 🦉                  | U          |
| Date    | (mg L <sup>-1</sup> ) | (kg)     | Date      | $(mg L^{-1})$ | (kg)       | Date      | (mg L <sup>-1</sup> ) | (kg)       |
| 19-Sep  | 0.48                  | 2        | 31-Oct    | 3.03          | 13         | 12-Dec    | 3.23                  | 13         |
| 20-Sep  | 0.37                  | 2        | 1-Nov     | 6.98          | 29         | 13-Dec    | 1.81                  | 8          |
| 21-Sep  | 0.76                  | 3        | 2-Nov     | 2.77          | 12         | 14-Dec    | 1.94                  | 8          |
| 22-Sep  | 1.62                  | 7        | 3-Nov     | 2.90          | 12         | 15-Dec    | 1.55                  | 6          |
| 23-Sep  | 0.57                  | 2        | 4-Nov     | 3.83          | 16         | 16-Dec    | 1.63                  | 7          |
| 24-Sep  | 0.67                  | 3        | 5-Nov     | 2.77          | 12         | 17-Dec    | 1.48                  | 6          |
| 25-Sep  | 1.62                  | 7        | 6-Nov     | 2.51          | 10         | 18-Dec    | 2.96                  | 12         |
| 26-Sep  | 1.52                  | 6        | 7-Nov     | 8.37          | 35         | _19-Dec   | 2.07                  | 9          |
| 27-Sep  | 5.70                  | 24       | 8-Nov     | 1.98          | 8          | 20-Dec    | 1.78                  | 7          |
| 28-Sep  | 1.62                  | 7        | 9-Nov     | 11.16         | 46         | 21-Dec    | 1.78                  | 7          |
| 29-Sep  | 0.95                  | 4        | 10-Nov    | 2.51          | 10         | 22-Dec    | 2.07                  | <b>9</b> . |
| 30-Sep  | 0.95                  | 4        | 11-Nov    | 2.90          | 12         | 23-Dec    | 1.48                  | 6          |
| 1-Oct   | 1.43                  | 6        | 12-Nov    | 3.43          | 14         | 24-Dec    | 5.33                  | 22         |
| 2-Oct   | 1.24                  | 5.       | 13-Nov    | 4.62          | 19         | 25-Dec    | 2.96                  | 12         |
| 3-Oct   | 2.66                  | 11       | 14-Nov    | 3.96          | 16         | 26-Dec    | 6.66                  | 28         |
| 4-Oct   | 3.14                  | 13       | 15-Nov    | 1.85          | · 8        | 27-Dec    | 6.07                  | 25         |
| 5-Oct   | 1.52                  | 6        | 16-Nov    | 1.98          | <b>8</b> · | 28-Dec    | 3.55                  | 15         |
| 6-Oct   | 2.28                  | 9        | · 17-Nov  | 1.58          | 7          | 29-Dec    | 2.52                  | 10         |
| 7-Oct   | 1.52                  | 6        | 18-Nov    | 1.40          | 6          | 30-Dec    | 2.66                  | 11         |
| 8-Oct   | 2.09                  | 9        | 19-Nov    | 3.32          | 14         | 31-Dec    | 1.78                  | 7          |
| 9-Oct   | 0.76                  | 3        | 20-Nov    | 2.21          | 9 ΄        |           |                       |            |
| 10-Oct  | 0.95                  | 4        | 21-Nov    | 43.20         | 180        | Ann Total |                       | 2800       |
| 11-Oct  | 2.09                  | 9        | 22-Nov    | 3.47          | 14         | Average   | 1.9                   | 8          |
| 12-Oct  | 1.33                  | 6        | 23-Nov    | 6.40          | 27         | StdDev    | 2.6                   | 11         |
| 13-Oct  | 2.38                  | 10       | 24-Nov    | 2.68          | 11         | Max       | 43                    | 180        |
| 14-Oct  | 1.71                  | 7        | 25-Nov    | 1.42          | 6          | Min       | 0.29                  | 1          |

( ) · · · · ·

<sup>a</sup> From NLCO 1959; original analytical data sheets from the Bioassay Department at FMPC.

| Page | L-74 |
|------|------|
|------|------|

50.XX.51

| <i></i> |                   |                      | <u> </u>     | inhole.17       | <u>5 in 19</u>           | 60                   |                     |         |  |  |
|---------|-------------------|----------------------|--------------|-----------------|--------------------------|----------------------|---------------------|---------|--|--|
|         |                   | <u> </u>             | January 1960 |                 |                          | February 1960        |                     |         |  |  |
| <br>•   |                   | Uranium <sup>a</sup> | Volumeh      | Uranium         |                          | Uranium <sup>a</sup> | Volume <sup>b</sup> | Uranium |  |  |
| ·       | Date              | $(mg L^{-1})$        | (gal)        | (kg)            |                          | $(mg L^{-1})$        | (gal)               | . (kg)  |  |  |
| 7       | 1                 | 1.63                 | 1180400      | 7               | ана алан<br>1946 - Салан | 0.95                 | 1090600             | 4       |  |  |
|         | 2                 | . 2.37               | 1180400      | 11              | l                        | 1.5                  | 1030750             | 6       |  |  |
| •       | <b>3</b> .        | 2.52                 | 1180400      | 11              |                          | 1.2                  | 1030750             | 5       |  |  |
|         | 4                 | 0.89                 | 1180400      | 4               | -                        | 2.54                 | 1047375             | 10      |  |  |
|         | 5                 | 11.83                | 1180400      | 46              |                          | 2.83                 | 984200              | 11      |  |  |
|         | 6                 | 1.63                 | 1180400      | .7              | in                       | 3.64                 | 1083950             | 15      |  |  |
| •       | 7                 | 1.92                 | 1180400      | 9               | the second               | 1.6                  | 1010800             | 6       |  |  |
| •       | 8                 | 1.78                 | 1180400      | 8               |                          | 1.75                 | 1044050             | 7       |  |  |
|         | 9                 | 1.63                 | 1180400      | 7               |                          | 9.9                  | 1067325             | 40      |  |  |
|         | 10                | 2.81                 | 1180400      | 13              |                          | 3.65                 | 1825000             | 25      |  |  |
| ••      | 11                | 2.97                 | 1180400      | 13              |                          | 1.95                 | 1057350             | 8       |  |  |
|         | 12                | 2.97                 | 1180400      | 13              | 4. 54                    | 3.1                  | 1014125             | 12      |  |  |
| • •     | 13                | 2.97                 | 1180400      | 13              |                          | 2.25                 | 1044050             | 9       |  |  |
| ÷       | 14                | 1.8                  | 1180400      | 8               |                          | 1.85                 | 1040725             | 7       |  |  |
| ·       | 15                | 2.01                 | 1180400      | 9               |                          | 1.75                 | 1093925             | 7       |  |  |
| ;       | . 16 <sup>°</sup> | 1.17                 | 1180400      | 5               | <b>!</b> · ·             | 2.55                 | 1024125             | 10      |  |  |
|         | 17                | 0.42                 | 1180400      | 2.              | • •                      | 2.6                  | 1056325             | 10 ·    |  |  |
|         | 18                | 2.33                 | 1180400      | 10              | 3                        | 13.4                 | 1052450             | 53      |  |  |
| •       | 19                | 0.95                 | 1180400      | · '4            |                          | 2.3                  | 1062765             | 9       |  |  |
| :       | 20                | 1                    | 1180400      | 4               |                          | 2.3                  | 1120525             | 10      |  |  |
|         | 21                | 1                    | 1180400      | 4               |                          | 2.4                  | 1047375             | 10      |  |  |
| • •     | 22                | 1.8                  | 1180400      | . 8             | 42. <b>*</b> 41          | 2.15                 | 1049880             | 9       |  |  |
| •       | 23                | 1                    | 1180400      | 4               |                          | 2.5                  | 1050700             | 10      |  |  |
|         | 24                | 1.35                 | 1180400      | 6               | 1.<br>1.                 | 1.75                 | 1117200             | 7       |  |  |
|         | 25                | 1.75                 | 964250       | 6               |                          | 2.8                  | 1250203             | 13      |  |  |
|         | . 26              | 2.8                  | 874499       | · 9             |                          | 1.95                 | 1250203             | 9       |  |  |
| ·       | 27                | 3.3                  | 1070660      | 13              | •                        | 1.65                 | 1250203             | 8       |  |  |
|         | 28                | 2.8                  | 1024100      | 11              | * *                      | 1.75                 | 1250203             | 8       |  |  |
| ۰ د     | 29                | 1.7                  | 970900       | 6               | स                        | 1.25                 | 1250203             | 6       |  |  |
|         | 30                | 1.85                 | 877800       | <sup>1</sup> 6  |                          |                      |                     |         |  |  |
| 1.      | 31                | 1.25                 | 1050700      | 5               |                          | . :                  | ·.                  |         |  |  |
|         | Totals            | 68.2                 | 35162509     | 286             | 1                        | 81.8                 | 32297335            | 343     |  |  |
|         | StdDev            | •                    | 1200000      | 21              |                          |                      | 780000              | 23      |  |  |
| ,       | Average           | ··· 2.2              | 1134274      | ・ <u></u><br>と9 | 14                       | 2.8                  | 1113701             | 12      |  |  |
|         | Max               | 11.8                 | 1180400      | 46              | 1 : :01                  | 13.4                 | 1825000             | 53      |  |  |
|         | Min               | 0.4                  | 874499       | 2               | <b>i</b> - ;             | 1                    | 984200              | 4       |  |  |

Table L1–6A. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1960

<sup>a</sup> From NLCO 1960–1962; 24 hour composite samples.

. . . . .

20

and the second second second

<sup>b</sup> From Cuthbert 1960–1962 and Fischoff 1960–1962; a monthly average value was used when daily measurments were not located.

CANCERSING STREET, STRE

. .

. . . . .

, j

### Page L-75

| Manhole 175 in 1960 |                      |                     |         |     |                       |                     |            |  |  |  |
|---------------------|----------------------|---------------------|---------|-----|-----------------------|---------------------|------------|--|--|--|
|                     | - <u></u>            | March 1960          | )       |     | April 1960            |                     |            |  |  |  |
|                     | Uranium <sup>a</sup> | Volume <sup>h</sup> | Uranium | · · | Uranium <sup>a</sup>  | Volume <sup>b</sup> | Uranium    |  |  |  |
| Uate                | $(mg L^{-1})$        | (gal)               | (kg)    | ļ   | (mg L <sup>-1</sup> ) | (gal)               | (kg)       |  |  |  |
| I                   | 1.45                 | 1028500             | 6       |     | 4.4                   | 997500              | 17         |  |  |  |
| 2                   | 1.6                  | 1028500             | 6       | } · | 2.8                   | 1010800             | 11         |  |  |  |
| 3                   | 1.9                  | 1028500             | 7       |     | 6.35                  | 1050700             | 25         |  |  |  |
| • 4                 | 2.5                  | 1028500             | 10      |     | 3.9                   | 1123850             | . 17       |  |  |  |
| 5                   | 1.45                 | 1028500             | 6       |     | 3.5                   | 1037400             | 14         |  |  |  |
| • 6                 | 0.9                  | 1028500             | 3       | ł   | 2.3                   | 984200              | 9          |  |  |  |
| 7                   | 1.2                  | 1028500             | • 5     |     | 3.5                   | 950925              | 13         |  |  |  |
| 8.                  | 1.35                 | 1028500             | 5       | ļ · | 2.15                  | 937650              | 8          |  |  |  |
| 9                   | 2.2                  | 1028500             | 9       | {   | 1.8                   | 931000              | <b>6</b> . |  |  |  |
| 10                  | 2.95                 | 1028500             | 11      | f   | 2.65                  | 970900              | 10         |  |  |  |
| 11                  | 2.46                 | 1028500             | 10      |     | 29.5                  | 931000              | 104        |  |  |  |
| 12                  | 2.6                  | 1028500             | 10      |     | 4.5                   | 990850              | 17         |  |  |  |
| 13                  | 1.95                 | 1028500             | 8       |     | 4.5                   | 964250              | 16         |  |  |  |
| 14                  | 1.65                 | 1028500             | 6       |     | 2.5                   | 927675              | 9          |  |  |  |
| 15                  | 1.25                 | 1028500             | 5       |     | 4.5                   | 940975              | 16         |  |  |  |
| . 16                | 3.9                  | 1028500             | 15      |     | 8.5                   | 924350              | 30         |  |  |  |
| 17                  | 5.45                 | 1028500             | 21      |     | 4.5                   | 997500              | 17         |  |  |  |
| 18                  | 2.85                 | 1028500             | 11      |     | 8                     | 924350              | 28         |  |  |  |
| 19                  | 2.4                  | 1028500 .           | 9.      |     | 3.5                   | 970900              | 13         |  |  |  |
| 20                  | 1.85                 | 1028500             | 7       |     | 3.65                  | 931000              | 13         |  |  |  |
| 21                  | 2.35                 | 1028500             | 9       |     | 5.5                   | 944300.             | 20         |  |  |  |
| 22                  | 1.65                 | 1028500             | 6       |     | 5.5                   | 944300              | 20         |  |  |  |
| 23                  | 1.75                 | 1028500             | 7       |     | 5                     | 1024100             | 19         |  |  |  |
| 24                  | 1.4                  | 1028500             | 5       |     | 3.5                   | 957600              | 13         |  |  |  |
| 25                  | 2.3                  | 860520              | 7       |     | 4                     | 984200              | 15         |  |  |  |
| 26                  | 4.9                  | 1049880             | 19      |     | 5.5                   | 824450              | 17         |  |  |  |
| 27                  | 2.15                 | 1030560             | · 8.    |     | 2.9                   | 856650              | . 9        |  |  |  |
| 28                  | 5.9                  | 936520              | 21      |     | 2.9                   | 924350              | 10         |  |  |  |
| 29                  | 5.4                  | 1010800             | 21      |     | 2.2                   | 933950              | 8          |  |  |  |
| 30                  | 3                    | 997500              | 11      |     | 7                     | 908150              | 24         |  |  |  |
| 31                  | 2.55                 | 931000              | · 9     |     |                       |                     |            |  |  |  |
|                     |                      |                     |         |     |                       |                     |            |  |  |  |
| Totals              | 77.2                 | 31500780            | 295     |     | 151                   | 28799825            | 544        |  |  |  |
| StdDev              |                      | 1040000             | 18      |     |                       | 527000              | 37         |  |  |  |
| Average             | 2.5                  | 1016154             | 10      |     | 5                     | 959994              | 18         |  |  |  |
| Max                 | 5.9                  | 1049880             | 21      |     | 29.5                  | 1123850             | 104        |  |  |  |
| Min                 | 0.9                  | 860520              | 3       | ·   | 1.8                   | 824450              | 6          |  |  |  |

## Table L1-6B. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1960

<sup>a</sup> From NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960-1962 and Fischoff 1960-1962; a monthly average was used when daily measurments were not located.

| Page L-76 | The Fernald Dosimetry Reconstruction Project  |
|-----------|-----------------------------------------------|
|           | Tasks 2 and 3. Source Terms and Uncertainties |

| Manhole 175 in 1960 |                      |                     |              |              |                      |                     |             |  |  |  |
|---------------------|----------------------|---------------------|--------------|--------------|----------------------|---------------------|-------------|--|--|--|
|                     |                      | May 1960            |              |              |                      | June 1960           | •           |  |  |  |
| Date                | Uranium <sup>a</sup> | Volume <sup>b</sup> | Uranium      | ·            | Uranium <sup>a</sup> | Volume <sup>h</sup> | Uranium     |  |  |  |
|                     | $(mg L^{-1})$        | (gal)               | (kg)         |              | $(mg L^{-1})$        | (gal)               | (kg)        |  |  |  |
| 1                   | 3.1                  | 914625              | + 11         | · ·          | 4.5                  | 1056400             | 18          |  |  |  |
| 2                   | 4.5                  | 995125              | - 17         |              | 5                    | 1056400             | 20          |  |  |  |
| 3.                  | 4.5                  | 1017450             | 17           |              | 3.5                  | 1056400             | 14          |  |  |  |
| 4                   | 2.75                 | 964250              | 10           | Í            | 4.5                  | 1056400             | 18          |  |  |  |
| 5                   | 2.75                 | 984200              | 10           | ]            | 3.5                  | 1056400             | 14          |  |  |  |
| 6                   | · 2.4                | 950950              | ÷9           |              | 3.5                  | 1056400             | 14          |  |  |  |
| 7                   | - 7.5                | 844550              | 24           | •            | <b>3</b> ·           | 1056400             | 12          |  |  |  |
| 8                   | 5.5                  | 957600              | 20           | · ·          | 5.5                  | 1056400             | 22          |  |  |  |
| 9                   | 4.1                  | 944300              | -15          | <b>]</b> .   | 3.5                  | 1056400             | 14          |  |  |  |
| 10                  | 7                    | 1000825             | 26           |              | 1.95                 | 1056400             | 8           |  |  |  |
| -11                 | 3.05                 | 997500              | 12           | · ·          | 3.5                  | 1056400             | 14          |  |  |  |
| 12                  | 6                    | 1057350             | .24          |              | 5.5                  | 1056400             | 22          |  |  |  |
| 13                  | 4.5                  | 977550              | 17           |              | 8                    | 1056400             | <b>32</b> · |  |  |  |
| 14                  | 3                    | 970900              | . 11         |              | 9                    | 1056400             | 36          |  |  |  |
| 15                  | 20.5                 | 957600              | 74           | }            | 7.5                  | 1056400             | 30          |  |  |  |
| 16                  | . 9                  | 897750              | 31 ·         |              | 9.5                  | 1056400             | 38          |  |  |  |
| 17                  | 4                    | 934325              | - 14         | 1            | 8.5                  | 1056400             | 34          |  |  |  |
| 18 ·                | 3                    | 917700              | 10           |              | 2.9                  | 1056400             | 12          |  |  |  |
| 19                  | 3.2                  | 877800              | 11           | ].           | 2.3                  | 1056400             | 9           |  |  |  |
| 20                  | 7.5                  | 834575              | 24           |              | 1.9                  | 1056400             | · <b>8</b>  |  |  |  |
| 21                  | 5.5                  | 970900              | 20           |              | 4                    | 1056400             | 16          |  |  |  |
| 22                  | 6.5                  | 867825              | . 21         | . ·          | 4.5                  | 1056400             | 18          |  |  |  |
| 23                  | 5                    | 934325              | . 18         |              | 5                    | 1056400             | <b>20</b> · |  |  |  |
| 24                  | 9.5                  | 960925              | 35           | · ·          | 5.5                  | 1056400             | 22          |  |  |  |
| 25                  | 3.5                  | 1056400             | 14           | 1.1          | 2.5                  | 950950              | 9           |  |  |  |
| 26                  | 7.5                  | 1056400             | <b>30</b>    | 1            | 4                    | 950950              | • 14        |  |  |  |
| 27                  | 6                    | 1056400             | :.24 •       | <u>ا ،</u>   | 2.4                  | 894425              | • 8         |  |  |  |
| 28                  | 5.5                  | 1056400             | 22           | <b>.</b>     | 4.2                  | 981550              | 16          |  |  |  |
| 29                  | 5.5                  | 1056400             | ≏22          | 1.1          | 2.8                  | 980875              | 10          |  |  |  |
| <b>30</b> ·         | 5.5                  | 1056400             | ÷ 22         | <sup>*</sup> | <b>2.05</b>          | 964250              | 7.          |  |  |  |
| 31                  | 4                    | 1056400             | ·. <b>16</b> | .  :         |                      |                     |             |  |  |  |
| Totals              | 172                  | 30125700            | 629          |              | 134                  | 31076600            | 528         |  |  |  |
| StdDev              |                      | 1430800             | :37          | <b>1</b>     |                      | 1060000             | 34          |  |  |  |
| Average             | 5.5                  | 971797              | ; <b>20</b>  | 111          | 4.5                  | 953833              | 11          |  |  |  |
| Max                 | 20.5                 | 1057350             | 74           | Į            | 9.5                  | 1056400             | 38          |  |  |  |
| Min                 | 24                   | 834575              | • 9          | l e.         | 1.9                  | 894425              | . 7         |  |  |  |

## Table L1-6C. Uranium Quantities and Effluent Volume Measured atManhole 175 in 1960

<u>.</u>

Sec. in

KANNA KANAGA

ç.

<sup>a</sup> From NLCO 1960-1962; 24 hour composite samples.

<sup>b</sup> From Cuthbert 1960–1962 and Fischoff 1960–1962; a monthly average was used when daily measurments were not located.

. - ..

| <u>Manhole 175 in 1960</u> |                       |          |         |                       |             |            |  |  |
|----------------------------|-----------------------|----------|---------|-----------------------|-------------|------------|--|--|
|                            | July 1960             |          |         |                       | August 1960 |            |  |  |
|                            | Uranium <sup>a</sup>  | Volumen  | Uranium | Uranium <sup>a</sup>  | Volume      | Uranium    |  |  |
| Date                       | (mg L <sup>-1</sup> ) | (gal)    | (kg)    | (mg L <sup>-1</sup> ) | (gal)       | (Kg)       |  |  |
| 1                          | 6                     | 984200   | 22      | 1.65                  | 778050      | 5          |  |  |
| 2                          | 2.7                   | 924350   | 9       | 2.25                  | 831250      | 7          |  |  |
| 3                          | 1.45                  | 1054025  | 6       | 2.5                   | 861175      | 8          |  |  |
| 4                          | 2.15                  | 994175   | 8       | . 9                   | 927675      | 32         |  |  |
| 5                          | 0.9                   | 977550   | 3       | 2.1                   | 914375      | 7          |  |  |
| 6                          | 1.7                   | 950700   | 6       | 2.3                   | 947625      | 8          |  |  |
| 7                          | 1.45                  | 815400   | 4       | 4.5                   | 1007475     | 17         |  |  |
| 8                          | 1.12                  | 946800   | 4       | 1.95                  | 950950      | 7          |  |  |
| 9                          | 1.2                   | 921100   | 4       | 2.7                   | 818000      | 8          |  |  |
| 10                         | • 3                   | 950700   | 11      | 4.5                   | 927500      | 16         |  |  |
| 11                         | 1.4                   | 899200   | 5       | · 6                   | 940975      | 21         |  |  |
| 12                         | 1.9                   | 884450   | 6       | 1.8                   | 901740      | 6          |  |  |
| 13                         | 1.75                  | 917700   | 6       | 2.15                  | 914622      | <b>7</b> . |  |  |
| 14                         | 2.65                  | 954300   | 10 ·    | 2                     | 908181      | 7          |  |  |
| 15                         | 2.6                   | 917700   | 9       | . 1.15                | 914622      | 4          |  |  |
| 16                         | 2                     | 937650   | 7       | 3                     | 917700      | 10         |  |  |
| 17                         | 0.9                   | 911050   | 3       | 1.7                   | 917700      | 6          |  |  |
| 18                         | 3.18                  | 957600   | 12      | 2.3                   | 897750      | 8          |  |  |
| <b>19</b> · ·              | 2.6                   | 907725   | 9       | 6.5                   | 944300      | 23         |  |  |
| 20                         | 2.95                  | 917750   | 10      | 2.65                  | 914375      | 9          |  |  |
| 21                         | 2.1                   | 884450   | ·7 ·    | 8.5                   | 899164      | 29         |  |  |
| 22                         | 6.5                   | 864500   | 21      | 4.5                   | 1020775     | 17         |  |  |
| 23                         | 4.5                   | 851200   | 14      | 5.5                   | 837900      | 17         |  |  |
| 24                         | 4.5                   | 837900   | . 14    | 12.5                  | 904400      | 43         |  |  |
| 25                         | 5                     | 891000   | 17      | 4.5                   | 1055500     | 18         |  |  |
| 26                         | 7                     | 891000   | . 24    | 7.5                   | 1138900     | 32         |  |  |
| 27                         | 4                     | 864500   | 13      | 4                     | 913800      | 14         |  |  |
| 28                         | 4.5                   | 791350   | 13      | <b>5.5</b> .          | 929900      | 19         |  |  |
| 29                         | 6                     | 864500   | 20      | 3.5                   | 1044700     | 14.        |  |  |
| 30                         | · 8                   | 864500   | 26      | 5.5                   | 1072200     | 22         |  |  |
| 31                         | 3                     | 854500   | 10 ·    | 5.5                   | 1080000     | 22         |  |  |
|                            |                       |          |         |                       |             |            |  |  |
| Totals                     | 98.7                  | 28183525 | 334     | 129.7                 | 29033279    | 466        |  |  |
| StdDev                     |                       | 1254400  | 19      |                       | 1019200     | 27         |  |  |
| Average                    | 3.2                   | 909146   | 11      | 4.2                   | 936557      | 15         |  |  |
| Max                        | · 8                   | 1054025  | 26.     | 12.5                  | 1138900     | 43         |  |  |
| Min                        | 1                     | 791350   | 3       | 1.2                   | 778050      | 4          |  |  |

### Table L1-6D. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1960

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960–1962 and Fischoff 1960–1962; a monthly average was used when daily measurments were not located.

<u>.</u> .

Radiological Assessments Corporation "Setting the standard in environmental health"

<u>.</u>...

.

### Page L-78

A166.7 C

and then have

NUX SEC.

| September 1960 . October 1960 |                      |                     |              |                  |                       | 0                   |                       |
|-------------------------------|----------------------|---------------------|--------------|------------------|-----------------------|---------------------|-----------------------|
|                               | Uranium <sup>a</sup> | Volume <sup>h</sup> | Urani        | um               | Uranium <sup>a</sup>  | Volume <sup>h</sup> | Uranium               |
| Date                          | $(mg L^{-1})$        | (gal)               | ſkg          | 1                | (mg L <sup>-1</sup> ) | (gal)               | (kg)                  |
| 1 .                           | 5.5                  | 1058000             | 22           | • •              | 16.5                  | 1128500             | 70 .                  |
| 2                             | 4                    | 1135000             | 17           | •                | 7.5                   | 971400              | 28                    |
| 3                             | 1.05                 | 1004000             | · 4          |                  | 5.5                   | 1128500             | 23                    |
| <b>4</b> · · · ·              | 1.8                  | 1018000             | · 7          |                  | 4.5                   | 1242800             | 21                    |
| 5                             | 0.9                  | 942000              | ÷ 3          | , .              | 6                     | 1189200             | 27                    |
| 6.                            | 1.3                  | 1121000             | te 6         |                  | 2.05                  | 1335600             | 10 ·                  |
| 7.                            | 1.45                 | 1058000             | :• <b>6</b>  | •                | 1.5                   | 1307100             | 7                     |
| 8                             | 1.35                 | 1019660             | : 5          | · ·              | 8                     | 1478500             | 45 .                  |
| · 9                           | 1.5                  | 1021490             | : 6          | • .              | 3                     | 1221400             | 14                    |
| 10                            | 6.5                  | 821900              | 20           |                  | 2.4                   | 1114200             | · 10                  |
| 11                            | 2.05                 | 861690              | 21° <b>7</b> |                  | . 4                   | 1282100             | 19                    |
| 12                            | 3.5                  | 867630              | • 11         | · .•·            | 1.95                  | 1128500             | 8                     |
| 13                            | 2.4                  | 907500              | F 8          | , ·              | 1.45                  | 1228400             | <b>7</b> <sup>.</sup> |
| 14                            | 1.5                  | 823400              | . 5          |                  | 1.55                  | 1349900             | 8                     |
| 15                            | 1.8                  | 857400              | 6            |                  | 5.5                   | 1314200             | 27.                   |
| - 16                          | 1.5 ·                | 876200              | 5            | •                | 2.05                  | 1264200             | 10                    |
| 17                            | 6.5                  | 877200              | · 22         |                  | 4                     | 1299900             | 20                    |
| 18                            | 3.5                  | 770000              | : 10         |                  | 1.5                   | 1399900             | 8                     |
| 19                            | 4                    | 1008800             | 15           | . <sup>4</sup> ± | <b>6</b>              | 1518500             | 34                    |
| 20                            | 4.5                  | 1077300             | 1. 18        |                  | 3.5                   | 1461350             | 19                    |
| 21                            | 6.5                  | 906000              | E 22         |                  | 2.15                  | 1364200             | 11                    |
| 22                            | 5.5                  | 1037200             | · 22         | ι.               | 2.2                   | 1278500             | 11                    |
| <b>23</b>                     | 10 ·                 | 1257100             | 48           | 1 m. j           | 2.2                   | 1211400             | 10                    |
| 24                            | 1.75                 | 1010600             | 7            | - •              | 2.65                  | 1354200             | 14                    |
| -25                           | 2.05                 | 1017800             | <u></u> 8    | ٠,               | 1                     | 1532100             | <b>6</b> ·            |
| 26                            | 8                    | 1210650             | : 37         | ,                | 2.6                   | 1439200             | 14                    |
| <b>27</b> '                   | 2.1                  | 1189200             | 2 9          |                  | 1.3                   | 1424900             | <sup>`</sup> 7        |
| <b>28</b>                     | 2                    | 1132100             | g 9          | • ·              | 1.9                   | 1449900             | 10                    |
| 29                            | 1.3                  | 1199900             | . 6          |                  | 1.35                  | 1428500             | 7                     |
| 30                            | 2.4                  | 1228600             | ST 11        |                  | 1.6                   | 1349900             | 8                     |
| 31                            |                      | •                   | 5.2          |                  | 2.7                   | 1492800             | 15                    |
| . Դ.                          |                      |                     |              |                  |                       | •                   |                       |
| Totals                        | 98.2                 | 30315320            | 381          | L                | 110.1                 | 40689750            | 530                   |
| StdDev                        | · , ·                | 1097600             | 24           |                  |                       | 1430800             | 35                    |
| Average                       | 3.3                  | 1010511             | te <b>13</b> | <u>(</u>         | 3.6                   | 1312573             | 17                    |
| Max                           | 10                   | 1257100             | त् <b>48</b> | 1 E 1            | 16.5                  | 1532100             | 70                    |
| Min 💷                         | 0.9                  | 770000              | :. 3         | •                | 1                     | 971400              | 6                     |
| ··· •                         |                      | х<br>1              | •••          | , <i></i>        | ÷.í                   |                     |                       |

### Table L1-6E. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1960

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960–1962 and Fischoff 1960–1962; a monthly average was used when daily measurments were not located.

Julian Contraction Contraction

. s. s.

! ور

2

٠.

| November 1960 December 196<br>Uranium <sup>a</sup> Volume <sup>h</sup> Uranium Uranium <sup>a</sup> , Volume <sup>h</sup> | 0<br>Uranium<br>(kg) |
|---------------------------------------------------------------------------------------------------------------------------|----------------------|
| Uranium <sup>a</sup> Volume <sup>h</sup> Uranium Uranium <sup>a</sup> , Volume <sup>h</sup>                               | Uranium<br>(kg)      |
|                                                                                                                           | (kg)                 |
| Date $(mgL^{-1})$ (gal) (kg) $(mgL^{-1})$ (gal)                                                                           |                      |
| 1 4.5 1514200 26 13.5 1178500-                                                                                            | 60                   |
| 2 1.5 1628500 9 6 1314200                                                                                                 | . 30                 |
| 3 2.5 1471400 14 4.25 1149900                                                                                             | 18                   |
| 4 1.7 1428500 9 4 1150000                                                                                                 | 17                   |
| 5 1.7 1171400 8 4.5 1178500                                                                                               | 20                   |
| 6 1.25 1214200 6 8 1207100                                                                                                | 37                   |
| 7 4.5 1214200 21 2.6 1357100                                                                                              | 13                   |
| 8 2.35 1263500 11 1.85 1342800                                                                                            | 9                    |
| 9 8 1177100 36 4.5 1378500                                                                                                | 23                   |
| 10 4.5 1429750 24 2.5 1371360                                                                                             | 13                   |
| 11 2.25 1197250 10 5 1542780                                                                                              | 29                   |
| 12 4 1173700 18 2 1271400                                                                                                 | 10                   |
| 13 3.5 1332100 18 3.2 1474900                                                                                             | 18                   |
| 14 1.85 1324900 9 4.5 1343900                                                                                             | 23                   |
| 15 1.7 1371360 9 6.5 1549900                                                                                              | 38                   |
| 16 5 1260650 24 5.5 1460600                                                                                               | 30                   |
| 17 4 1182100 18 5 1482800                                                                                                 | 28                   |
| 18 1.6 1249900 8 3.15 1342800                                                                                             | 16                   |
| 19 4.5 1171370 20 4.5 1442800                                                                                             | 25                   |
| 20 2.75 1092800 11 1.65 1557100                                                                                           | 10                   |
| 21 2.5 1121400 11 4 1507100                                                                                               | 23                   |
| 22 7 1314200 35 3.1 1535600                                                                                               | 18                   |
| 23 15.5 1207100 71 5 1535600                                                                                              | 29                   |
| 24 5.5 999950 21 2.5 1471400                                                                                              | 14                   |
| 25 2.45 1364200 13 3.15 1517800                                                                                           | 18                   |
| 26 2 1213700 9 7 1478500                                                                                                  | 39                   |
| 27 1.85 1242800 9 3.2 1292800                                                                                             | 16                   |
| 28 6 1342800 30 11 1107100                                                                                                | 46                   |
| 29 4 1199900 18 4 1214200                                                                                                 | 18                   |
| 30 4.5 1200000 20 3.35 1114200                                                                                            | .14                  |
| 31 3.55 1309900                                                                                                           | 18 -                 |
| Totals 115 38074930 544 143 42181140                                                                                      | 720                  |
| StdDev 1391600 33 1489600                                                                                                 | 39                   |
| Average 3.8 1269164 18 4.6 1360682                                                                                        | 22                   |
| Max 15.5 1628500 71 13.5 1557100                                                                                          | 60                   |
| Min 1.3 999950 6 1.7 1107100                                                                                              | 9                    |

### Table L1-6F. Uranium Quantities and Effluent Volume Measured at

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960-1962 and Fischoff 1960-1962; a monthly average was used when daily measurments were not located.

341. SZ

.

مان ما جلام و من الم المراجع و المان من ال

|         | I            | anuary 196          | lannoie 17 | <u>5 m</u> | 1901<br>F   | ebruary 196         |          |
|---------|--------------|---------------------|------------|------------|-------------|---------------------|----------|
| Date    | Uranjuma     | Volume <sup>b</sup> | IIranium   |            | Ilraniumä   | Volume <sup>b</sup> | IIranium |
| 2000    | (mg I -l)    | (pal)               | (ko)       |            | (mat-l)     | (gal)               | (kg)     |
| - 1     | - 45         | 1192800             | 20         |            | 4.5         | 1542800             | 26       |
| 2       | 5.5          | 1359900             | 20         |            |             | 1521400             | 13       |
| 2       | 5.5          | 14000000            | 20         | <i></i> ,  | 1 55        | 1464200             | 9        |
| A       | 3.45         | 1349800             | 18         |            | 215         | 1407100             | 11       |
| 5       | 6.5          | 1378500             | 34         |            | 1.85        | 1592800             | 11       |
| 6.      | 33           | 1399900             | 17         |            | 3           | 1621300             | 18       |
| 7       | 3 75         | 1642775             | 23         |            | 26          | 1571300             | 15       |
| 8       | 3.05         | 1400000             | ,20<br>99  |            | <u>2.0</u>  | 1635600             | · 25     |
| g       | 65           | 1564200             | 38         | ;,         | 5           | 1671300             | 32       |
| 10      | 0.5          | 1580200             | 00         |            | 65          | 1671300             | 41       |
| 10      | , 4.0<br>0.7 | 1405200             | .15        | :          | 5.5         | 1679500             |          |
| 10      | 2.1          | 1403000 .           | 20         |            | . 2         | 1671300             | 51       |
| 12      | 0.5          | 1400000             | 20         | ,          | 115.        | 1402800             | . 51     |
| 10      | 2.5          | 1499900             | .14        |            | 11.0        | 000000              | . 00     |
| 14 *    | 4 <b>4</b>   | 1000700             | 23         |            | <br>        | 1579500             | 41<br>22 |
| . 10    | 5            | 1200700             | -23        |            | 5.5         | 1040800             | . 33     |
| 10 (0.  | 3.15         | 1578500             | *1A<br>*1A |            | 4.          | 1642000             | 20       |
| 17      | 2.25         | 1478500             | 13         |            | 5.5         | 1005000             | 33       |
| 18      | 4.5          | 1478500             | .25        |            | <b>0.</b> 0 | 1001400             |          |
| 19      | 2.2          | 1499900             | 12         |            | 2.45        | 1201400             | . 12     |
| 20 1    | 1.55         | 1642775             | 10         |            | 2.2         | 1242000             | 10       |
| . 21    | 1.7          | 1557100             | ·10        |            | 2.15        | 1000000             | 10       |
| 22      | 2.1          | 1521350             | · 12       |            | 6.5         | 1289200             | 32       |
| 23      | 3.5          | 1542800             | · 20       |            | 2.75        | 1428500             | 15       |
| 24      | 2.05         | 1556100             | 12         |            | 2.45        | 1383200             | 13       |
| 25      | - 1.7        | 1692800             | <11<br>(00 |            | 6           | 1549900             | 35       |
| 26      | 3.5          | 1671300             | 22         |            | 6.5         | 1564200             | 38       |
| 27      | 2.05         | 1692800             | 13         |            | 4.5         | 1549900             | 26       |
| 28      | 3.5          | 1664200 :           | - 22       | l          | 5           | 1635600             | 31       |
| 29      | . 5          | 1657100             | 31         | l          | • •         |                     |          |
| 30      | 3.5          | 1514200             | 20         |            |             |                     |          |
| 31      | 3.5          | 1628500             | 22         |            |             |                     |          |
| Totals  | 110          | 47047100            | 627        |            | 130         | 41906700            | 727      |
| Average | 3.6          | 1517648             | 20         | -          | 4.6         | 1500000             | 26       |
| Stdev   | 1.3          | 125004              | 7          |            | 2.4         | 171000              | 42       |
| Max     | 6.5          | 1692800             | 38         | (127) ·    | 11          | 1680000             | 65       |
| Min     | 1.6          | 1192800             | 10         | 1          | 1.6         | 900000              | 9        |

### Table L1-7A. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1961

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> Cuthbert 1960–1962 and Fischoff 1960–1962

J

، •••

|            |                      | March 1961          | lannole 17 | April 1961                                       |
|------------|----------------------|---------------------|------------|--------------------------------------------------|
| Date       | Uranium <sup>a</sup> | Volume <sup>h</sup> | Uranium    | Uranium <sup>a</sup> Volume <sup>b</sup> Uraniun |
|            | (mg [-l)             | (gal)               | (kg)       | $(mr I^{-1})$ (gal) (kg)                         |
| 1          | 2.4                  | 1649900             | 15         | 3.1 1307100 15                                   |
| 2          | 4.5                  | 1635600             | 28         | 4.5 1321400 22                                   |
| 3          | 2.45                 | 1564200             | 14         | 5.5 1464200 30                                   |
| 4          | 4.5                  | 1485600             | 25         | 4 1571300 24                                     |
| 5          | 4                    | 1421400             | 21         | 3.2 1374900 17                                   |
| 6          | 6.5                  | 1324900             | 33         | 2.8 1367800 14                                   |
| 7          | 6                    | 1267100             | 29         | 2.15 1421400 12                                  |
| 8          | 5.5                  | 1432800             | 30         | 2.75 1339200 14                                  |
| 9          | 2.05                 | 1521400             | 12         | 6.5 1507100 37                                   |
| 10         | 1.6                  | 1499900             | 9          | 7.5 1414200 40                                   |
| 11         | 4                    | 1428500             | 22         | 4 1514200 23                                     |
| 12         | 2.6                  | 1442800             | 14         | 6 1567100 <sup>-</sup> 36                        |
| 13         | 3.5                  | 1438200             | 19         | 10.5 1557100 62                                  |
| 14         | 2.6                  | 1410600             | 14         | 4.5 1614200 27                                   |
| 15         | 2.45                 | 1428500             | 13         | 7.5 1514400 43                                   |
| · 16       | 3.5                  | 1428500             | 19         | 7 1364200 36                                     |
| :7         | 5.5                  | 1457100             | 30         | 8.5 1485600 48                                   |
| 18         | 4.5                  | 1442800             | 25         | 4.5 1546500 26                                   |
| 19         | 5.5                  | 1307100             | 27         | 5 1614200 31                                     |
| 20         | 4.5                  | 1257100             | 21         | 5 1585600 30                                     |
| 21         | 6.5                  | 1485600             | 37         | 5 1564200 30                                     |
| 22         | 5                    | 1571700             | 30         | 6.5 1439200 35                                   |
| 23         | 5.5                  | 1571400             | 33         | 6 1617800 37                                     |
| 24.        | 5                    | 1514200             | 29         | 5.5 1714200 36                                   |
| 25         | 4.5                  | 1557100             | 26         | 7.5 1682100 48                                   |
| 26         | · 4.5                | 1557100             | 26         | 7.5 1514200 43                                   |
| 27         | 5.5                  | 1621300             | · 34       | 8.5 1524900 49                                   |
| 28         | 5.5                  | 1635600             | 34         | 7.5 1471400 42                                   |
| 29         | 3.6                  | 1599900             | 22         | 13 1499900 74                                    |
| 30         | 2.3                  | 1435600             | 12         | 6.5 1571300 - 39                                 |
| 31         | 4.5                  | 1507000             | . 26       |                                                  |
| <b>m</b> 1 | 100                  |                     |            |                                                  |
| Totals     | 130                  | 45900500            | 728        |                                                  |
| Average    | 4.2                  | 1480000             | 23         | 5.9 1501697 75                                   |
| Stdev      | 1.4                  | 103000              | 39         |                                                  |
| Max        | 6.5                  | 1650000             | 37         |                                                  |
| Min        | 1.6                  | 1260000             | 9          | 2.15 1307100 25                                  |

### Table L1–7B. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1961

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> Cuthbert 1960–1962 and Fischoff 1960–1962

| Page L-82                             | The Fernald Dosimetry Reconstruction Project  |
|---------------------------------------|-----------------------------------------------|
| · · · · · · · · · · · · · · · · · · · | Tasks 2 and 3, Source Terms and Uncertainties |

|            |           |                      | IM                  | annole 17                | ό m ] | 1961                 |                     |                  |
|------------|-----------|----------------------|---------------------|--------------------------|-------|----------------------|---------------------|------------------|
|            |           |                      | May 1961            |                          |       |                      | June 1961           |                  |
|            | Date      | Uranium <sup>a</sup> | Volume <sup>h</sup> | Uranium                  |       | Uranium <sup>a</sup> | Volume <sup>b</sup> | Uranium          |
|            |           | $(mg L^{-1})$        | (gal)               | (kg)                     |       | $(mg L^{-1})$        | (gal)               | (kg)             |
| -          | 1         | 6.5                  | 1514200             | 37                       |       | 4.5                  | 1057100             | 18               |
|            | 2         | 5                    | 1542800             | 29                       | 1     | 4.5                  | 1157100             | 20               |
|            | . 3       | 5.5                  | 1635600             | 34                       |       | 4.5                  | 1085700             | 18               |
|            | 4         | . 6                  | 1471400             | ັ 33                     |       | 2.1                  | 1028500             | 8                |
|            | 5         | 6.5                  | 1592800             | 39                       | · ·   | 5.5                  | 1142800             | 24               |
|            | 6         | 7.5                  | 1528500             | 43                       |       | 4.5                  | 999950              | 17               |
| •.         | 7.        | 7.5                  | 1549900             | 44                       |       | 4.5                  | 1185500             | 20               |
|            | 8         | 9                    | 1518500             | . 52                     |       | 5.5                  | 1278600             | 27               |
| <i>•</i> . | 9 -       | 6.5                  | 1564200             | 38                       |       | 6.5                  | 1230750             | 30               |
|            | 10        | 4.5                  | 1692800             | 29                       |       | 4.5                  | 1053350             | 18               |
|            | <b>11</b> | 3.5                  | 1642800             | 22                       | `.·   | 4.5                  | 1049300             | 18 <sup></sup>   |
| ;          | 12        | 3.5                  | 1485000             | 20                       | •     | 2.8                  | 1029600             | 11               |
| •          | 13        | 4.5                  | 1628500             | 28                       |       | 3.5                  | 1024100             | 14               |
|            | 14        | <u>:</u> 4           | 1471400             | 22                       |       | 6                    | 1321100             | 30               |
|            | 15        | 5.5                  | 1492800             | 31                       | •     | 5.5                  | 1098000             | 23               |
| · .        | 16        | 5.5                  | 1499900             | 31                       | I     | 2.8                  | 1678500             | 18               |
|            | 17        | 4.5                  | 1289200             | 22                       | •     | 2.3                  | 1349900             | 12               |
| r          | 18        | 7.5                  | 1292800             | 37                       |       | 3.5                  | 1671300             | 22               |
|            | 19        | 4 .                  | 1310600             | 20                       |       | 4.5                  | 1135700             | 19               |
|            | 20        | 4                    | 1499400             | 23                       |       | 8                    | 1449900             | 44               |
|            | 21        | 5.5                  | 1185650             | . 25                     |       | 7.5                  | 1528500             | 43               |
| ·,- ·      | 22        | 6.5                  | 1142800             | . 28                     | · · . | 4.5                  | 1521300             | 26               |
|            | 23        | 2.5                  | 1189200             | 11                       |       | 5.5                  | 1399900             | 29               |
| • ;        | 24        | 5.5                  | 1178500             | 25                       |       | 2.65                 | 1528500             | 15               |
|            | 25        | 5                    | 1174900             | <del>,</del> . <b>22</b> | •     | 4.15                 | 1460600             | 23               |
|            | 26        | 5                    | 1139200             | 22                       |       | 4.5                  | 1560600             | 27 .             |
| ;          | 27        | 2.5                  | 1244200             | 12                       |       | 3.5                  | 1571400             | 21 .             |
| :          | 28        | 3.5                  | 1162400             | 15                       |       | 4.5                  | 1542800 ·           | 26               |
|            | . 29      | , <b>3.6</b> 5       | 1228500             | , 17                     |       | 2.5                  | 1485600             | 14               |
|            | 30        | 3.5                  | 1171400             | ່ 15 ເ                   |       | 1.8                  | 1476500             | 10               |
|            | 31        | 4.5                  | 1128500             | 19                       |       | •                    |                     |                  |
|            |           |                      | •                   |                          |       | <i>.</i>             |                     |                  |
|            | Totals    | 160                  | 43168350            |                          |       | 131.1                | 39102450            | 645 <sub>.</sub> |
|            | Average   | 5.1                  | 1392527             | , 27                     |       | 4.4                  | 1303415             | 22               |
| •          | Stdev     | 1.5                  | 183101              | 40                       | -     | 1.5                  | 218659              | 35               |
|            | Max       | 9                    | 1692800             | 52                       |       | . 8                  | 1678500             | 44               |
|            | Min       | 2.5                  | 1128500             | $\frac{11}{1}$           |       | 1.8                  | 999950              | 8                |
|            | •         |                      | i                   |                          | •     | · -                  |                     |                  |

# Table L1–7C. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1961

<sup>a</sup> NLCO 1960–1962; 24 hour composite samples <sup>b</sup> Cuthbert 1960–1962 and Fischoff 1960–1962

36.40

and we have

£

.

• • •

e. . .

| Appendi | хL    |            |
|---------|-------|------------|
| Surface | Water | Discharges |

•

|                       |                       | M                   | anhole 17 | 5 in 1961               |                     |         |
|-----------------------|-----------------------|---------------------|-----------|-------------------------|---------------------|---------|
|                       |                       | July 1961           | • •       |                         | August 1961         |         |
|                       | Uranium <sup>a</sup>  | Volume <sup>b</sup> | Uranium   | Uraniúm <sup>a</sup>    | Volume <sup>b</sup> | Uranium |
| Date                  | (mg L <sup>-1</sup> ) | (gal)               | (kg)      | - (mg L <sup>-1</sup> ) | (gal)               | (kg)    |
| 1                     | 3.3                   | 1328500             | 17        | 2.25                    | 1571400             | 13      |
| <b>2</b> <sup>-</sup> | 2.3                   | 1421400             | 12        | 5.5                     | 1685600             | 35      |
| 3                     | 2.35                  | 1371400             | 12        | . 3                     | 1678500             | · 19    |
| 4.                    | 7                     | 1414200             | 37        | 7.5                     | 1699900             | 48      |
| 5                     | 3.7                   | 1521400             | 21        | 14                      | 1664200             | 88      |
| . 6                   | 4.5                   | 1407100             | 24        | 21.5                    | 1699900             | 138     |
| 7                     | 2.4                   | 1617100             | 15        | 25                      | 1685600             | 159     |
| 8                     | 2.1                   | 1582800             | 13        | <sup>:</sup> 6          | 1692800             | 38      |
| 9                     | 2.55                  | 1642800             | 16        | 5                       | 1685600             | 32      |
| 10                    | 1.8                   | 1578500             | 11        | 2.45                    | 1642800             | 15      |
| 11                    | 1.7                   | 1417800             | 9         | 4.5                     | 1657100             | 28      |
| 12                    | 5.5                   | 1592800             | 33        | 2.85                    | 1549900             | 17      |
| 13                    | 4.5                   | 1621300             | 28        | 1.1                     | 1457100             | 6       |
| 14                    | 1                     | 1257100             | 5         | 1.7                     | 1607100             | 10      |
| 15                    | 3.5                   | ·· <b>1221400</b> · | 16        | 1.4                     | 1564200             | 8       |
| 16                    | 3.5                   | 1602100             | 21        | 1.75                    | 1578500             | 10      |
| 17                    | 1.6                   | 1407100             | 9         | 1.45                    | 1635600             | 9       |
| 18                    | 1.45                  | 1632100             | 9         | 4.5                     | 1539200             | 26      |
| 19                    | 4                     | 1642900             | 25        | 1.45                    | 1614200             | 9       |
| 20                    | 1.8                   | 1630600             | 11        | 1.75                    | 1599900             | 11      |
| 21                    | 3.5                   | 1649900             | · 22      | 2.25                    | 1607100             | 14      |
| 22                    | 2.9                   | 1528500             | 17        | 4                       | 1692800             | 26      |
| 23                    | 4.5                   | 1653500             | 28        | 9.5                     | 1657100             | 60      |
| 24                    | 1.5                   | 1621300             | 9         | 5.5                     | 1635600             | 34      |
| 25                    | 1.85                  | 1599900             | 11        | . 4.5                   | 983160              | 17      |
| 26                    | 1.3                   | 1564200             | 8         | 1.75                    | 983160              | 7       |
| 27                    | 0.9                   | 1578500             | 5         | 1.8                     | 983160              | 7       |
| 28                    | 2.1                   | 1599900             | 13        | - 1.55                  | 983160              | 6       |
| 29                    | 1.45                  | 1664200             | 9         | 2.15                    | 983160              | 8 .     |
| 30 、                  | 6.5                   | 1628500             | 40        | 4.5                     | 983160              | 17      |
| 31                    | 4.5                   | 1642800             | .28       | 3.5                     | 983160              | 13      |
| Totals                | 90                    | 47641600            | 534       | 155.7                   | 45983820            | 928     |
| Average               | 3                     | 1536826             | 17        | 5                       | 1483349             | 70      |
| Stdey                 | 1.6                   | 123133              | 30        | 5.5 ·                   | 275414              | 36      |
| Max                   | 7                     | 1664200             | 40        | 25                      | 1699900             | 159     |
| Min                   | 0.9                   | 1221400             | 5         | 1.1                     | 983160              | 6       |

#### Table L1-7D. U nium Quantifies and Effluent Volu red at

<sup>a</sup> NLCO 1960–1962; 24 hour composite samples <sup>b</sup> Cuthbert 1960–1962 and Fischoff 1960–1962

### Page L–84

- 1

We see the second

Suppose

| Manhole 175 in 1961 |                       |                     |              |                                              |                          |                     |         |
|---------------------|-----------------------|---------------------|--------------|----------------------------------------------|--------------------------|---------------------|---------|
|                     | Se                    | ptember 19          | 61           |                                              | (                        | October 196         | L       |
|                     | Uranium <sup>a</sup>  | Volume <sup>D</sup> | Uranium      |                                              | Uranium <sup>a</sup>     | Volume <sup>b</sup> | Uranium |
| Date                | (mg L <sup>-1</sup> ) | (gal)               | (kg)         | <u>.                                    </u> | $(mg L^{-1})$            | (gal)               | (kg)    |
| 1                   | 7                     | 983160              |              |                                              | 11.5                     | 746000              | 32      |
| 2                   | 4.5                   | 983160              | 17           | ••••                                         | 3.8                      | 746000              | - 11    |
| <b>.</b> 3          | 2.65                  | 983160              | 10           |                                              | 2.1                      | 746000              | 6       |
| 4                   | 2.45                  | 983160              | ·] 9         | -                                            | 2.15                     | 746000              | 6       |
| 5                   | 2.5                   | 983160              | <sub>.</sub> |                                              | 1.75                     | 746000              | 5       |
| 6                   | 3.5                   | 983160              | 13           |                                              | 6.5                      | 746000              | 18      |
| 7                   | 1.7                   | 983160              | <b>,</b> 6   |                                              | 1.8                      | 746000              | 5       |
| 8                   | 1.8                   | 983160              | <b>7</b>     |                                              | 4                        | 746000              | 11      |
| 9                   | 1.75                  | 983160              | ຼ່ 7 🚶       |                                              | 2.1                      | 746000              | 6       |
| 10                  | 1.5                   | 983160              | 6            |                                              | 1.9                      | 746000              | 5       |
| 11                  | 3                     | 983160              | 11           | •••                                          | 1.55                     | 746000              | 4       |
| 12                  | 5                     | 983160              | 19           | • •                                          | 1.65                     | 746000              | 5       |
| 13                  | 10                    | 983160              | 37           |                                              | 1.35                     | 746000              | 4       |
| 14                  | 6                     | 983160              | 22           | •                                            | 1.05                     | 746000              | 3       |
| 15                  | 5.5                   | 983160              | 20           |                                              | 1.55                     | 746000              | 4       |
| 16                  | 5                     | 983160              | 19           |                                              | 0.95                     | 746000              | 3       |
| . 17                | 5.5                   | 983160              | 20           |                                              | 1.15                     | 746000              | 3       |
| 18                  | 4.5                   | 983160              | 17           | •                                            | 1.25                     | 746000              | 4       |
| 19                  | 3.65                  | 983160              | 14           | ••••                                         | 4.5                      | 746000              | 13      |
| 20                  | 6.5                   | 983160              | 24           |                                              | 1.7                      | 746000              | 5       |
| 21                  | 5.5                   | 983160              | 20           | •.                                           | 1.1                      | 746000              | 3       |
| 22 .                | 5.5                   | 983160              | . 20         |                                              | 1.5                      | 746000              | 4       |
| 23                  | 6.5                   | 983160              | 24           |                                              | 1.4                      | 746000              | 4       |
| 24                  | 7.5                   | 983160              | 28           |                                              | 1.4                      | 746000              | 4.      |
| 25                  | 4.5                   | 746225              | 13           |                                              | 3.1                      | 746000              | 9       |
| 26                  | 4.5                   | 746225              | 13           |                                              | <b>I.1</b> <sup>11</sup> | 942200              | 4       |
| 27                  | 4.5                   | 746225              | 13           | •                                            | 1.6                      | 942200              | 6       |
| 28                  | 4.5                   | 746225              | <b>13</b>    |                                              | 1.4                      | 942200              | 5       |
| 29                  | 4.5                   | 746225              | 13 ,         | ٠                                            | 0.6                      | 942200              | 2       |
| 30                  | 4.5                   | 746225              | 13           | •                                            | 1.7                      | 942200              | 6       |
| 31                  |                       |                     | 1. v         | 1                                            | 1.5                      | 942200              | 5       |
| • •                 | · •                   | 1                   |              |                                              |                          |                     |         |
| Totals              |                       | 28073190            | 481          |                                              |                          | 24303200            | 205     |
| Stddev              |                       | 1030000             | 31           |                                              |                          | 880000              | 16      |
| Average             | <b>4.5</b> ,          |                     | 16           | •                                            | 2.3                      |                     | 7       |
| Max                 | 10                    | 1                   | 37           |                                              | 11.5                     | •                   | 32      |
| Min                 | 1.5                   | :                   | 6            |                                              | 0.6                      | `                   | 2       |
|                     | ••                    |                     |              |                                              |                          |                     |         |

 Table L1–7E. Uranium Quantities and Effluent Volume Measured at

 Manhole 175 in 1961

a NLCO 1960-1962; 24 hour composite samples

÷., ,

<sup>b</sup> From Cuthbert 1960-1962 and Fischoff 1960-1962; a monthly average was used when daily measurments were not located.

....

.

|         |                      | M                   | anhole 17 | 5 in 1961             |                     |          |  |
|---------|----------------------|---------------------|-----------|-----------------------|---------------------|----------|--|
|         | N                    | ovember 196         | 31        | De De                 | December 1961       |          |  |
|         | Uranium <sup>a</sup> | Volume <sup>b</sup> | Uranium   | Uranium <sup>a</sup>  | Volume <sup>b</sup> | Uranium  |  |
| Date    | $(mg L^{-1})$        | (gal)               | (kg)      | (mg L <sup>-1</sup> ) | (gal)               | (kg)     |  |
| 1       | 1.75                 | 942200              | 6         | 1.85                  | 944300              | 7        |  |
| 2       | 1.6                  | 942200              | 6         | 2.5                   | 944300              | 9        |  |
| 3       | 7.5                  | 942200              | 27        | 1.55                  | 944300              | 6        |  |
| 4       | 2.45                 | 942200              | 9         | 2.8                   | 944300              | 10       |  |
| 5       | 0.95                 | 942200              | 3         | 6                     | 944300              | 21       |  |
| .6      | 1.55                 | 942200              | 6         | 2.95                  | 944300              | 11       |  |
| 7       | 1                    | 942200              | 4         | 1.95                  | 944300              | 7        |  |
| 8       | 1.2                  | 942200              | 4         | 2.15                  | 944300              | 8        |  |
| 9       | 2.12                 | 942200              | 8         | 2.6                   | 944300              | 9        |  |
| 10      | 7 _                  | 942200              | 25        | 8                     | 944300              | 29       |  |
| 11      | 1.65                 | 942200              | 6         | 3.05                  | 944300              | 11       |  |
| 12      | 2.15                 | 942200              | 8         | 2.2                   | 944300              | 8        |  |
| 13      | 3.1                  | 942200              | 11        | 1.35                  | 944300              | <b>5</b> |  |
| 14      | 10                   | 942200              | 36        | 2.2                   | 944300              | 8        |  |
| 15      | 2.4                  | 942200              | 9         | 1.2                   | 944300              | 4        |  |
| 16      | 7.5                  | 942200              | 27        | 2.3                   | 944300              | . 8      |  |
| 17      | 2.5                  | 942200              | 9         | 3                     | 944300              | 11       |  |
| 18      | 1.1                  | 942200              | 4         | 5.5                   | 944300              | 20       |  |
| 19      | 1.9                  | 942200              | · 7 ·     | 5.5                   | 944300              | 20       |  |
| 20      | 2.5                  | 942200              | 9         | 1.95                  | 944300              | 7        |  |
| 21      | 2.75                 | 942200              | 10        | 1.15                  | 944300              | -4       |  |
| 22      | 2.15                 | 942200              | 8         | 1.4                   | 944300              | 5        |  |
| 23      | 6                    | 942200              | 21        | 3.55                  | 944300              | 13       |  |
| 24      | 3                    | 942200              | 11        | · 1.25                | 944300              | 4        |  |
| 25      | 1.4                  | 942200              | 5         | 1.45                  | 944300              | 5        |  |
| 26      | 2.85                 | 944300              | 10        | 2                     | 1056250             | 8        |  |
| 27 .    | 1.6                  | 944300              | · 6       | 2.55                  | 1056250             | 10       |  |
| 28 ·    | 1.45                 | 944300              | • 5       | 1.8                   | 1056250             | 7        |  |
| 29      | 1.3                  | 944300              | 5         | 2.25                  | 1056250             | 9        |  |
| 30      | 1.75                 | 944300              | 6         | 1.7                   | 1056250             | · 7      |  |
| . 31    |                      |                     |           | 2.05                  | 1056250             | 8        |  |
| Totals  | •                    | 28276500            | 307       |                       | 29945000            | 297      |  |
| StdDev  |                      | 1030000             | 23        |                       | 1100000             | 20       |  |
| Average | 2.9                  |                     | 10        | 2.6                   |                     | 10       |  |
| Max     | 10                   |                     | 36        | 8                     |                     | 29       |  |
| Min     | 1                    |                     | 3         | 1.2                   |                     | 4        |  |

#### Table L1-7F. Ur Quantities and Effluent Volu te he **…**…

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960-1962 and Fischoff 1960-1962; a monthly average was used when daily measurments were not located.

| Page | L-86 |
|------|------|
|------|------|

÷ ÷.

A COLOR

NA 18

i.

1997-1993 1997-1997-1997

|                | January 1962         |                     |                 |            |                      |           | 2       |
|----------------|----------------------|---------------------|-----------------|------------|----------------------|-----------|---------|
|                | Uranium <sup>a</sup> | Volume <sup>b</sup> | Uranium         |            | Uranium <sup>a</sup> | Volumeb   | Uranium |
| Date           | $(mg L^{-1})$        | (gal)               | (kg)            | 2.415      | $(mg L^{-1})$        | (gal)     | (kg)    |
| 1              | 9.00                 | 1090000             |                 |            | 3.05                 | 1144000   | 13      |
| 2              | 1.20                 | 1090000             | 5               |            | 8.50                 | 1144000   | 37      |
| 3              | 1.75                 | 1090000             | 7               | 16.0       | 6.50                 | 1144000   | - 28    |
| <b>4</b> ·     | 6.00                 | 1090000             | 25              |            | 2.70                 | 1144000   | 12      |
| 5 🐪 👾          | 7.00                 | 1090000             | 29              | 1.1.1      | 4.50                 | 1144000   | 19      |
| 6 <sup>.</sup> | 5.50                 | 1090000 !           | 23              |            | 2.80                 | 1144000   | 12      |
| 7              | 3.50                 | 1090000             | 14              | - · ·      | 6.50                 | 1144000   | 28      |
| 8              | 1.60                 | 1090000             | 7               | ł          | 1.60                 | 1144000   | 7       |
| 9              | 1.85                 | 1090000             | ÷8              | · ·        | 6.50                 | 1144000   | 28      |
| 10             | 2.15                 | 1090000             | <b>9</b>        | 1 en       | 1.75                 | 1144000   | 8       |
| 11             | 1.30                 | 1090000             | 5               | . f.,      | 1.30                 | 1144000   | 6       |
| 12             | 1.60                 | 1090000             | 7               | ]          | 2.25                 | 1144000   | 10      |
| 13             | 2.55                 | 1090000             | 11              |            | 2.25                 | 1144000   | 10      |
| 14             | 3.35                 | 1090000             | 14              | · · ·      | 2.35                 | 1144000 - | 10      |
| 15             | 4.50                 | 1090000             | 19              | }          | 8.00                 | 1144000   | 35      |
| 16             | 1.60                 | 1090000             | .7              | 100        | 13.50                | 1144000   | 58      |
| 17             | 2.05                 | 1090000             | -8              |            | 2.10                 | 1144000   | 9       |
| 18             | 2.30                 | 1090000             | 9               | <b>j</b> . | 1.90 •               | 1144000   | 8       |
| 19             | 1.65                 | 1090000             | 7               |            | 6.50                 | 1144000   | 28      |
| 20             | 2.40                 | 1090000             | 10              | <b>1</b> : | 4.50                 | 1144000   | 19      |
| 21             | 4.50                 | 1090000             | - 19            | - 70 s.    | 5.50                 | 1144000   | 24      |
| 22             | 3.60                 | 1090000             | 15              | 12         | 5.00                 | 1144000   | 22      |
| 23             | 1.55                 | 1090000             | 6               | 10. T      | 4.50                 | 1144000   | 19      |
| 24             | 1.60                 | 1090000             | 7               |            | 1.70                 | 1144000   | 7       |
| 25             | 1.55                 | 1090000             | 6               | ļ          | 4.00                 | 1144000   | 17      |
| 26             | 6.50                 | 1259860             | <sup>-</sup> 31 | } .        | 6.00                 | 1144000   | 26      |
| 27             | 2.45                 | • 1144000           | 11              |            | 4.00                 | 1058600   | 16      |
| 28             | 1.35                 | 1144000             | 6               | <u>۱</u> . | 4.50                 | 1058600   | 18      |
| 29             | 4.50                 | 1144000             | 19              |            |                      |           | • •     |
| 30             | 20.50                | 1144000             | 89              | [          | -                    | •         |         |
| 31             | 3.05                 | 1144000             | 1 <b>3</b>      |            |                      | •         | •       |
| Totals         |                      | 34229860            | 480             |            |                      | 31861200  | 535     |
| StdDev         |                      | 1230000             | 40              | 11         |                      | 1200000   | 38      |
| Average        | 3.7                  | 1104189             | 15              | 1          | 4.4                  | 1137900   | 19      |
| Max            | 20.5                 | 1259860             | 89              | 1          | 13.5                 | 1144000   | 58      |
|                | _                    |                     | 4 D L           | 1          |                      |           | · •     |

| Table L1–8A. Uranium                                                                                           | Quantities and Effluent Volume Measured at |
|----------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| the second s | Manhole 175 in 1962                        |

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960-1962 and Fischoff 1960-1962; a monthly average was used when Mr. A. B. B. Car daily measurments were not located. •

.

٠.

### Appendix L

. . .

Page L-87

| Surface Water | Discharges | ÷ |
|---------------|------------|---|
|               |            |   |

| • •     | March 1962           |                     |         | April 1962           |                     |         |  |
|---------|----------------------|---------------------|---------|----------------------|---------------------|---------|--|
|         | Uranium <sup>a</sup> | Volume <sup>b</sup> | Uranium | Uranium <sup>a</sup> | Volume <sup>b</sup> | Uranium |  |
| Date    | $(mg L^{-1})$        | (gal)               | (kg)    | $(mg L^{-1})$        | (gal)               | · (kg)  |  |
| 1       | 2.00                 | 1058600             | 8       | 14.00                | 853528              | 45      |  |
| 2       | 13.50                | 1058600             | 54      | 9.00                 | 853528              | 29      |  |
| 3       | 4.50                 | 1058600             | 18      | 12.00                | 853528              | 39      |  |
| 4       | 4.00                 | 1058600             | 16      | 8.50                 | 853528              | 27      |  |
| 5.      | 2.45                 | 1058600             | . 10    | 9.00                 | 853528              | 29      |  |
| 6       | 1.60                 | 1058600             | 6       | <sup>2</sup> 6.50    | 853528              | 21      |  |
| 7       | 1.75                 | 1058600             | 7       | 7.00                 | 853528              | 23      |  |
| 8       | 1.90                 | 1058600             | 8       | 7.00                 | 853528              | 23      |  |
| 9       | 3.05                 | 1058600             | 12      | 5.50                 | 853528              | 18      |  |
| 10      | 1.30                 | 1058600             | 5       | 5.00                 | 853528              | 16      |  |
| 11      | 2.90                 | 1058600             | 12      | 4.00                 | 853528              | 13      |  |
| 12      | 1.90                 | 1058600             | 8       | 11.00                | 853528              | 35      |  |
| 13      | 2.05                 | 1058600             | 8       | 3.70                 | 853528 -            | 12      |  |
| 14      | 3.15                 | 1058600             | 13      | 3.45                 | 853528              | 11      |  |
| 15      | 1.30                 | 1058600             | 5       | 2.15                 | 853528              | 7       |  |
| 16      | 1.55                 | 1058600             | 6       | 2.90                 | 853528              | 9       |  |
| 17      | 1.60                 | 1058600             | 6       | 5.50                 | 853528              | 18      |  |
| 18      | 1.70                 | 1058600             | 7       | 11.00 -              | 853528              | 35      |  |
| 19      | 2.30                 | 1058600             | 9       | 4.50                 | 853528              | 15      |  |
| 20      | 5.00                 | 1058600             | 20      | 2.20                 | 853528              | 7       |  |
| 21      | 7.00                 | 1058600             | 28      | . 5.50               | 853528              | 18      |  |
| 22      | 5.00                 | 1058600             | 20      | 7.50                 | 853528              | 24      |  |
| 23      | 3.10                 | 1058600             | 12      | 4.00                 | 853528              | 13      |  |
| 24      | 4.50                 | 1058600             | 18      | 2.05                 | 853528              | · · 7   |  |
| 25      | 1.55                 | 1058600             | 6       | 2.20                 | 853528              | 7       |  |
| 26      | 1.95                 | 1058600             | 8       | 1.50                 | 853528              | 5       |  |
| 27      | 2.55                 | 853528              | - 8     | 8.00                 | 754300              | 23      |  |
| 28      | 4.50                 | 853528              | 15      | 5.00                 | 754300              | 14      |  |
| 29      | 5.00                 | 853528              | 16      | 4.00                 | 754300              | 11      |  |
| 30      | . 6.50               | 853528              | 21      | 6.50                 | 754300              | 19      |  |
| 31      | 5.00                 | 853528              | 16      |                      |                     |         |  |
| Totals  | • •                  | 31791240            | 407     |                      | 2520000             | 572     |  |
| Stdev   |                      |                     | 30      |                      | •                   | 38      |  |
| Average | 3.4                  |                     | 13      | 6.0                  |                     | 19      |  |
| Max     | 13.5                 |                     | 54      | 14.0                 |                     | 45      |  |
| Min     | 1.3                  |                     | 5.      | 1.5                  |                     | 5       |  |

# Table L1-8B. Uranium Quantities and Effluent Volume Measured at

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960–1962 and Fischoff 1960–1962; a monthly average was used when daily measurments were not located.

**Radiological Assessments Corporation** 

"Setting the standard in environmental health"
| <u></u>     | · ·                   | Manh                  | ole 175       | in 19    | 62                    |                     |         |
|-------------|-----------------------|-----------------------|---------------|----------|-----------------------|---------------------|---------|
|             | ·                     | May 1962              |               | 54 C     |                       | June 1962           |         |
| Date        | Uranium <sup>a</sup>  | Volume <sup>b</sup> U | Iranium ;     |          | Uranium <sup>a</sup>  | Volume <sup>b</sup> | Uranium |
|             | (mg L <sup>-1</sup> ) | (gal)                 | (kg)          | · .      | (mg L <sup>-1</sup> ) | (gal)               | (kg)    |
| 1           | 6.00                  | 754300                | 17            | 1        | 2.05                  | 959400              | 7       |
| 2           | 9.00                  | 754300                | 26            | · · ·    | 2.25                  | 959400              | 8       |
| .3          | .2.80                 | 754300                | 8             |          | 1.45                  | 959400              | 5       |
| 4           | 5.50                  | 754300                | 16            | [        | 1.90                  | 959400              | 7       |
| . 5         | 2.55                  | 754300                | 7             | Í        | 4.50                  | 959400              | 16      |
| 6           | 6.00                  | 754300                | 17            | }        | 1.50                  | 959400              | 5       |
| 7           | 6.50                  | 754300                | 19            |          | 1.85                  | 959400              | 7       |
| 8           | 5.50                  | 754300                | 16            | 1        | 2.55                  | 959400              | 9       |
| 9.          | 1.95                  | 754300                | <b>6</b> ·    | ·        | 6.50                  | 959400              | 24      |
| 10          | 6.00                  | 754300                | 17            |          | 5.00                  | 959400              | 18      |
| .11         | .2.50                 | 754300                | <b>7</b> 🤤    |          | 5.00                  | 959400              | 18      |
| - 12        | 3.75                  | 754300                | 11 🕂          | 1.1      | 1.75                  | 959400              | 6       |
| 13          | 3.95                  | 754300                | 11 🗠          |          | 1.45                  | 959400              | 5       |
| 14          | 3.50                  | 754300                | 10            |          | 1.45                  | 959400              | 5       |
| 15          | 2.50                  | 754300                | 7             |          | 2.25                  | 959400              | 8       |
| . 16        | 4.50                  | 754300                | 13            |          | 5.00                  | 959400              | 18      |
| 17          | 6.00                  | 754300                | 17            |          | 4.00                  | 959400              | 15      |
| 18          | 3.50                  | 754300                | 10            |          | 5.50                  | 959400              | 20      |
| 19          | 2.25                  | 754300                | 6             |          | 10.50                 | 959400              | 38      |
| : 20        | 7.00                  | 754300                | 20            |          | 1.65                  | 959400              | 6       |
| 21          | 5.50                  | 754300                | 16            |          | 2.85                  | 959400              | 10      |
| 22          | 6.50                  | 754300                | . 19          |          | 1.75                  | 959400              | 6       |
| 23          | 11.50                 | 754300                | 33            | <u>:</u> | 1.15                  | 959400              | 4       |
| 24          | 2.70                  | 754300                | 8 .,          |          | 5.00                  | 959400              | 18      |
| 25          | 7.50                  | 754300                | <b>21</b> .   |          | 2.45                  | 959400              | 9       |
| , 26        | 6.50                  | 959400                | 24            |          | 2.25                  | 898600              | 8       |
| 27          | 5.50                  | 959400                | 20 ·          |          | 2.15                  | 898600              | 7       |
| <b>28</b> . | 5.50                  | 959400                | 20            |          | 1.95                  | 898600              | 7       |
| <b>29</b> 😣 | 5.00                  | 959400 C              | 18 🦿          | ;        | 1.50                  | 898600              | 5       |
| 30          | 5.50                  | 959400 a              | 20            | i        | 1.00                  | 898600              | 3       |
| .31         | 5.50                  | 959400                | <b>20</b> (4) | 1.6.     | · ·                   |                     |         |
| Totals      |                       | 24613900 at 1         | 478 -         |          |                       | 28478000            | 325     |
| Average     | -5.1                  | ; ;                   | 15            |          | . 3.0                 | •                   | 11      |
| Stdev       |                       |                       | 30            |          |                       |                     | 20      |
| Max         | 11.5                  | •                     | 33            |          | 10.5                  | •                   | 38      |
| Min         | 2.0                   |                       | 6             |          | 1.0                   |                     | 3       |
|             |                       | ł                     |               | ]        |                       |                     |         |

Table L1–8C. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1962

a NLCO 1960-1962; 24 hour composite samples

11

<sup>b</sup> From Cuthbert 1960–1962 and Fischoff 1960–1962; a monthly average was used when daily measurments were not located.

. : :

i.

|             |                       | Mar                 | hole 175 | in 1962                  | <u> </u>            |          |
|-------------|-----------------------|---------------------|----------|--------------------------|---------------------|----------|
|             |                       | July 1962           |          | ł                        | August 1962         |          |
| Date        | Uranium <sup>a</sup>  | Volume <sup>b</sup> | Uranium  | Uranium <sup>a</sup>     | Volume <sup>b</sup> | Uranium  |
|             | (mg L <sup>-1</sup> ) | (gal)               | (kg)     | (mg L <sup>-1</sup> )    | (gal)               | (kg)     |
| 1           | 1.35                  | 928560              | 5        | 5.00                     | 1040800             | 20       |
| 2           | 0.95                  | 928560              | · 3      | 5.50                     | 1040800             | 22       |
| 3           | 8.50                  | 928560              | 30       | 2.10                     | 1040800             | 8        |
| 4           | 6.50                  | 928560              | 23       | 1.75                     | 1040800             | 7        |
| 5           | 11.50                 | 928560              | 40       | 2.35                     | 1040800             | 9        |
| . 6         | 8.50                  | 928560              | 30       | 6.00                     | 1040800             | 24       |
| 7           | 1.80                  | 928560              | 6        | <b>3.00</b> <sup>-</sup> | 1040800             | 12       |
| 8           | 3.50                  | 928560              | 12       | 5.00                     | 1040800             | 20       |
| 9           | 1.15                  | 928560              | 4        | 2.95                     | 1040800             | 12       |
| 10          | 1.40                  | 928560              | • 5      | 1.40                     | 1040800             | 6        |
| 11          | 2.80                  | 928560              | 10       | 1.40                     | 1040800             | 6        |
| 12          | 1.80                  | 928560              | 6        | 2.00                     | 1040800             | 8        |
| 13          | 2.70                  | 928560              | 9        | 2.00                     | 1040800             | 8        |
| 14          | 4.50                  | 928560              | 16       | 1.65                     | 1040800             | 6        |
| 15          | 5.50                  | 928560              | 19       | 1.55                     | 1040800             | 6        |
| <b>16</b> . | 4.50                  | 928560              | 16       | 1.30                     | 1040800             | 5        |
| 17          | 3.45                  | 928560              | 12       | 2.45                     | 1040800             | 10       |
| 18          | 1.70                  | 928560              | 6        | 1.90                     | 1040800             | 7        |
| 19          | 1.20                  | 928560              | 4        | 1.85                     | 1040800             | 7        |
| 20          | 1.15                  | 928560              | 4        | 2.15                     | 1040800             | 8        |
| 21          | 1.90                  | 928560              | 7        | 2.75                     | 1040800             | 11 · · · |
| 22          | 1.65                  | 928560              | 6        | 5.50                     | 1040800             | 22       |
| 23          | <b>2.65</b>           | 928560              | 9        | 2.60                     | 1040800             | 10       |
| 24          | 1.20                  | 928560              | 4        | 3.10                     | 1040800             | 12       |
| 25          | 0.85                  | 928560              | 3        | 5.50                     | 1040800             | 22       |
| 26          | 0.65                  | 1040800             | 3        | 7.50 ·                   | 1040800             | 30       |
| <b>27</b> · | 0.70                  | 1040800             | 3        | 4.00                     | 930400              | 14       |
| 28          | 1.10                  | 1040800             | 4        | 2.40                     | 930400              | 8        |
| 29          | 1.35                  | 1040800             | 5        | 5.50                     | 930400              | 19       |
| 30          | 1.45                  | 1040800             | 6        | 3.50                     | 930400              | 12       |
| 31          | 1.00                  | 1040800             | 4        | 5.00                     | 930400              | 18       |
| Totals      | •                     | 29458800            | 315      |                          | 31712800            | 387      |
| Average     | 2.9                   |                     | 10       | 3.2                      |                     | 12       |
| Stdev       | 2.6                   |                     | 24       | 1.7                      |                     | 25       |
| Max         | 11.5                  |                     | 40       | 7.5                      |                     | 30       |
| Min         | 0.7                   |                     | 3        | 1.3                      |                     | 5        |

Table L1-8D. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1962

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960-1962 and Fischoff 1960-1962; a monthly average was used when daily measurments were not located.

÷ ;

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

| Page | L-90 |
|------|------|
|------|------|

|               | Ma                                      | <u>nhole 175</u> | in 1962                      |                     |           |
|---------------|-----------------------------------------|------------------|------------------------------|---------------------|-----------|
| . <u> </u>    | September 19                            | 62               | <u> </u>                     | ctober 1962         | <u>:</u>  |
| Date Ura      | nium <sup>a</sup> / Volume <sup>b</sup> | Uranium          | Uranium <sup>a</sup>         | Volume <sup>b</sup> | Uranium   |
| ·(mį          | g L <sup>-1</sup> ) ; (gal)             | (kg)             | (mg L <sup>−1</sup> )        | (gal)               | (kg)      |
| 1 4           | 1.00 930400                             | 14               | 2.30                         | 736900              | 6         |
| 2 2           | 2.85 930400                             | 10               | ' <u>ଅନେ</u> ର୍ମ <b>6.00</b> | 736900              | 17        |
| 3 2           | 2.00 930400                             | 7                | 6.50                         | 736900              | 18        |
| 4 9           | 9,50 930400                             | 33               | 2.05                         | 736900              | 6         |
| 5 1           | 0.50 930400                             | 37               | 1.70                         | 736900              | .5        |
| 6 4           | 5.00 1100000                            | 187              | 6.50                         | 736900              | 18        |
| 7             | 3,50 c 1200000                          | 39               | 2.55                         | 736900              | 7         |
| 8 4           | 5.00 / 1000000                          | 170              | 0010 5 <b>.50</b>            | 736900              | 15        |
| 9 6           | 3.50 930400                             | 23               | 2.10                         | 736900              | - 6       |
| . 10 12       | 25.00 1440000                           | 680              | 284 1° <b>7.50</b>           | 736900              | 21        |
| <b>11 1</b>   | 5.00 1130000                            | 64               | 2.60                         | 736900              | 7         |
| 12 5          | 5.00 930400                             | 18 ·             | 2.35                         | 736900              | 7         |
| 13 5          | 5.00 930400                             | 18               | 10.00                        | .736900             | 28        |
| 14 4          | 4.50 930400                             | 16               | 12.00                        | 736900              | 33        |
| 15 5          | 5.50 930400                             | 19               | í 💷 <b>8.5</b> 0             | 736900              | 24        |
| 16 3          | 3.50 930400                             | 12               | 4.50                         | 736900              | 13        |
| · 17 - 8 2    | 2.70 930400                             | 9                | 10.50                        | 736900              | 29        |
| 18 18 4       | 4.00 930400                             | 14               | 7.00                         | 736900              | 19        |
| 19 2          | 2.95 930400                             | 10               | 2.05                         | 736900              | 6         |
| <b>: 20</b> 4 | 4.00 930400                             | 14               | 2.30                         | 736900              | 6         |
| 21 2          | 2.60 930400                             | 9                | 1.45                         | 736900              | - 4       |
| 22 2          | 2.05 930400                             | 7                | 1.45                         | 736900              | · 4       |
| <b>23</b>     | 1.85 930400                             | 7                | 1.25                         | 736900              | 3         |
| 24            | 1.80 930400                             | 6                | 1.30                         | 736900              | 4         |
| 25            | 5.00 930400                             | 18               | 2.20                         | 736900              | 6         |
| 26            | 3.50 930400                             | 12               | 7.50                         | 796231              | 23        |
| 27 2          | 2.35 736900                             | 7                | 2.60                         | 796231              | . 8       |
| 28            | 4.00 736900                             | 11               | 7.12                         | 796231              | <b>21</b> |
| : <b>29</b>   | 1.75 736900                             | 5                | 2.95                         | 796231              | 9         |
| 30            | 1.60 736900                             | 4                | 2.10                         | 796231              | 6         |
| 31            |                                         | 1                | 3.38                         | 796231              | 10        |
| Takel         |                                         | 1401             |                              | 02100860            | 200       |
| Totals        | 20356000                                | 1481             |                              | 53193000            | ้อยบ      |
| Statley       | 11.0                                    | 238              |                              | 034000              | 20<br>19  |
| Average       | 11.3                                    | 49               | 4.4                          |                     | 10        |
|               | 125.0                                   | 680              | 12.0                         | · ·                 | .' n      |
| Min           | 1.0                                     | 4                | 1.3                          |                     | . J       |

Table L1–8E. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1962

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960–1962 and Fischoff 1960–1962; a monthly average was used when daily measurments were not located.

والمستحد والمتحافظ والمعتان والمعتاد والمعتاد والمعتم والمعتم والمعتم والمعالي والمعاري والمعار والمستري والمست

.

11111

| •                        |   |    |  |           |
|--------------------------|---|----|--|-----------|
| Appendix L               |   | ۰. |  | Page L-91 |
| Surface Water Discharges | • |    |  | -         |

|         | Manhole 175 in 1962   |                     |         |                         |                     |         |  |  |  |  |
|---------|-----------------------|---------------------|---------|-------------------------|---------------------|---------|--|--|--|--|
| •       | N                     | ovember 196         | 52      | December 1962           |                     |         |  |  |  |  |
| Date    | Uranium <sup>a</sup>  | Volume <sup>b</sup> | Uranium | Uranium <sup>a</sup>    | Volume <sup>b</sup> | Uranium |  |  |  |  |
|         | (mg L <sup>-1</sup> ) | (gal)               | (kg)    | - (mg L <sup>-1</sup> ) | (gal)               | (kg)    |  |  |  |  |
| 1       | 5.62                  | 796231              | 17      | 1.90                    | 790030              | 6       |  |  |  |  |
| 2       | 2.85                  | 796231              | 9       | 2.30                    | 790030              | 7       |  |  |  |  |
| 3       | 2.75                  | 796231              | - 8     | 2.00                    | 790030              | 6       |  |  |  |  |
| 4       | 8.00                  | 796231              | 24      | 0.95                    | 790030              | 3       |  |  |  |  |
| 5       | 3.25                  | 796231              | 10      | 8.00                    | 790030              | 24      |  |  |  |  |
| 6       | 4.00                  | 796231              | 12      | 4.50                    | 790030              | 13      |  |  |  |  |
| . 1     | 2.35                  | 796231              | 7       | 1.25                    | 790030              | 4       |  |  |  |  |
| 8       | 1.70                  | 796231              | 5       | 0.65                    | 790030              | 2       |  |  |  |  |
| 9       | 5.00                  | 796231              | 15      | 0.65                    | 790030              | 2       |  |  |  |  |
| 10      | 4.50                  | 796231              | 14      | 1.35                    | 790030              | 4       |  |  |  |  |
| 11      | 1.90                  | 796231.             | 6       | 1.40                    | 790030              | 4       |  |  |  |  |
| 12      | 8.50                  | 796231              | 26      | 1.65                    | 790030              | 5       |  |  |  |  |
| 13      | 2.45                  | 796231              | 7       | 36.00                   | · 946500            | 129     |  |  |  |  |
| 14      | 1.70                  | 796231              | 5       | 8.50 ·                  | 1093000             | 35      |  |  |  |  |
| 15      | 2.25                  | 796231              | 7       | 7.50                    | 1093000             | 31      |  |  |  |  |
| 16      | 2.20                  | 796231              | 7       | . 3.20                  | 1093000             | 13      |  |  |  |  |
| 17      | 3.25                  | 796231              | 10      | 1.00                    | 1093000             | 4       |  |  |  |  |
| 18      | 3.55                  | 796231              | 11      | 3.90                    | 1093000             | 16      |  |  |  |  |
| 19 ·    | 3.05                  | 796231              | 9       | 3.25                    | 1093000             | 13      |  |  |  |  |
| 20 -    | 12.00                 | 796231              | 36      | 4.00                    | 1093000             | 17      |  |  |  |  |
| 21      | 2.40                  | 796231              | 7       | 2.65                    | 1093000             | . 11    |  |  |  |  |
| 22      | 2.25                  | 796231              | 7       | 2.25                    | 1093000             | 9       |  |  |  |  |
| 23      | 2.05                  | 796231              | 6       | 1.65                    | 1093000             | 7       |  |  |  |  |
| 24      | 2.30                  | 796231              | 7       | 5.00                    | 1093000             | 21      |  |  |  |  |
| 25      | 2.10                  | 796231              | 6       | 1.50                    | 1093000             | 6       |  |  |  |  |
| 26      | 15.50                 | 790030              | 46      | . 1.25                  | 1093000             | 5       |  |  |  |  |
| 27      | 2.75                  | 790030              | · 8     | 4.50                    | 1093000             | 19      |  |  |  |  |
| 28      | 6.50                  | 790030 <sup>°</sup> | 19      | 6.50                    | 1093000             | 27      |  |  |  |  |
| 29      | 2.75                  | 790030              | · 8     | 2.30                    | 1093000             | 10      |  |  |  |  |
| 30      | 2.15                  | 790030              | 6       | 1.35                    | 1093000 ·           | 6 ·     |  |  |  |  |
| 31      |                       |                     |         | 1.85                    | 1093000             | 8       |  |  |  |  |
| Totals  |                       | 23855925            | 365     |                         | 30100860            | 465     |  |  |  |  |
| Average | 4.1                   |                     | 12      | . 4.0                   |                     | 15      |  |  |  |  |
| Stdev   |                       | 871000              | 28      |                         | 1090000             | 50      |  |  |  |  |
| Max     | 15.5                  |                     | 46      | 36.0                    |                     | 129     |  |  |  |  |
| Min     | 1.7                   |                     | 5       | 1.0                     |                     | 1       |  |  |  |  |

Table L1-8F. Uranium Quantities and Effluent Volume Measured at Manhole 175 in 1962

<sup>a</sup> NLCO 1960-1962; 24 hour composite samples

<sup>b</sup> From Cuthbert 1960–1962 and Fischoff 1960–1962; a monthly average was used when daily measurments were not located.

•

Radiological Assessments Corporation "Setting the standard in environmental health"

11.11

## The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

|          | <u>.                                    </u> |            | Manh     | ole 175 in     | 1963    | <u></u>   |                       |                 |
|----------|----------------------------------------------|------------|----------|----------------|---------|-----------|-----------------------|-----------------|
| 1963     | Ua                                           | Total U    | 1963     | U <sup>a</sup> | Total U | 1963      | Ua                    | Total U         |
| Date     | (mg L <sup>-1</sup> )                        | kg U       | Date     | $(mg L^{-1})$  | kg U    | Date      | (mg L <sup>-1</sup> ) | kg U            |
| 1-Apr    | 2.50                                         | 10         | 13-May   | . <b>0.98</b>  | 4       | 25-Nov    | 2.20                  | 9               |
| 2-Apr    | 2.45                                         | 10         | 14-May   | 2.00           | 8       | 27-Nov    | 2.20                  | 9               |
| 3-Apr    | 3.15                                         | 13         | 15-May   | 2.00           | 8       | 28-Nov    | 2.60                  | 11              |
| 4-Apr    | 2.65                                         | 11         | 16-May - | 1.12           | 5       | 29-Nov    | 5.20                  | 22              |
| 5-Apr    | 2.35                                         | 10         | 17-May   | 2.00           | 8       | 30-Nov    | 4.40                  | 18              |
| 6-Apr    | 5.50                                         | 23         | 18-May   | 1.10           | 5       | 1-Dec     | 4.20                  | 17              |
| 7-Apr    | 2.65                                         | 11         | 19-May   | 1.14           | 5       | 2-Dec     | 2.80                  | 12              |
| 8-Apr    | 2.34                                         | 10         | 20-May   | 2.00           | · 8     | 3-Dec     | 2.00                  | 8               |
| 9-Apr    | 2.40                                         | 10         | 21-May   | 1.16           | 5       | 4 Dec     | 2.80                  | 12              |
| 10-Apr   | 2.75                                         | 11.        | 22-May   | 0.72           | 3       | 5-Dec     | 3.00                  | 12              |
| 11-Apr   | 1.80                                         | 7          | 23-May   | 0.74           | 3       | 6-Dec     | 3.00                  | 12              |
| 12-Apr · | 1.55                                         | 6          | 24-May   | 1.80           | 7       | 7-Dec     | 3.00                  | 12              |
| 13-Apr   | 1.60                                         | <b>7</b> · | 25-May   | 2.20           | 9       | 8-Dec     | 5.80                  | 24              |
| 14-Apr   | 7.50                                         | 31         | 26-May   | 1.24           | · 5     | 9-Dec     | 2.80                  | 12              |
| 15-Apr   | 2.75                                         | 11         | 27-May   | 2.20           | 9.      | 10-Dec    | 3.80                  | 16              |
| 17-Apr   | 7.00                                         | 29         | 28-May   | 1.34           | 6       | 12-Dec    | 10.40                 | 43              |
| 18-Apr   | 6.00                                         | 25         | 30-May   | 0.98           | 4       | 13-Dec    | 4.80                  | 20              |
| 19-Apr   | 3.05                                         | 13         | 31-May   | 1.02           | 4       | 14-Dec    | <b>2.60</b>           | · 11            |
| 20-Apr   | 2.75                                         | 11         | 2-Nov    | 2.80           | 12      | 15-Dec    | 3.00                  | 12              |
| 21-Apr   | 2.15                                         | 9          | 3-Nov    | 1.00           | 4       | 16-Dec    | 4.00                  | 17              |
| 22-Apr   | 5.50                                         | 23         | 4-Nov    | 4.00           | 17      | 17-Dec    | 2.60                  | 11              |
| 23-Apr   | 1.90                                         | 8          | 5-Nov    | 4.20           | 17      | 18-Dec    | 4.40                  | 18              |
| 24-Apr   | 1.45                                         | 6          | 6-Nov    | 2.20           | 9       | 19-Dec    | 3.40                  | <sup>5</sup> 14 |
| 25-Apr   | 2.25                                         | 9          | 7-Nov    | 2.80           | 12      | 20-Dec    | 4.20                  | 17              |
| 26-Apr   | 1.75 ·                                       | 7          | 8-Nov    | 5.00           | 21      | 21-Dec    | 1.60                  | "· 7 ·          |
| 27-Apr   | 1.85                                         | 8          | 9-Nov    | 5.20           | 22      | 22-Dec    | 2.00                  | . 8             |
| 28-Apr   | 1.50                                         | 6          | 10-Nov   | 3.80           | 16      | 23-Dec    | 2.20                  | <sup>-</sup> 9  |
| 29-Apr   | 2.20                                         | 9          | 11-Nov   | 3.00           | 12      | 24-Dec    | 1.00                  | - 4             |
| 30-Apr   | 3.72                                         | 15         | 12-Nov   | 4.00           | 17      | 25-Dec    | 5.60                  | 23              |
| 1-May    | 1.60                                         | 7          | 13-Nov   | 4.00           | 17      | 26-Dec    | 5.80                  | 24              |
| 2-May    | 1.75                                         | 7.         | 14-Nov   | 6.60           | 27      | 27-Dec    | 3.00                  | 12              |
| 3-May    | 1.10                                         | 5          | 15-Nov   | 6.80           | 28      | 28-Dec    | 2.80                  | 12              |
| 4-May    | 2.05                                         | 9          | 16-Nov   | 4. <b>4</b> 0  | - 18    | 29-Dec    | 0.80                  | 3               |
| 5-May    | 1.55                                         | 6          | 17-Nov   | 2.60           | · 11    | 30-Dec    | 0.80                  | 3               |
| 6-May    | 1.25                                         | 5          | 18-Nov   | 1.32           | 5       | 31-Dec    | 0.80                  | 3               |
| 7-May    | 1.28                                         | 5          | 19-Nov   | 1.52           | 6       | <u>۳.</u> |                       |                 |
| 8-May    | 0.92                                         | 4          | 20-Nov   | 4.00           | 17      | AnnTotal  |                       |                 |
| 9-Mav    | 2.20                                         | 9          | 21-Nov   | 0.72           | 3       | Average   | 2.86                  | 12              |
| 10-Mav   | 0.90                                         | 4          | 22-Nov   | 3.20           | 13      | StdDev    | 1.81                  | 8               |
| 11-Mav   | 0.68                                         | 3          | 23-Nov   | 8.20           | 34      | Мах       | 10.40                 | 43              |
| 12.Mev   | 0.72                                         | 2          | 24-Nov   | 4 80           | 20      | Min       | 0.68                  | 3               |

Table L1-9. Measured Concentrations and Calculated Quantities of Uranium at Manhole 175 in 1963

<sup>a</sup> From NLCO 1963, analytical data sheets from the Bioassay Department at the FMPC.

No. W.

Section -

.

.

| Appendix L<br>Surface Water Discharges |   | • | Page L–93 |
|----------------------------------------|---|---|-----------|
| earrace mater Discharges               | · |   | •         |

;•••

1990

 $\langle \cdot \rangle$ 

272

| Table L1-10A. Measured Concentrations and Calculated Quant | ities of Uranium at |
|------------------------------------------------------------|---------------------|
| Manhole 175 in 1964                                        |                     |

|        |                       |         | i i i a i i | noie 119 I    | n 1964      |        |               |           |
|--------|-----------------------|---------|-------------|---------------|-------------|--------|---------------|-----------|
| 1964   | Ua                    | Total U | 1964        | Ua            | Total U     | 1964   | Ua            | Total U   |
| Date   | (mg L <sup>-1</sup> ) | (kg)    | Date,       | $(mg L^{-1})$ | (kg)        | Date   | $(mg L^{-1})$ | (kg)      |
| 1-Jan  | 3.00                  | 12      | 14-Feb      | 2.60          | 11          | 29-Mar | 3.40          | 14        |
| 2-Jan  | 2.40                  | 10      | 15-Feb      | 6.00          | <b>25</b> · | 30-Mar | 3.00          | 12        |
| 3-Jan  | 4.00                  | 17      | 16-Feb      | 3.00          | 12          | 31-Mar | 2.20          | 9         |
| 4-Jan  | 5.20                  | 22      | 17-Feb      | 2.40          | 10          | 1-Apr  | 3.00          | . 12      |
| 5-Jan  | 3.00                  | 12      | 18-Feb      | 5.60          | 23          | 2-Apr  | 3.80          | 16        |
| 6-Jan  | 4.60                  | 19      | 19-Feb      | 6.20          | 26          | 3-Apr  | . 3.40        | 14        |
| 7-Jan  | 4.80                  | 20      | 20-Feb      | 4.60          | 19          | 4-Apr  | 2.80          | 12        |
| 8-Jan  | 4.60                  | 19      | 21-Feb      | 4.20          | 17          | 5-Apr  | 3.00          | 12        |
| 9-Jan  | 4.40                  | 18      | 22-Feb      | 5.20          | 22          | 6-Apr  | 2.60          | 11        |
| 10-Jan | 4.40                  | 18      | 23-Feb      | 3.20          | 13          | 7-Apr  | 3.60          | 15        |
| 12-Jan | 2.20                  | 9       | 25-Feb      | 15.40         | 64          | 9-Apr  | 3.60          | 15        |
| 13-Jan | 2.00                  | 8       | 26-Feb      | 10.60         | 44          | 10-Apr | 2.60          | 11        |
| 14-Jan | 2.20                  | 9       | 27-Feb      | 7.40          | 31          | 11-Apr | 2.60          | 11        |
| 15-Jan | 5.40                  | 22      | 28-Feb      | 7.00          | 29          | 12-Apr | 2.60          | 11        |
| 16-Jan | 7.40                  | 31      | 29-Feb      | 7.40          | 31          | 13-Apr | 2.20          | 9         |
| 17-Jan | 2.40                  | 10      | 1-Mar       | 4.20          | 17          | 14-Apr | 2.20          | 9         |
| 18-Jan | 2.00                  | 8       | 2-Mar       | 6.80          | 28          | 15-Apr | 2.80          | 12        |
| 19-Jan | 4.00                  | 17      | 3-Mar       | 7.60          | 32          | 16-Apr | 3.20          | 13        |
| 20-Jan | 5.20                  | 22      | 4-Mar       | 5.80          | 24          | 17-Apr | 3.00          | 12        |
| 21-Jan | 3.00                  | 12      | 5-Mar       | 6.40          | 27          | 18-Apr | 4.80          | 20        |
| 22-Jan | 2.40                  | 10      | 6-Mar       | 5.60          | 23          | 19-Apr | 3.60          | 15        |
| 23-Jan | 2.60                  | 11      | 7-Mar       | 6.00          | 25          | 20-Apr | 4.80          | 20        |
| 24-Jan | 3.80                  | 16      | 8-Mar       | 7.00          | 29          | 21-Apr | 4.40          | 18        |
| 25-Jan | 3.80                  | 16      | 9-Mar       | 3.80          | 16          | 22-Apr | 3.40          | 14        |
| 26-Jan | 2.00                  | 8       | 10-Mar      | 5.00          | 21          | 23-Apr | 4.20          | 17        |
| 27-Jan | 2.40                  | 10      | 11-Mar      | 3.40          | 14          | 24-Apr | 2.60          | 11        |
| 28-Jan | 2.00                  | 8       | 12-Mar      | 3.20          | 13          | 25-Apr | 3.80          | <b>i6</b> |
| 29-Jan | 2.20                  | 9       | 13-Mar      | 6.20          | 26          | 26-Apr | 8.60          | 36        |
| 30-Jan | 2.20                  | 9       | 14-Mar      | 10.00         | 42          | 27-Apr | 4.00          | 17        |
| 31-Jan | 2.60                  | 11 .    | 15-Mar      | 6.20          | 26          | 28-Apr | 3.00          | 12        |
| 1-Feb  | 3.00                  | 12      | 16-Mar      | 4.80          | 20          | 29-Apr | 2.20          | 9         |
| 2-Feb  | 2.60                  | 11      | 17-Mar      | 4.20          | 17          | 30-Apr | 4.40          | 18        |
| 3-Feb  | 1.34                  | 6       | 18-Mar      | 3.00          | 12          | 1-May  | 5.00          | 21        |
| 4-Feb  | 2.40                  | 10      | 19-Mar      | 2.60          | 11          | 2-May  | 2.80          | 12        |
| 5-Feb  | 2.80                  | 12      | 20-Mar      | 5.00          | 21          | 3-May  | 2.80          | 12        |
| 6-Feb  | 4.20                  | 17      | 21-Mar      | 4.60          | 19          | 4-May  | 4.40          | 18        |
| 7-Feb  | 3.20                  | 13      | 22-Mar      | 4.60          | 19          | 5-May  | 6.60          | 27        |
| 8-Feb  | 2.40                  | 10      | 23-Mar      | 3.00          | 12          | 6-May  | 3.40          | 14        |
| 9-Feb  | 2.00                  | 8       | 24-Mar      | 4.00          | 17          | 7-May  | 1.28          | 5         |
| 10-Feb | 2.80                  | 12      | 25-Mar      | 5.00          | 21          | 8-May  | 2.40          | 10        |
| 11-Feb | 4.60                  | 19      | 26-Mar      | 3.80          | 16          | 9-May  | 3.20          | 13 .      |
| 12-Feb | 3.80                  | 16      | 27-Mar      | 2.00          | 8           | 10-Mav | 2.40          | 10        |

(Continued on next page)

Radiological Assessments Corporation

"Setting the standard in environmental health"

• • • •

| , | 4 | P | а | g | е | L- | 94 |  |
|---|---|---|---|---|---|----|----|--|
|---|---|---|---|---|---|----|----|--|

. PARA

and and the second

Sec.

. : :

•••

. .

| Manhole 175 in 1964 (cont'd) |                     |                       |            |           |                       |                   |          |               |                |
|------------------------------|---------------------|-----------------------|------------|-----------|-----------------------|-------------------|----------|---------------|----------------|
| ·· · ]                       | 1964                | Ua                    | Total U    | 1964      | U <sup>a</sup> .      | Total U           | 1964     | Ua -          | Total U        |
|                              | Date .              | (mg L <sup>-1</sup> ) | (kg)       | Date on   | (mg L <sup>-1</sup> ) | . (kg)            | Date -   | $(mg L^{-1})$ | (kg)           |
| 1                            | 12-May              | 4.20                  | 17         | 25-Jun.   | 3.00                  | 12                | 8-Aug    | 0.96          | 4              |
| -                            | 13-May              | 6.60                  | 27 ·       | 26-Jun    | 1.42                  | т <b>б</b> . 1    | 9-Aug    | 2.20          | 9              |
| ••                           | 14-May              | 3.60                  | 15         | 27-Jun    | 4.40                  | 18                | 10-Aug   | 1.36          | 6 <sup>.</sup> |
| •                            | 15-May              | 4.60                  | 19         | 28-Jun :  | 1.46                  | ·· 6              | 11-Aug   | 2.00          | 8              |
| ,                            | 16-May              | 2.60                  | 11         | 29-Jun    | 1.28                  | 5                 | 12-Aug   | 2.20          | 9              |
| 2                            | 17-May              | 1.20                  | 5          | 30-Jun (  | 5.80                  | 24                | 13-Aug   | 2.20          | 9              |
| •                            | 18-May              | <b>4.20</b> : :       | 17 -       | 1-Jul     | <b>2.20</b> '         | 9                 | 14-Aug   | 1.10          | 5              |
| •                            | 19-May <sup>-</sup> | 4.00;                 | 17         | 2-Jul     | 2.40                  | 10                | 15-Aug   | 0.80          | 3              |
|                              | 20-May              | 5.60                  | 23         | 3-Jul D   | 1.28                  | 5                 | 16-Aug   | 0.52          | 2              |
| '                            | 21-May              | 9.20                  | 38         | 4-Jul     | 2.20                  | 9 -               | 17-Aug   | 3.40          | 14             |
| _                            | 22-May              | 2.60                  | 11 .       | 5-Jul     | 1.06                  | 4                 | 18-Aug   | 1.08          | 4              |
| •                            | 23-May              | • 14.60               | 61         | 6-Jul     | 3.60                  | 15                | 19-Aug   | 2.00          | 8              |
| •.                           | 24-May              | 8.00                  | 33         | 7-Jul     | 3.80                  | 16                | 20-Aug   | 1.08          | 4              |
|                              | 25-May              | 3.00                  | 12         | 8-Jul     | 2:00                  | <b>8</b> °        | 21-Aug   | 2.00          | 8              |
|                              | 26-May              | 2.60                  | 11         | 9-Jul     | 1.12                  | - 5               | 22-Aug   | 1.38          | <b>6</b> .     |
| ¢                            | 27-May              | 2.20                  | 9          | 10-Jul    | 0.84                  | 3                 | 23-Aug   | 3.40          | 14             |
| :                            | 28-May :            | 3.00                  | 12         | 11-Jul    | 0.88                  | · 4               | 24-Aug   | 0.86          | 4              |
| :                            | 29-May              | 2.20                  | 9          | 12-Jul    | 3.60                  | 15                | 25-Aug   | 0.90          | 4              |
| :                            | 31-May              | 0.72                  | 3          | 14-Jul    | 1.34                  | 6                 | 27-Aug   | 1.30          | 5              |
| 2                            | 1-Jun               | 3.60                  | 15         | 15-Jul    | 3.20                  | 13                | 28-Aug   | 2.00          | 8              |
|                              | 2-Jun               | 7.20                  | 30         | 16-Ju] (- | 1.06                  | 4                 | 29-Aug   | 1.32          | 5              |
|                              | .3-Jun              | 3.00                  | 12         | 17-Jul    | 1.80                  | 7                 | 1-Sep    | 0.92          | 4              |
|                              | 4-Jun               | 3.80                  | : 16       | 18-Jul    | 3.80                  | 16                | 2-Sep    | 0.88          | 4              |
|                              | 5-Jun               | 4.40                  | 18         | 19-Jul    | 2.20                  | 9                 | 3-Sep    | 0.72          | 3              |
|                              | 6-Jun               | 5.40                  | 22 7       | 20-Jul    | 1.80                  | 7                 | 4-Sep    | 1.10          | 5              |
|                              | 7-Jun               | 2.80                  | 12         | 21-Jul    | 1.24                  | 5                 | 5-Sep    | 0.74          | 3              |
|                              | 8-Jun               | 2.40                  | 10         | 22-Ju]    | 0.94                  | 4                 | 6-Sep    | 0.80          | 3              |
|                              | 9-Jun               | 2.80                  | 12         | 23-Jul '  | 2.60                  | 11                | 7-Sep    | 0.76          | 3              |
| •                            | 10-Jun              | 2.20                  | <b>'</b> 9 | 24-Jul    | 1.50                  | 6                 | 8-Sep    | 0.62          | 3              |
|                              | 11-Jun              | 2.20                  | 9          | 25-Jul (* | 1.10                  | 5                 | 9-Sep    | 2.00          | 8              |
|                              | 12-Jun              | 2.80                  | 12         | 26-Jul 8  | . 1.24                | 5.,               | 10-Sep   | 0.74          | 3              |
|                              | 13-Jun              | 3.20                  | 13         | 27-Jul    | 0.94 8                | 4 .               | 11-Sep " | 0.70          | 3              |
|                              | 14-Jun              | 2.20                  | · 9 🗉      | 28-Jul    | 2.40                  | 10                | 12-Sep   | 0.52          | 2.             |
|                              | 15-Jun              | 1.20                  | 5          | 29-Jul    | 3.40                  | 14                | 13-Sep   | 0.36          | 1              |
|                              | 16-Jun              | 1.04                  | 4          | 30-Jul    | <b>2.40</b> : 1       | 10                | 14-Sep   | 0.52          | 2              |
| • ~ .                        | 17-Jun              | 1.46                  | 6          | 31-Jul    | 4.40 ~ ~              | <sup>;</sup> 18 · | 15-Sep   | 0.70          | 3              |
|                              | 18-Jun              | 3.60                  | 15         | 1-Aug     | 3.80                  | 16                | 16-Sep   | 0.82          | 3              |
|                              | 19-Jun              | 1.50                  | 6          | 2-Aug     | 3.60                  | 15                | 17-Sep   | 0.72          | 3              |
|                              | 21-Jun              | 2.80                  | 12         | 4-Aug     | 2.60                  | ÷ 11              | 19-Sep   | 2.40          | 10             |
|                              | 22-Jun              | 2.20                  | 9          | 5-Aug ''  | 2.40                  | · 10              | 20-Sep   | 1.14          | 5              |
|                              | 23-Jun              | - 1.54                | 6          | 6-Aug     | 2.20                  | 9                 | 21-Sep   | 1.24          | 5              |
| -                            | 24-Jun              | 116                   | 5          | 7 1.00    | 1 20                  | с                 |          | 9.40          | 10             |

(Continued on next page)

: - :

• • • •

· ..

. :

.

. .

• .

.

: ::

Page L-95

| Table L1–10C. Measured Concentrations and Calculated Quantities of Uranium at |
|-------------------------------------------------------------------------------|
| Manhole 175 in 1964 (cont'd)                                                  |

|        |               |         | Manhole  | <u>175 in 19</u> | <u>64 (cont'a</u> | I)             |               | ·       |
|--------|---------------|---------|----------|------------------|-------------------|----------------|---------------|---------|
| 1964   | · Ua          | Total U | 1964     | Ua               | Total U           | 1964           | Ua            | Total U |
| Date   | $(mg L^{-1})$ | (kg)    | Date     | $(mg L^{-1})$    | (kg) -            | · Date         | $(mg L^{-1})$ | (kg)    |
| 23-Sep | 2.40          | 10      | 2-Nov    | 1.80             | 7                 | 12-Dec         | 2.00          | 8       |
| 24-Sep | 2.80          | 12      | 3-Nov    | 0.64             | 3                 | 13-Dec         | 1.32          | 5       |
| 25-Sep | 0.98          | 4       | 4-Nov    | 0.68             | 3                 | 14-Dec         | 0.90          | 4       |
| 26-Sep | 0.76          | 3       | 5-Nov    | 1.26             | 5                 | 15-Dec         | 0.82          | 3       |
| 27-Sep | 2.40          | 10      | 6-Nov    | 0.78             | 3                 | 16-Dec         | 1.40          | 6       |
| 28-Sep | 1.56          | 6       | 7-Nov    | 1.60             | 7                 | 17-Dec         | 1.26          | 5       |
| 29-Sep | 1.52          | 6       | 8-Nov    | 1.20             | · 5               | 18-Dec         | 0.70          | 3       |
| 30-Sep | . 1.18        | 5       | 9-Nov    | 0.94             | 4                 | 19-Dec         | 1.10          | 5       |
| 1-Oct  | 1.04          | 4       | 10-Nov   | 0.72             | 3 '               | 20-Dec         | 0.52          | 2       |
| 2-Oct  | 3.00          | 12      | 11-Nov   | 1.28             | 5                 | 21-Dec         | 0.50          | 2       |
| 3-Oct  | 1.39          | 6       | 12-Nov   | 1.28             | 5                 | 22-Dec         | 0.66          | 3       |
| 4-Oct  | 0.72          | 3       | 13-Nov.  | 1.80             | 7                 | 23-De <b>c</b> | 0.76          | 3       |
| 5-Oct  | 0.60          | 2       | 14-Nov   | 0.92             | 4                 | 24-Dec         | 2.00          | 8       |
| 6-Oct  | 0.68          | 3       | 15-Nov   | 3.80             | 16                | 25-Dec         | 2.00          | 8       |
| 7-Oct  | 0.82          | 3       | . 16-Nov | 2.20             | 9                 | 26-Dec         | 2.20          | 9       |
| 8-Oct  | 0.72          | 3       | 17-Nov   | 0.98             | 4 ·               | 27-Dec         | 1.28          | 5       |
| 9-Oct  | 0.60          | 2       | 18-Nov   | 0.98             | 4                 | 28-Dec         | 1.38          | 6       |
| 10-Oct | 0.64          | 3       | 19-Nov   | 2.20             | 9                 | 29-Dec         | 1.20          | 5       |
| 11-Oct | 0.90          | 4       | 20-Nov   | 1.12             | 5                 | 30-Dec         | 1.26          | 5       |
| 12-Oct | 0.56          | 2       | 21-Nov   | 2.20             | 9                 | 31-Dec         | 0.88          | 4       |
| 13-Oct | 1.00          | 4       | 22-Nov   | 0.74             | 3                 |                |               |         |
| 14-Oct | 1.04          | 4       | 23-Nov   | 1.60             | 7                 |                |               |         |
| 15-Oct | 0.86          | 4       | 24-Nov   | 1.60             | 7                 |                |               |         |
| 16-Oct | 0.58          | 2       | 25-Nov   | 2.40             | 10                |                |               |         |
| 17-Oct | 0.60          | 2       | 26-Nov   | 1.16             | 5                 |                |               |         |
| 18-Oct | 2.60          | 11      | 27-Nov   | 0.50             | 2                 |                | •             |         |
| 19-Oct | 2.60          | 11      | 28-Nov   | 2.60             | 11                |                | •             |         |
| 20-Oct | 1.23          | 5       | 29-Nov   | 0.82             | 3                 |                | -             |         |
| 21-Oct | 1.20          | 5       | 30-Nov   | · 1.12           | 5                 |                |               |         |
| 22-Oct | 2.40          | 10      | 1-Dec    | 0.64             | 3                 |                |               |         |
| 23-Oct | 0.92          | 4       | 2-Dec    | 2.20             | 9                 | ł              |               |         |
| 24-Oct | 0.52          | 2       | 3-Dec    | 3.00             | 12                |                |               |         |
| 25-Oct | 0.66          | 3       | 4-Dec    | 1.80             | 7                 |                |               |         |
| 26-Oct | 1.60          | 7       | 5-Dec    | 1.16             | 5                 | ł              |               |         |
| 27-Oct | 1.40          | 6       | 6-Dec    | 1.06             | 4                 |                |               |         |
| 28-Oct | 2.60          | 11      | 7-Dec    | 1.50             | 6                 | Total          |               | 5100    |
| 29-Oct | 4.20          | 17      | 8-Dec    | 1.08             | 4                 | Average        | 3.3 ·         | 14      |
| 30-Oct | 3.00          | 12      | 9-Dec    | 1.02             | 4                 | StdDev         | 1.3           | . 8     |
| 31-Oct | . 1.20        | 5       | 10-Dec   | 1.34             | 6                 | Max            | 7.4           | 64      |
| 1-Nov  | 0.64          | 3       | 11-Dec   | 2.40             | 10                | Min            | 1.3           | 1.5     |

<sup>a</sup> From NLCO 1964, original analytical data sheets from the Bioassay Department at the FMPC.

A.K.S.

and the second second

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

÷

· . . . • • • • •

÷. ... 

٤.

|        | Manhole 175 in 1966 |        |               |        |               |        |                       |                    |               |  |
|--------|---------------------|--------|---------------|--------|---------------|--------|-----------------------|--------------------|---------------|--|
| 1966   | Ua                  | 1966   | Ua            | 1966   | Ua            | 1966   | Ua                    | 1966               | Ua            |  |
| Date   | $(mg L^{-1})$       | Date   | $(mg L^{-1})$ | Date   | $(mg L^{-1})$ | Date   | (mg L <sup>-1</sup> ) | Date               | $(mg L^{-1})$ |  |
| 1-Jan  | 2.4                 | 10-Feb | 3.6           | 22-Mar | 0.98          | 1-May  | 1.36                  | 10-Jun             | 1.58          |  |
| 2-Jan  | : 1.46              | 11-Feb | 3.6           | 23-Mar | 2.2           | 2-May  | 1.18                  | 11-Jun             | 1.46          |  |
| 3-Jan  | 1.02                | 12-Feb | 4.2           | 24-Mar | 1.34          | 3-May  | 0.84                  | 12-Jun             | 0.7           |  |
| 4-Jan  | 1.1                 | 13-Feb | 4.2           | 25-Mar | 1.12          | 4-May  | 0.66 <sup>-</sup>     | 13-Jun             | 2.4           |  |
| 5-Jan  | 1.12                | 14-Feb | 22            | 26-Mar | 1.04          | 5-May  | 0.68                  | 14-Jun             | 1.72          |  |
| 6-Jan  | 1.16                | 15-Feb | 8             | 27-Mar | 0.72          | 6-May⇔ | 0.82                  | -15-Jun            | 1.14          |  |
| 7-Jan  | 1.42                | 16-Feb | 3.1           | 28-Mar | 0.82          | 7-May  | 0.78                  | 16-Jun             | 2.6           |  |
| 8-Jan  | 0.98                | 17-Feb | 3 ·           | 29-Mar | 1.22          | 8-May  | 0.88                  | 17-Jun             | 1.28          |  |
| 9-Jan  | 0.92                | 18-Feb | 1.26          | 30-Mar | 2.4           | 9-May  | 2                     | 18-Jun             | 2.8           |  |
| 10-Jan | 0.82                | 19-Feb | 1.22          | 31-Mar | 1.6           | 10-May | <b>2</b> +c           | 19-Jun             | 0.74          |  |
| 11-Jan | 0.78                | 20-Feb | 0.8           | 1-Apr  | 1.5           | 11-May | 2.2                   | 20-Jun             | 1.06          |  |
| 12-Jan | 1.28                | 21-Feb | 1.14          | 2-Apr  | 0.88          | 12-May | 5                     | 21-Jun             | 1.14          |  |
| 13-Jan | 1.08                | 22-Feb | 1.02          | 3-Apr  | 2             | 13-May | 2.2                   | 22-Jun             | 2.2           |  |
| 14-Jan | 0.78                | 23-Feb | 2.6           | 4-Apr  | 1.2           | 14-May | 1                     | 23-Jun             | 1.8           |  |
| 15-Jan | 1.08                | 24-Feb | 1.36          | 5-Apr  | 1.08          | 15-May | 0.88                  | 24-Jun             | 1.02          |  |
| 16-Jan | 0.68                | 25-Feb | 2             | 6-Apr  | 0.9           | 16-May | 1.3 : .               | ·25-Jun            | 0.76          |  |
| 17-Jan | 2                   | 26-Feb | 0.96          | 7-Apr  | 1.24          | 17-May | 0.82                  | :26-Jun            | 0.78          |  |
| 18-Jan | 0.94                | 27-Feb | 1.38          | 8-Apr  | 1.8           | 18-May | 2.2                   | 27-Jun             | 2             |  |
| 19-Jan | 1.1                 | 28-Feb | 3.8           | 9-Apr  | 1             | 19-May | 2.4 .                 | 28-Jun             | 2.2           |  |
| 20-Jan | 0.48                | 1-Mar  | 2.2           | 10-Apr | 1.28          | 20-May | 0 <b>.</b> 96 ;       | 29-Jun             | 1.06          |  |
| 21-Jan | 1.42                | 2-Mar  | 1.34          | 11-Apr | 3.8           | 21-May | 1.2                   | 30-Jun             | 3             |  |
| 22-Jan | 2.6                 | 3-Mar  | 3.2           | 12-Apr | 4.6           | 22-May | <b>3</b> (            | 1-Jul              | . 1.24        |  |
| 23-Jan | 0.9                 | 4-Mar  | 2.2           | 13-Apr | 6.4           | 23-May | 1.38                  | 2-Jul              | 0.9           |  |
| 24-Jan | 1.08                | 5-Mar  | 1.06          | 14-Apr | 4.4           | 24-May | <b>2</b> · .          | 3-Jul              | 0.6           |  |
| 25-Jan | 0.74                | 6-Mar  | 1.14          | 15-Apr | 2             | 25-May | 3                     | 4-Jul              | 2             |  |
| 26-Jan | 0.9                 | .7-Mar | 0.84          | 16-Apr | 2.2           | 26-May | 1.24                  | ี 5-Jul            | 1             |  |
| 27-Jan | 0.82                | 8-Mar  | 0.66          | 17-Apr | 0.78          | 27-May | 1.6                   | <sup>-</sup> 6-Jul | 1.62          |  |
| 28-Jan | 2.8                 | 9-Mar  | 0.98          | 18-Apr | . 2.2         | 28-May | 2.2                   | 7-Jul              | 0.8           |  |
| 29-Jan | 0.92                | 10-Mar | 0.76          | 19-Apr | · 2.4         | 29-May | 1.2                   | 1 8-Jul            | 0.94          |  |
| 30-Jan | 0.6                 | 11-Mar | 0.8           | 20-Apr | 16            | 30-May | 0.76                  | 9-Jul              | 0.7           |  |
| 31-Jan | 0.66                | 12-Mar | 4             | 21-Apr | 3.8           | 31-May | 2                     | 10-Jul             | 0.68          |  |
| 1-Feb  | 4                   | 13-Mar | 1.28          | 22-Apr | 2.4           | 1-Jun  | 2.2                   | 11-Jul             | • 0.82        |  |
| 2-Feb  | <b>3</b> .          | 14-Mar | 1.06          | 23-Apr | 1.54          | 2-Jun  | 1.04                  | [ 12-Jul           | 0.88          |  |
| 3-Feb  | <b>3.2</b>          | 15-Mar | 1.04          | 24-Apr | 3.6           | 3-Jun  | 1.46                  | 13-Jul             | 2.4           |  |
| 4-Feb  | 3.8                 | 16-Mar | 0.88          | 25-Apr | · <b>2</b>    | 4-Jun  | 0.86                  | 14-Jul             | 0.96          |  |
| 5-Feb  | 1 1                 | 17-Mar | 1,46          | 26-Apr | 2.8           | 5-Jun  | 0.84                  | 15-Jul             | 0.58          |  |
| 6-Feb  | 2.2                 | 18-Mar | 2             | 27-Apr | ~ <b>3</b>    | 6-Jun  | 136                   | 16-Jul             | 0.76          |  |
| 7-Feb  | 3.8                 | 19-Mar | 1.6           | 28-Apr | 5.8           | 7-Jun' | <b>10.2</b>           | 17-Jul             | 0.76          |  |
| 8-Feb  | 4.6                 | 20-Mar | ·~1.7 '       | 29-Apr | 1.32          | 8-Jun  | <b>3.6</b>            | 18-Jul             | 0.52          |  |
| '9-Feb | 3                   | 21-Mar | <b>2.2</b>    | 30-Apr | 1.2           | 9-Jun  | 2                     | 19-Jul             | 0.82          |  |

#### Table L1-11A. centrations Measured at TI

.

(Continued on next page) . . .

...

.....

.

·...

Page L-97

|        | Manhole 175 in 1966 (cont'd) |                     |                    |        |               |         |               |  |  |  |
|--------|------------------------------|---------------------|--------------------|--------|---------------|---------|---------------|--|--|--|
| 1966   | Uja                          | 1966                | Ua                 | 1966   | Ua            | 1966    | Ua.           |  |  |  |
| Date   | $(mg L^{-1})$                | Date                | $(m\sigma L^{-1})$ | Date   | $(mg L^{-1})$ | Date    | $(mg L^{-1})$ |  |  |  |
| 20-Jul | 1.18                         | 29-Aug              | 0.78               | 8-Nov  | 2             | 17-Dec  | 0.52          |  |  |  |
| 21-Jul | 1.1                          | 30-Aug              | 1                  | 9-Nov  | 1.26          | 18-Dec  | 0.58          |  |  |  |
| 22-Jul | 0.78                         | 31-Aug              | 0.68               | 10-Nov | .0.88         | 19-Dec  | 0.6           |  |  |  |
| 23-Jul | 4.8                          | 1-Sep               | 0.68 ·             | 11-Nov | 1.22          | 20-Dec  | 0.5           |  |  |  |
| 24-Jul | 2                            | 2-Sep               | 0.68               | 12-Nov | 0.74          | 21-Dec  | 0.82          |  |  |  |
| 25-Jul | 0.7                          | 3-Sep               | . 2.2              | 13-Nov | 0.4           | 22-Dec  | 0.94          |  |  |  |
| 26-Jul | 0.64                         | 4-Sep               | 1.4                | 14-Nov | 0.92          | 23-Dec  | 0.88          |  |  |  |
| 27-Jul | 0.54                         | 5-Sep               | 0.72               | 15-Nov | 1.24          | 24-Dec  | 0.76          |  |  |  |
| 28-Jul | 0.8                          | 6-Sep               | 1.8                | 16-Nov | 1.06          | 25-Dec  | 0.74          |  |  |  |
| 29-Jul | 0.54                         | 7-Sep               | 0.92 ·             | 17-Nov | 0.98          | 26-Dec  | 3.2           |  |  |  |
| 30-Jul | 0.56                         | 8-Sep               | . 0.7              | 18-Nov | 0.9           | 27-Dec  | 2.2           |  |  |  |
| 31-Jul | 0.58                         | 9-Sep               | 1.12               | 19-Nov | 1.34          | 28-Dec  | 5.2           |  |  |  |
| 1-Aug  | 0.72                         | 10-Sep              | 1.04               | 20-Nov | 0.86          | 29-Dec  | <b>5.6</b>    |  |  |  |
| 2-Aug  | <b>80</b> · ·                | 11-Sep              | 3.4                | 21-Nov | 0.9           | 30-Dec  | 3 .           |  |  |  |
| 3-Aug  | 10                           | 12-Sep              | 0.72               | 22-Nov | 0.88          | 31-Dec  | 2.2           |  |  |  |
| 4-Aug  | 5.6                          | · 13-Sep            | 0.84               | 23-Nov | 2.4           |         | •             |  |  |  |
| 5-Aug  | 5.2                          | 14-Sep              | 1.06               | 24-Nov | 0.86          |         |               |  |  |  |
| 6-Aug  | 3                            | 15-Sep              | 2.4                | 25-Nov | 2.8           |         |               |  |  |  |
| 7-Aug  | 2.8                          | 16-Sep              | 1.26               | 26-Nov | 2.6           | -       |               |  |  |  |
| 8-Aug  | 2.6                          | 17-Sep              | 1.6                | 27-Nov | 2             | -       |               |  |  |  |
| 9-Aug  | 1.48                         | 18-Sep              | 1.46               | 28-Nov | 2.4           |         |               |  |  |  |
| 10-Aug | 2.2                          | 19-Sep              | 2.8                | 29-Nov | 2             |         |               |  |  |  |
| 11-Aug | 5.8                          | 20-Sep              | 2.8                | 30-Nov | 22            |         |               |  |  |  |
| 12-Aug | 4.4                          | 21-Sep              | 2.2                | 1-Dec  | 2.8           |         |               |  |  |  |
| 13-Aug | 3                            | 22-Sep              | 1.04               | 2-Dec  | 1.38          |         |               |  |  |  |
| 14-Aug | 2.8                          | 23-Sep              | 1.08               | 3-Dec  | 1.14          |         |               |  |  |  |
| 15-Aug | 2.4                          | 24-Sep              | 1.36               | 4-Dec  | 0.78          | •       |               |  |  |  |
| 16-Aug | 2.6                          | 25-Sep              | 3.6                | 5-Dec  | 2.4           |         |               |  |  |  |
| 17-Aug | 0.9                          | 26-Sep              | 2.2                | 6-Dec  | 0.82          | •       | •             |  |  |  |
| 18-Aug | 2.2                          | 27-Sep              | 2.6                | 7-Dec  | 3.2           |         |               |  |  |  |
| 19-Aug | 1.36                         | <sup>-</sup> 28-Sep | 2.2                | 8-Dec  | 2.4           |         |               |  |  |  |
| 20-Aug | 1.34                         | 29-Sep              | 1.34               | 9-Dec  | 0.96          |         |               |  |  |  |
| 21-Aug | 2.2                          | 30-Sep              |                    | 10-Dec | 0.64          |         |               |  |  |  |
| 22-Aug | 2.2                          | 1-Nov               | 4.6                | 11-Dec | 1.16          |         |               |  |  |  |
| 23-Aug | 2                            | 2-Nov               | 3.6                | 12-Dec | 0.44          |         |               |  |  |  |
| 24-Aug | 1.4                          | 3-Nov               | 2.6                | 13-Dec | 0.74          |         |               |  |  |  |
| 25-Aug | 2                            | 4-Nov               | 3.2                | 14-Dec | 0.84          | Average | 2.6           |  |  |  |
| 26-Aug | 1.56                         | 5-Nov               | 3.8                | 15-Dec | 0.56          | StdDev  | 8.8           |  |  |  |
| 27-Aug | 0.9                          | 6-Nov               | 2.2                | 16-Dec | 0.58          | Max     | 136           |  |  |  |
| 28-Aug | 0.62                         | 7-Nov               | 2.2                | 17-Dec | 0.52          | Min     | 0.4           |  |  |  |

### 4 ... $\mathbf{T}_{\mathbf{n}}$

<sup>a</sup> From NLCO 1966, analytical data sheets from the Bioassay Department at the FMPC.

.

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

•••

8

• • • • •

(Altra):

. . .

がくくいたい

Provide Concerna

51.1.1.1.1

BUAND .

| Manhole 175 in 1967 |                |        |                  |                            |                          |          |                |  |  |
|---------------------|----------------|--------|------------------|----------------------------|--------------------------|----------|----------------|--|--|
| Date                | Uª             | Date   | U <sup>a</sup> . | Date U <sup>a</sup>        | Date U <sup>a</sup>      | Date     | U <sup>a</sup> |  |  |
| 1967                | $(mg L^{-1})$  | 1967   | $(mg L^{-1})$    | 1967 (mg L <sup>-1</sup> ) | 1967 (mg L <sup>-1</sup> | 1967     | $(mg L^{-1})$  |  |  |
| i-Jan               | 1.2            | 11-Feb | 1.2              | 24-Mar: () 1.52            | 4-May 2.4                | -14-Jun  | 0.94           |  |  |
| 2-Jan               | 1.38           | 12-Feb | 0.6              | 25-Mar 👌 1                 | 5-May 0.86               | 15-Jun   | 3              |  |  |
| 3-Jan               | 0.84           | 13-Feb | 0.52             | 26-Mar 👌 1.14              | 6-May 3                  | 16-Jun   | 1.6            |  |  |
| 4-Jan               | 1.08           | 14-Feb | 0.66             | 27-Mar 2.8                 | 7-May 2.6                | 17-Jun   | 1.4            |  |  |
| 5-Jan               | 2.2            | 15-Feb | 2.8              | 28-Mar 2.8                 | 8-May 2.2                | 18-Jun   | 0.74           |  |  |
| 6-Jan               | 0.74           | 16-Feb | 2.2              | 29-Mar 1.24                | 9-May 1.32               | 19-Jun   | 1.14           |  |  |
| 7-Jan               | 2.4            | 17-Feb | 1.06 🕔           | 30-Mar 1.22                | 10-May 2                 | 20-Jun   | 0.84           |  |  |
| ' 8-Jan             | 0.82 ·         | 18-Feb | 0.88             | 31-Mar 0.42                | 11-May 3                 | 21-Jun   | 3              |  |  |
| 9-Jan               | 0.98           | 19-Feb | 0.9              | 1-Apr 2 g                  | 12-May 1.1               | 22-Jun   | 2.2            |  |  |
| 10-Jan              | 0.8            | 20-Feb | 1.26             | 2-Apr : 0.96               | 13-May 2                 | 23-Jun   | 0.98           |  |  |
| 11-Jan              | 0.32           | 21-Feb | · 0.62 ·         | 3-Apr 2.4                  | 14-May 2.8               | 24-Jun   | 0.98           |  |  |
| 12-Jan              | 2 : 2          | 22-Feb | 1.2              | 4-Apr 2.6                  | 15-May 1.76              | 25-Jun   | 1.02           |  |  |
| 13-Jan              | . 0.74         | 23-Feb | 0.94             | 5-Apr 3                    | 16-May 1.36              | 26-Jun   | 0.86           |  |  |
| 14-Jan              | 0.76           | 24-Feb | 1.26             | 6-Apr 2.2                  | 17-May 2.6               | 27-Jun   | 1.18           |  |  |
| 15-Jan              | 0.5            | 25-Feb | 0.78             | 7-Apr 1.48                 | 18-May 2.4               | 28-Jun   | 2.8            |  |  |
| 16-Jan              | 1.2            | 26-Feb | 0.76             | 8-Apr 1.24                 | 19-May 2.2               | 29-Jun   | 2.6            |  |  |
| 17-Jan              | 1.08           | 27-Feb | 3.2              | 9-Apr 1.3                  | 20-May 0.62              | 30-Jun   | 1.2            |  |  |
| 18-Jan              | 0.44           | 28-Feb | 1.38             | 10-Apr 1.04                | 21-May 0.76              | 1-Jul    | 1.36           |  |  |
| 19-Jan              | 0.98           | 1-Mar  | 1.52             | 11-Apr 0.58                | 22-May 0.98              | 2-Jul    | · 1.22         |  |  |
| 20-Jan              | 1.22           | 2-Mar  | 2.2              | 12-Apr   0.88              | 23-May 2.2               | 3-Jul    | 0.66           |  |  |
| 21-Jan              | 0.76           | 3-Mar  | 3.2              | 13-Apr 3.4                 | 24-May 1.02              | 4-Jul    | 1.24           |  |  |
| 22-Jan              | 1.24           | 4-Mar  | 6.2              | 14-Apr. 1.22               | 25-May 1.02              | 5-Jul    | 0.92           |  |  |
| 23-Jan              | 1.8            | 5-Mar  | 5.6              | 15-Apr 1.08                | 26-May 2.4               | 6-Jul    | 1.34           |  |  |
| 24-Jan              | 4 .            | 6-Mar  | 3.4              | 16-Apr 0.34                | 27-May 1.42              | 7-Jul    | 0.94           |  |  |
| 25-Jan              | 2.4            | 7-Mar  | 3                | 17-Apr 2.2                 | 28-May 1.24              | 8-Jul    | 0.88           |  |  |
| 26-Jan              | 3.4            | 8-Mar  | 1.22             | 18-Apr 1.28                | 29-May 1.42              | 9-Jul    | 1.4            |  |  |
| 27-Jan              | 2.6            | 9-Mar  | 2                | 19-Apr 1.1                 | 30-May 1.12              | 10-Jul   | 2              |  |  |
| 28-Jan              | 2.4            | 10-Mar | 1 4              | 20-Apr 1.42                | 31-May 0.74              | 11-Jul   | 0.74           |  |  |
| 29-Jan              | 0.5            | 11-Mar | 1.4 ·            | .21-Apr 8 3                | 1-Jun 1.08               | -12-Jul  | . 0.94         |  |  |
| 30-Jan              | 0.76           | 12-Mar | 1.32             | 22-Apr 0.74                | 2-Jun 1.36               | 13-Jul   | 0.62           |  |  |
| 31-Jan              | 1.3            | 13-Mar | 1.8              | 23-Apr 1.12                | 3-Jun 🖾 3 💡              | 14-Jul   | 1              |  |  |
| 1-Feb               | 2.4            | 14-Mar | 2.6              | 24-Apr 1.36                | 3-Jan 1.14               | 15-Jul   | 1.2            |  |  |
| 2-Feb               | 1.72           | 15-Mar | 3.4              | 25-Apr. 1.62               | 5-Jun 0.78               | 16-Jul   | 1.2            |  |  |
| 3-Feb               | 0.96           | 16-Mar | 1.6              | 26-Apr 3.4                 | 6-Jun 0.9                | 17-Jul   | 2.2            |  |  |
| 4-Feb               | 0.84           | 17-Mar | 0.98 J           | 27-Apr) 1.64               | 7-Jun 0.88               | 18-Jul   | 1.8            |  |  |
| 5-Feb               | 1.22           | 18-Mar | 2                | 28-Apr 1.3                 | 8-Jun 1.14               | · 19-Jul | 2.2            |  |  |
| 6-Feb               | <b>0.68</b> .: | 19-Mar | 1.8              | 29-Apr 2.4                 | 9-Jun 🖂 1.12             | 20-Jul   | 2.4            |  |  |
| 7-Feb               | 0.82           | 20-Mar | 4                | 30-Apr 2.8                 | 10-Jun 😳 1.04 :          | 21-Jul   | 1.3            |  |  |
| 8-Feb               | 1.04           | 21-Mar | 3.4              | 1. 1. May 2.2              | 11-Jun 0.76              | 22-Jul   | 0.84           |  |  |
| 9-Feb               | 1.12           | 22-Mar | 2.6              | 2-May 2.4                  | 12-Jun 1.04              | 23-Jul   | 0.78           |  |  |
| 10-Feb              | · 1.08         | 23-Mar | 0.92             | 3-May 0.9                  | 13-Jun 1.08              | 24-Jul   | 1.1            |  |  |

| Table L1–12A. Ur | anium Concentrations Measured at |
|------------------|----------------------------------|
|                  | Janhola 175 in 1967              |

(Continued on next page)

..

i

Page L-99

|             | i i          | <b>a</b> <sup>*</sup> |          |     |
|-------------|--------------|-----------------------|----------|-----|
| Table L1-12 | B. Uranium ( | Concentrations        | Measured | at. |
|             |              |                       |          |     |

| Manhole 175 in 1967 (cont'd) |                       |                     |                       |          |                       |         |                       |  |  |
|------------------------------|-----------------------|---------------------|-----------------------|----------|-----------------------|---------|-----------------------|--|--|
| Date                         | . Ua                  | Date                | : U <sup>a</sup>      | Date     | Uª                    | Date    | Ua                    |  |  |
| 1967                         | (mg L <sup>-1</sup> ) | 1967                | (mg L <sup>-1</sup> ) | 1967     | (mg L <sup>-1</sup> ) | 1967    | (mg L <sup>-1</sup> ) |  |  |
| 25-Jul                       | 1                     | · 4-Sep             | 0.52                  | 15-Oct   | 0.9                   | 25-Nov  | 2                     |  |  |
| 26-Jul                       | · 1                   | 5-Sep               | 0.58                  | 16-Oct   | 0.92                  | 26-Nov  | 0.9                   |  |  |
| 27-Jul                       | 0.7                   | 6-Sep               | 0.74                  | 17-Oct   | 3                     | 27-Nov  | 0.92                  |  |  |
| 28-Jul                       | 0.02                  | 7-Sep               | 0.64                  | 18-Oct   | 0.76                  | 28-Nov  | 2.2                   |  |  |
| 29-Jul                       | 0.08                  | 8-Sep               | 1.4                   | 19-Oct   | 0.48                  | 29-Nov  | 2.4                   |  |  |
| -30-Jul                      | 0.1                   | 9-Sep               | 1.34                  | 20-Oct ( | 1.26                  | 30-Nov  | 5.6                   |  |  |
| 31-Jul                       | 0.98                  | 10-Sep              | 0.54                  | 21-Oct   | 0.8                   | 1-Dec   | 4                     |  |  |
| . 1-Aug                      | 0.48                  | 11-Sep              | 0.52                  | 22-Oct   | 0.52                  | 2-Dec   | 3.6                   |  |  |
| · 2-Aug                      | 0.74                  | 12-Sep              | 2                     | 23-Oct   | 0.76                  | 3-Dec   | 2.6                   |  |  |
| 3-Aug                        | 0.8                   | 13-Sep              | 1.2                   | 24-Oct   | 1.24                  | 4-Dec   | 2.8                   |  |  |
| 4-Aug                        | 5.6                   | 14-Sep              | 0.58                  | 25-Oct   | 1.6                   | 5-Dec   | 1.6                   |  |  |
| 5-Aug                        | 0.7                   | 15-Sep              | 1.28                  | 26-Oct   | 2.2                   | 6-Dec   | 1.6                   |  |  |
| 6-Aug                        | 0.88                  | 16-Sep              | 1.12                  | 27-Oct   | 2.4                   | 7-Dec   | 1.56                  |  |  |
| 7-Aug                        | 0.46                  | 17-Sep              | 1.16                  | 28-Oct   | 3.4                   | 8-Dec   | 0.94                  |  |  |
| 8-Aug                        | 0.64                  | 18-Sep              | 0.88                  | 29-Oct   | 1.02                  | 9-Dec   | 2.8                   |  |  |
| 9-Aug                        | 1.4                   | 19-Sep              | 2.4                   | 30-Oct   | 0.84                  | 10-Dec  | 4                     |  |  |
| 10-Aug                       | 0.78                  | 20-Sep              | 1.34                  | 31-Oct   | 4                     | 11-Dec  | 3.6                   |  |  |
| 11-Aug                       | 0.86                  | 21-Sep              | 2                     | · 1-Nov  | 3.4                   | 12-Dec  | 3                     |  |  |
| 12-Aug                       | 0.52                  | 22-Sep              | 2.2                   | 2-Nov    | 2.2                   | 13-Dec  | 1.02                  |  |  |
| 13-Aug                       | 0.58                  | 23-Sep              | 1.8                   | 3-Nov    | 0.82                  | 14-Dec  | 6.6                   |  |  |
| 14-Aug                       | 0.8                   | 24-Sep              | 3                     | 4-Nov    | 0.72                  | 15-Dec  | 2.8                   |  |  |
| 15-Aug                       | 0.6                   | 25-Sep              | 0.68                  | 5-Nov    | 0.76                  | 16-Dec. | 1.44                  |  |  |
| 16-Aug                       | 0.92                  | 26-Sep              | 1.22                  | 6-Nov    | 0.52                  | 17-Dec  | 2.2                   |  |  |
| 17-Aug                       | 2.4                   | 27-Sep              | 3                     | 7-Nov    | 0.88                  | 18-Dec  | 3.2                   |  |  |
| 18-Aug                       | 1.42 <sup>-</sup>     | 28-Sep              | 1.38                  | 8-Nov    | 1.26                  | 19-Dec  | 1.56                  |  |  |
| 19-Aug                       | .1.54                 | <sup>•</sup> 29-Sep | 1.06                  | 9-Nov    | 0.74                  | 20-Dec  | 3.2                   |  |  |
| 20-Aug                       | 0.84                  | 30-Sep              | 0.78                  | 10-Nov   | 1.02                  | 21-Dec  | 1.58                  |  |  |
| 21-Åug                       | 0.66                  | 1-Oct               | 0.74                  | 11-Nov   | 3                     | 22-Dec  | 2.2                   |  |  |
| 22-Aug                       | 0.6                   | 2-Oct               | 0.58                  | 12-Nov   | 1.4                   | 23-Dec  | 1.02                  |  |  |
| 23-Aug                       | 1.42                  | 3-Oct               | 0.42                  | 13-Nov   | 0.76                  | 24-Dec  | 0.58                  |  |  |
| 24-Aug                       | 1.38                  | 4-Oct               | 0.9                   | 14-Nov.  | 0.84                  | 25-Dec  | 0.58                  |  |  |
| 25-Aug                       | 1.8                   | 5-Oct               | 1.04                  | 15-Nov   | 2.4                   | 26-Dec  | 0.32                  |  |  |
| 26-Aug                       | 0.48                  | 6-Oct               | 3                     | 16-Nov   | 1.12                  | 27-Dec  | 0.52                  |  |  |
| 27-Aug                       | 1.1                   | 7-Oct               | 1.14                  | 17-Nov   | 4.4                   | 28-Dec  | 0.62                  |  |  |
| 28-Aug                       | 0.84                  | 8-Oct               | 1.06                  | 18-Nov   | 1.08                  | 29-Dec  | 1.32                  |  |  |
| 29-Aug                       | 1.12                  | 9-Oct               | 0.94                  | 19-Nov   | 0.9                   | 30-Dec  | 1.02                  |  |  |
| 30-Aug                       | 0.64                  | 10-Oct              | 1.16                  | 20-Nov   | 1.14                  | 31-Dec  | 2.4                   |  |  |
| 31-Aug                       | 0.9                   | 11-Oct              | 0.54                  | 21-Nov   | 0.46                  | Average | 1.5                   |  |  |
| 1-Sep                        | 0.54                  | 12-Oct              | 0.98                  | 22-Nov   | 1.6                   | StdDev  | 1.0                   |  |  |
| 2-Sep                        | . <b>0.24</b>         | 13-Oct              | 1:                    | 23-Nov   | 0.9                   | Max     | 6.6                   |  |  |
| 3-Sep                        | 0.2                   | 14-Oct              | 0.38                  | 24-Nov   | 1.4                   | Min     | . 0.02                |  |  |

<sup>a</sup> From NLCO 1967, analytical data sheets from the Bioassay Department at the FMPC.

# Radiological Assessments Corporation

"Setting the standard in environmental health"

### Page L-100 .

.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

| Manbole 175 in 1969 |                |        |                       |          |                         |        |               |          |               |
|---------------------|----------------|--------|-----------------------|----------|-------------------------|--------|---------------|----------|---------------|
| 1969                | Ua             | 1969   | Ua .                  | 1969     | Ua                      | 1969   | Ua            | 1969     | Uª            |
| Date                | $(mg L^{-1})$  | Date   | (mg L <sup>-1</sup> ) | Date     | $mg L^{-1}$             | Date   | $(mg L^{-1})$ | Date     | $(mg L^{-1})$ |
| 1-Jan               | 18             | 11-Feb | 2.8                   | 23-Mar 👾 | -1.28 -                 | 6-May  | - 0.94        | 18-Jun   | 0.96          |
| 2-Jan               | 4 <sup>·</sup> | 12-Feb | 2.2                   | 24-Mar   | 4.2                     | 7-May  | 3.8           | 19-Jun   | 0.8           |
| 3-Jan               | 2.6            | 13-Feb | 2.2                   | 25-Mar   | 2.8                     | 8-May  | 4.4           | 20-Jun   | 0.98          |
| 4-Jan               | 2.4            | 14-Feb | 1.04                  | 26-Mar   | 2                       | 9-May  | 2.8           | 21-Jun   | 1.1           |
| 5-Jan               | 3              | 15-Feb | 3                     | 28-Mar   | 2.6                     | 10-May | 2.2           | 22-Jun   | 1.5           |
| 6-Jan               | 2.4            | 15-Feb | 3                     | 29-Mar   | 3                       | 11-May | 1.02          | 23-Jun   | 2.2           |
| 7-Jan               | 2              | 16-Feb | 2.8                   | 30-Mar   | 2.2                     | 12-May | 1.34          | 24-Jun   | 1.6           |
| 8-Jan               | 2.2 (          | 17-Feb | 1.54 ″                | 31-Mar   | 1.1                     | 13-May | 0.92          | 25-Jun   | 2.8           |
| 9-Jan               | 2.4            | 18-Feb | 2.8                   | 1-Apr    | 1.1                     | 14-May | 0.62          | 26-Jun   | 2.2           |
| 10-Jan              | 2.2            | 19-Feb | 5.2                   | 2-Apr    | 2.8                     | 15-May | 0.9           | 27-Jun   | 1.18          |
| 11-Jan              | 2.8            | 20-Feb | 5.6                   | 3-Apr    | 1.32                    | 16-May | 1.38          | 28-Jun   | 1.38          |
| 12-Jan              | 2.2            | 21-Feb | 8.2                   | 4-Apr    | 1.44                    | 17-May | 1.2           | 29-Jun   | 1.16          |
| 13-Jan              | 2.2            | 22-Feb | 5                     | 5-Apr    | 3                       | 18-May | 2.2           | 30-Jun   | 1.28          |
| 14-Jan              | 1.68           | 23-Feb | 3.2                   | 6-Apr    | 2.8                     | 19-May | 0.84          | 1-Jul    | 2.2           |
| 15-Jan              | 1.4            | 24-Feb | 5.8                   | 7-Apr    | 2.6                     | 20-May | 0.98          | 2-Jul    | 1.8           |
| 16-Jan              | 3.4            | 25-Feb | 12.6                  | 8-Apr    | 2.2                     | 21-May | 1.06          | 3-Jul    | <b>2</b> ·    |
| 17-Jan              | 3.8            | 26-Feb | 11                    | 9-Apr    | 3                       | 22-May | 0.98          | 4-Jul    | 2             |
| 18-Jan              | 2.8            | 27-Feb | 10.2                  | 10-Apr   | 2.2                     | 23-May | 1.24          | 5-Jul    | 2             |
| 19-Jan              | 1.34           | 28-Feb | 6.6                   | 11-Apr   | 1.2                     | 24-May | 0.96          | 6-Jul    | 2.2           |
| 20-Jan              | 2.4            | 1-Mar  | 5.4                   | 12-Apr   | 1.12                    | 25-May | 0.42          | ์ 7-Jul  | 2.4           |
| 21-Jan              | 2.4            | 2-Mar  | 2.4                   | 13-Apr   | 0.78                    | 26-May | 1.2           | 8-Jul    | 4.4           |
| 22-Jan              | 2.2            | 3-Mar  | 3.4                   | 14-Apr   | 0.7                     | 27-May | 1.16          | 9-Jul    | 3.2           |
| 23-Jan              | 3.8            | 4-Mar  | 3                     | 15-Apr   | 2.4                     | 28-May | 1.6           | 10-Jul   | 5             |
| 24-Jan              | 2.6            | 5-Mar  | 1.54                  | 16-Apr   | 1.1                     | 29-May | 1.8           | 11-Jul   | 3.6           |
| 25-Jan              | 2.6            | 6-Mar  | 7                     | 17-Apr   | 1.42                    | 30-May | 2.2           | 12-Jul   | 2.4           |
| 26-Jan              | 2.2            | 7-Mar  | 5.6                   | 18-Apr   | 2.2                     | 31-May | 1.6           | 13-Jul   | 3             |
| 27-Jan              | 1.48           | 8-Mar  | 4.6                   | 19-Apr   | 3                       | 2-Jun  | 1.8           | 14-Jul   | 2.2           |
| 28-Jan              | 3.2            | 9-Mar  | 2.6                   | 20-Apr   | 2.2                     | 3-Jun  | 1.04          | 15-Jul   | 2             |
| 29-Jan              | · 2.2          | 10-Mar | 3.8                   | 22-Apr   | 1.42                    | 4-Jun  | 2.8           | 16-Jul   | 2.2           |
| 30-Jan              | 2              | 11-Mar | 4                     | 23-Apr   | 1.3                     | 5-Jun  | 0.88          | 18-Jul   | 1.44          |
| 31-Jan              | 3.2            | 12-Mar | 4                     | 24-Apr   | 1.1                     | 6-Jun  | 1.42          | 19-Jul   | 3.2           |
| 1-Feb               | 2.8            | 13-Mar | 4                     | 25-Apr   | 2                       | 7-Jun  | 1.16          | 20-Jul   | 3.4           |
| 2-Feb               | 2.8            | 14-Mar | 2.6                   | 26-Apr   | 1.14                    | 8-Jun  | 0.74          | 21-Jul   | 3.2           |
| 3-Feb               | 2.4            | 15-Mar | 2                     | 27-Apr   | 1.22                    | 9-Jun  | 0.86          | 22-Jul   | 2             |
| 4-Feb               | 2.4            | 16-Mar | 2.4                   | 28-Apr   | 0.8                     | 10-Jun | 0.72          | 23-Jul   | 2.2           |
| 5-Feb               | 1.04           | 17-Mar | 3.8                   | 29-Apr   | 0.44                    | 12-Jun | 5.2           | 24-Jul   | 2.2           |
| 6-Feb               | 2.4            | 18-Mar | 3.2                   | 1-May    | 2.8                     | 13-Jun | 2.8           | 25-Jul   | 8.2           |
| 7-Feb               | 2.2            | 19-Mar | 3                     | 2-May    | ( <b>1</b> )            | 14-Jun | 3.2           | 26-Jul   | 8.4           |
| 8-Feb               | 1.28           | 20-Mar | 2.2                   | 3-May    | 0.7                     | 15-Jun | 2.6           | 27-Jul   | 4             |
| 9-Feb               | 2.6            | 21-Mar | 1.58                  | 4-May    | 0.54                    | 16-Jun | 2             | 28-Jul   | 5.2           |
| 10-Feb              | 2.6            | 22-Mar | 2.6                   | 5-May    | <b>0.9</b> <sup>1</sup> | 17-Jun | 1.16          | , 29-Jul | 2.4           |

Table L1-13A. Uranium Concentrations Measured at

. . . . .

(Continued on next page)

No. Contractor

Page L-101 .

|        | Manhole 175 in 1969 (cont'd) |        |                       |        |                |         |               |  |  |
|--------|------------------------------|--------|-----------------------|--------|----------------|---------|---------------|--|--|
| 1969   | Ua                           | 1969   | U <sup>a</sup>        | 1969   | U <sup>a</sup> | 1969    | Ua            |  |  |
| Date   | $(mg L^{-1})$                | Date   | (mg L <sup>-1</sup> ) | Date   | $(mg L^{-1})$  | Date    | $(mg L^{-1})$ |  |  |
| 30-Jul | 2.2                          | 14-Sep | 0.38                  | 27-Oct | 1.42           | 7-Dec   | 2.6           |  |  |
| 31-Jul | 1.16                         | 15-Sep | 0.94                  | 28-Oct | 1.42           | 8-Dec   | 3.4           |  |  |
| 1-Aug  | 2                            | 16-Sep | 1.06                  | 29-Oct | 1.38           | 9-Dec   | 4.6           |  |  |
| 2.Aug  | 2.2                          | 17-Sep | 1.42                  | 30-Oct | 1.24           | 10-Dec  | 3             |  |  |
| 3-Aug  | 3                            | 18-Sep | 0.78                  | 31-Oct | 1.36           | 11-Dec  | 2             |  |  |
| 4-Aug  | 2.8                          | 19-Sep | 0.78                  | 1-Nov  | 2.6            | 12-Dec  | 0.9           |  |  |
| 5-Aug  | 3.2                          | 20-Sep | 2.2                   | 2-Nov  | 2.2            | 13-Dec  | 0.72          |  |  |
| 6-Aug  | 1.54                         | 21-Sep | 0.76                  | 3-Nov  | 1.24           | 14-Dec  | 1.24          |  |  |
| 7-Aug  | 2.2                          | 22-Sep | 0.5                   | 4-Nov  | 3              | 15-Dec  | 1.4           |  |  |
| 8-Aug  | 3.2                          | 23-Sep | 0.9                   | 5-Nov  | 1.36           | 16-Dec  | 1.36          |  |  |
| 9-Aug  | 3.8                          | 24-Sep | 0.88                  | 6-Nov  | 2.2            | 17-Dec  | 2             |  |  |
| 10-Aug | 2                            | 25-Sep | 0.74                  | 7-Nov  | ·3.6           | 18-Dec  | 3.2           |  |  |
| 11-Aug | 1.32                         | 27-Sep | 2.2                   | 8-Nov  | 3              | 19-Dec  | 2.8           |  |  |
| 12-Aug | 3                            | 28-Sep | 1.16                  | 9-Nov  | 2.2            | 20-Dec  | 2.4           |  |  |
| 13-Aug | 4.4                          | 29-Sep | 0.64                  | 10-Nov | 0.72           | 21-Dec  | 4.6           |  |  |
| 14-Aug | 1                            | 30-Sep | 0.58                  | 11-Nov | 0.98           | 22-Dec  | 3             |  |  |
| 15-Aug | 1.08                         | 1-Oct  | 1                     | 12-Nov | 2.4            | 23-Dec  | 2.4           |  |  |
| 16-Aug | 1.32                         | 2-Oct  | 0.92                  | 13-Nov | 4              | 24-Dec  | 3.4           |  |  |
| 17-Aug | 1.26                         | 3-Oct  | 1.24                  | 14-Nov | 1.3            | 25-Dec  | 2.2           |  |  |
| 18-Aug | 2.2                          | 4-Oct  | 1.24                  | 15-Nov | 0.8            | 26-Dec  | 1.34          |  |  |
| 19-Aug | 3.2                          | 6-Oct  | 1.06                  | 16-Nov | 0.9            | 27-Dec  | 2.2           |  |  |
| 20-Aug | 0.7                          | 7-Oct  | 1.04                  | 17-Nov | 3              | 28-Dec  | 1.16          |  |  |
| 21-Aug | 0.7                          | 8-Oct  | 0.76                  | 18-Nov | 3.4            | 29-Dec  | 3.6           |  |  |
| 22-Aug | 0.72                         | 9-Oct  | 1.02                  | 19-Nov | -1.12          | 30-Dec  | ·             |  |  |
| 23-Aug | · 1.16 ·                     | 10-Oct | 1.4                   | 20-Nov | 1              | 31-Dec  | 3.6           |  |  |
| 24-Aug | 0.8                          | 11-Oct | 1.8                   | 21-Nov | 1.34           |         |               |  |  |
| 27-Aug | 2                            | 12-Oct | 0.98                  | 22-Nov | 1.06           |         |               |  |  |
| 28-Aug | 1.44                         | 13-Oct | 1.12                  | 23-Nov | 2              |         | •             |  |  |
| 29-Aug | 0.8                          | 14-Oct | · 1.32                | 24-Nov | 0.72           |         |               |  |  |
| 30-Aug | 0.64                         | 15-Oct | 2.2                   | 25-Nov | 2.2            |         |               |  |  |
| 31-Aug | 0.84                         | 16-Oct | 1.3                   | 26-Nov | 2.4            |         |               |  |  |
| 2-Sep  | 3.4                          | 17-Oct | 1.02                  | 27-Nov | 2.6            | •       |               |  |  |
| 3-Sep  | 1.28                         | 18-Oct | 0.68                  | 28-Nov | 2.8            |         |               |  |  |
| 5-Sep  | 1.04                         | 19-Oct | 1.02                  | 29-Nov | 0.9            |         |               |  |  |
| 6-Sep  | 1.5                          | 20-Oct | 0.84                  | 30-Nov | 0.48           |         |               |  |  |
| 7-Sep  | 1.58                         | 21-Oct | 0.92                  | 1-Dec  | 0.44           |         | • •           |  |  |
| 9-Sep  | 1.28                         | 22-Oct | 0.68                  | 2-Dec  | 0.92           | l       |               |  |  |
| 10-Sep | 1.26                         | 23-Oct | 0.58                  | 3-Dec  | 2.2            | Average | 2.21          |  |  |
| 11-Sep | 0.7                          | 24-Oct | 1.2                   | 4-Dec  | 1.22           | StdDev  | 1.76          |  |  |
| 12-Sep | 0.78                         | 25-Oct | 0.86                  | 5-Dec  | 1              | Max     | 18            |  |  |
| 13-Sep | 1.1                          | 26-Oct | 1.2                   | 6-Dec  | 1.26           | Min     | 0.38          |  |  |

..... Table L1-13B in e -

<sup>a</sup> From NLCO 1969, analytical data sheets from the Bioassay Department at the FMPC

**Radiological Assessments Corporation** 

"Setting the standard in environmental health"

.;

÷

18. C

• :.• -

····· (\*\*\*)

••

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

| ·        | Storm Sewer Outfall in 1954 a |                  |                |  |  |  |  |  |  |  |
|----------|-------------------------------|------------------|----------------|--|--|--|--|--|--|--|
| Date     | $U(mg L^{-1})$                | Date             | $U(mg L^{-1})$ |  |  |  |  |  |  |  |
| 6-Jun    | 0.892                         | 15-Aug           | 0.08           |  |  |  |  |  |  |  |
| 6-Jul    | <b>0.064</b>                  | 16-Aug           | 0.15           |  |  |  |  |  |  |  |
| 9-Jul    | 0.112                         | 17-Aug           | 0.037          |  |  |  |  |  |  |  |
| 16-Jul   | <b>0.086</b>                  | 22-Aug           | 0.107          |  |  |  |  |  |  |  |
| 17-Jul   | 0.491                         | 25-Aug           | 0.029          |  |  |  |  |  |  |  |
| 18-Jul   | 2.52                          | 28-Aug           | 0.284          |  |  |  |  |  |  |  |
| ์ 19-Jul | 0.54                          | 🐑 🐘 11-Sep       | 0.214          |  |  |  |  |  |  |  |
| 22-Jul   | .0.1338                       | · 14-Sep         | 0.086          |  |  |  |  |  |  |  |
| 25-Jul   | 0.406                         | 18-Sep           | 0.026          |  |  |  |  |  |  |  |
| 27-Jul   | 0.216                         |                  | 0.083          |  |  |  |  |  |  |  |
| grab     | 4.15                          | 26-Sep           | 0.107          |  |  |  |  |  |  |  |
| 31-Jul   | 0.11                          | 197 <b>2-Oct</b> | 0.064          |  |  |  |  |  |  |  |
| 1-Aug    | 0.026                         | 5-Oct            | 0.091          |  |  |  |  |  |  |  |
| 2-Aug    | 0.134                         | 6-Oct            | 0.112          |  |  |  |  |  |  |  |
| 3-Aug    | 0.139                         | 7-Oct            | 0.299          |  |  |  |  |  |  |  |
| 4-Aug    | . 0.1498                      | 10-Oct           | 0.067          |  |  |  |  |  |  |  |
| 5-Aug    | 0.061                         | 14-Oct           | 0.164          |  |  |  |  |  |  |  |
| 6-Aug    | <b>0.112</b> 1 1              | 18-Oct           | 0.244          |  |  |  |  |  |  |  |
| 7-Aug 🐃  | 0.4815                        | 24-Oct           | 0.564          |  |  |  |  |  |  |  |
| 9-Aug    | 0.075                         |                  | · _ •          |  |  |  |  |  |  |  |
| 11-Aug   | 0.067                         | Avg              | 0.49           |  |  |  |  |  |  |  |
| 12-Aug   | 0.051                         | StdDev           | 0.93           |  |  |  |  |  |  |  |
| 13-Aug   | 0.396                         | Max              | 4.15           |  |  |  |  |  |  |  |
| ·14-Aug  | 0.321                         | Min              | 0.026          |  |  |  |  |  |  |  |

Table L1-14. Uranium Quantities Measured at the

<sup>a</sup> From NLCO 1954; all samples were taken at the storm sewer outfall because the storm sewer lift station was not operational until August 17, 1955.

213

11

. ..1

• • •

1.21.1

÷

21.00

.

100

÷.,

. .

. . . .

Page L-103

|        |                       | 0                     | )utfall ar | d Lift Sta    | ation in 19           | 955     |                       |                       |
|--------|-----------------------|-----------------------|------------|---------------|-----------------------|---------|-----------------------|-----------------------|
| 1955   | U                     | Sample                | . 1955     | U             | Sample                | 1955    | U                     | Sample                |
| Date   | (mg L <sup>-1</sup> ) | Location <sup>a</sup> | Date       | $(mg L^{-1})$ | Location <sup>a</sup> | Date    | (mg L <sup>-1</sup> ) | Location <sup>a</sup> |
| 1-Jan  | 0.887                 |                       | 25-May     | 0.07          |                       | 24-Sep  | 0.773                 | Lift                  |
| 15-Jan | 0.374                 |                       | 30∙May     | 0.284         |                       | 27-Sep  | 0.567                 | Lift                  |
| 18-Jan | 0.927                 |                       | 3-Jun      | 0.586         |                       | 30-Sep  | 0.567                 | Lift                  |
| 21-Jan | 0.25                  |                       | -6-Jun     | 0.634         | ]                     | 6-Oct   | 1.1133                | Lift                  |
| 24-Jan | 0.015                 |                       | 10-Jun     | 0.516         |                       | 9-Oct   | 0.206                 | Lift                  |
| 28-Jan | 0.148                 |                       | 13-Jun     | 0.554         |                       | 12-Oct  | 2.782                 | Lift                  |
| 30-Jan | 0.176                 |                       | 16-Jun     | 0.157         |                       | 15-Oct  | 0.618                 | b                     |
| 2-Feb  | 0.515                 |                       | 19-Jun     | 0.342         |                       | 21-Oct  | 0.31                  | Ь                     |
| 5-Feb  | 0.438                 |                       | 24-Jun     | 0.351         |                       | 24-Oct  | 0.516                 | Lift                  |
| 9-Feb  | 0.309                 |                       | 27-Jun     | 0.115         |                       | 27-Oct  | 0.512                 | Lift                  |
| 12-Feb | 0.297                 | i                     | 30-Jun     | 0.166         |                       | 30-Oct  | 0.824                 | Lift                  |
| 8-Mar  | 0.399                 | l                     | 3-Jul      | 0.39          |                       | 2-Nov   | 1.236                 | Outfall               |
| 13-Mar | 0.204                 |                       | 7-Jul      | 0.293         |                       | 5-Nov   | 0.348                 | Lift                  |
| 16-Mar | 0.375                 |                       | 10-Jul     | 0.412         |                       | 9-Nov   | 0.359                 | Lift                  |
| 19-Mar | 0.361                 |                       | 13-Jul     | 0.29          |                       | 12-Nov  | 0.464                 | Lift                  |
| 24-Mar | 0.121                 |                       | 16-Jul     | 0.251         |                       | 15-Nov  | 0.876                 | Lift                  |
| 27-Mar | 0.158                 |                       | 19-Jul     | 0.193         |                       | 18-Nov  | 0.3                   | b                     |
| 3-Apr  | · 0.5                 |                       | 22-Jul     | 0.068         |                       | 24-Nov  | 0.506                 | Lift                  |
| 6-Apr  | 0.927                 |                       | 25-Jul     | 0.513         | , · ·                 | 27-Nov  | 0.282                 | Lift                  |
| 9-Apr  | 0.148                 |                       | 28-Jul     | 0.261         |                       | 30-Nov  | 1.893                 | Lift                  |
| 12-Apr | 1.334                 |                       | 1-Aug      | 0.361         |                       | 6-Dec   | 0.328                 | D                     |
| 15-Apr | 0.287                 |                       | 4-Aug      | 0.135         |                       | 12-Dec  | 0.366                 | b                     |
| 18-Apr | 0.148                 |                       | 8-Aug      | 0.406         |                       | 15-Dec  | 0.318                 | Lift                  |
| 21-Apr | 0.115                 |                       | 11-Aug     | 0.3           |                       | 18-Dec  | 0.194                 | Lift                  |
| 24-Apr | 0.234                 | • ,                   | 14-Aug     | 0.218         |                       | 21-Dec  | 0.316                 | Lift                  |
| 27-Apr | 0.144                 |                       | 17-Aug     | 0.126         | Lift <sup>a</sup>     | 24-Dec  | 0.176                 | Lift                  |
| 1-May  | 0.172                 |                       | 20-Aug     | 0.361         | Lift                  | 28-Dec  | 0.168                 | Lift                  |
| 7-May  | 0.379                 |                       | 24-Aug     | 0.198         | Outfall               |         |                       |                       |
| 9-May  | 0.168                 |                       | 27-Aug     | 0.329         | Outfall               |         |                       |                       |
| 12-May | 1.327                 |                       | 31-Aug     | 0.242         | Lift                  | Average | 0.43                  |                       |
| 15-May | 0.107                 |                       | 7-Sep      | 0.184         | Lift                  | StdDev  | 0.42                  |                       |
| 18-May | 0.078                 |                       | 10-Sep     | 1.634         | Lift                  | Max     | 2.782                 |                       |
| 21-May | 0.095                 |                       | 21-Sep     | 0.444         | h                     | Min     | 0.015                 |                       |

| Table L1–15. Uranium Quantities Me | easured at the Storm Sewer |
|------------------------------------|----------------------------|
| Outfall and Lift Stat              | tion in 1955               |

<sup>a</sup> NLCO 1955; all samples taken at outfall until August 17 when lift station opened.
 <sup>b</sup> Location not specified on the analytical data sheets.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3. Source Terms and Uncertainties

| -         |               |           | Lift Stati    | on in 1956 | set the the t |           |                |
|-----------|---------------|-----------|---------------|------------|---------------|-----------|----------------|
| Date      | U             | Date      | U             | Date       | ·.U           | Date      | υ              |
| Collected | $(mg L^{-1})$ | Collected | $(mg L^{-1})$ | Collected  | $(mg L^{-1})$ | Collected | $(mg L^{-1})$  |
| 1-Jan     | 0.072         | 16-May    | 0.522         | 26-Jun     | 0.638         | 6-Aug     | 0.312          |
| 4-Jan     | 0.264         | 17-May    | 1.01          | 27-Jun     | 0.612         | 7-Aug     | 0.176          |
| ·7-Jan    | 0.104         | 18-May    | 0.366         | 28-Jun     | 0.612         | 8-Aug     | 0.722          |
| 10-Jan    | 0.081         | 19-May    | 0.592         | 29-Jun     | · 0.29        | 9-Aug     | 0.274          |
| 13-Jan    | 0.176         | 20-May    | 0.244         | 30-Jun     | 0.612         | 10-Aug    | 0.946          |
| 16-Jan    | 0.282         | 21-May    | 0.244         | l-Jul      | 0.522         | 11-Aug    | 0.214          |
| 19-Jan    | 0.678         | 22-May    | 0.522         | 2-Jul      | 0.6           | 12-Aug    | 0.234          |
| 22-Jan    | 0.405         | 23-May    | 0.586         | 3-Jul      | 1.632         | 13-Aug    | 0.566          |
| 25-Jan    | 0.564         | 24-May    | 0.14          | 4-Jul      | 2.04          | 14-Aug    | 0.63           |
| 28-Jan    | 2.71          | 25-May    | 0.156         | 5-Jul      | 1.428         | 15-Aug    | 0.63           |
| 1-Feb     | 0.58          | 26-May    | 0.976         | 6-Jul      | 0.426         | 16-Aug    | 0.352          |
| 4-Feb     | 1.742         | 27-May    | 0.976         | 7-Jul      | 0.232         | 17-Aug    | 0.174          |
| 15-Apr    | 1.58          | 28-May    | 0.592         | 8-Jul      | 0.194         | 18-Aug    | 0.202          |
| 16-Apr    | 0.572         | 29-May    | 0.586         | 9-Jul      | 0.254         | 19-Aug    | 0.036          |
| 17-Apr    | 1.186         | 30-May    | 0.504         | 10-Jul     | 0.312         | 20-Aug    | 0.698          |
| 18-Apr    | 0.71          | 31-May    | 0.586         | 11-Jul     | 0.78          | 21-Aug    | 0.166          |
| 19-Apr    | 1.36          | 1-Jun     | 0.574         | 12-Jul     | 2.1           | 22-Aug    | 1.188          |
| 20-Apr    | 0.314         | 2-Jun     | 0.382         | . 13-Jul   | 0.63          | 23-Aug    | 0.718          |
| 21-Apr    | 0.226         | 3-Jun     | 2.928         | 14-Jul     | 0.526         | 24-Aug    | 0.792          |
| 22-Apr    | 0.586         | 4-Jun     | 1.624         | 15-Jul     | 0.37          | 25-Aug    | 0.404          |
| 23-Apr    | 0.488         | 5-Jun     | 0.714         | 16-Jul     | 0.84          | 26-Aug    | 0.694          |
| 24-Apr    | 0.488         | 6-Jun     | 0.658         | 17-Jul     | 1.786         | 27-Aug    | 7.92           |
| 25-Apr    | 2.538         | 7-Jun     | 0.58          | 18-Jul     | 0.488         | 28-Aug    | 1.584          |
| 26-Apr    | 0.586         | 8-Jun     | 0.406         | 19-Jul     | 0.84          | 29-Aug    | 0.792          |
| 27-Apr    | 0.488         | 9-Jun     | 0.426         | 20-Jul     | 1.26          | 30-Aug    | 0.99           |
| 28-Apr    | 1.756         | 10-Jun    | 0.136         | 21-Jul     | 0.739         | 31-Aug    | 1.188          |
| 29-Apr    | 1.756         | 11-Jun    | 0.816         | 22-Jul     | 0.63          | 1-Sep     | 0.718          |
| 30-Apr    | , 0.592       | 12-Jun    | 0.368         | 23-Jul     | 0.946         | 2-Sep     | 0.396          |
| 1-May     | 0.644         | 13-Jun    | 0.562         | 24-Jul     | 0.912         | 3-Sep     | 0.478          |
| 2-May     | 0.78          | 14-Jun    | 0.272         | 25-Jul     | 0.946         | 4-Sep     | 0.304          |
| 3-May     | 0.696         | 15-Jun    | 1.364         | 26-Jul     | 0.254         | 5-Sep     | 0.138          |
| 4-May     | 0.54          | 16-Jun    | 0.368         | 27-Jul     | 0.214         | 6-Sep     | 0.594          |
| 5-May     | 0.974         | 17-Jun    | 0.388         | 28-Jul     | 1.47          | 7-Sep     | <b>0.184</b> · |
| 6-May     | 0.626         | 18-Jun    | 0.29          | 29-Jul     | 2.1           | 8-Sep     | 0.202          |
| 7-May     | 0.436         | 19-Jun    | 1.16          | 30-Jul     | 0.74          | 9-Sep     | 1.98           |
| 8-May     | 0.192         | 20-Jun    | 1.224         | 31-Jul     | 2.72          | 10-Sep    | 0.792          |
| 9-May     | 0.436         | 21-Jun    | . 0.658       | 1-Aug      | 0.37          | 11-Sep    | 1.09           |
| 10-May    | 0.452         | 22-Jun    | 0.816         | 2-Aug      | 0.39          | 12-Sep    | 0.46           |
| 11-May    | 0.244         | 23-Jun    | 0.638         | 3-Aug      | 0.39          | 13-Sep    | 0.35           |
| 12-May    | · 0.296       | 24-Jun    | 0.348         | 4-Aug      | 0.118         | 14-Sep    | 1.782          |
| 13-May    | 0.104         | 25-Jun    | 0.446         | 5-Aug      | 0.214         | 15-Sep    | 2.178          |

#### Table L1-16A, Uraniu e Sto 0. 4:4: Moach C.

<sup>a</sup> From NLCO 1956; All samples taken at lift station.

3.00 AC 23

South Sec.

Page L-105

•

|          | Lift          | Station | in 1956 * (C  | onra)  | · · · ·               |
|----------|---------------|---------|---------------|--------|-----------------------|
| 1956     | Ŭ             | 1956    | U             | 1956   | U                     |
| Date     | $(mg L^{-1})$ | Date    | $(mg L^{-1})$ | Date   | (mg L <sup>-1</sup> ) |
| l6-Sep   | 1.08          | 24-Oct  | 0.542         | 1-Dec  | 5.89                  |
| 17-Sep   | 0.392         | 25-Oct  | 0.342         | 2-Dec  | 0.672                 |
| 18-Sep   | 0.426         | 26-Oct  | 1.728         | 3-Dec  | 0.57                  |
| 19-Sep   | 0.63          | 27-Oct  | 0.362         | 4-Dec  | 0.576                 |
| 20-Sep [ | 0.306         | 28-Oct  | 0.476         | 5-Dec  | 0.23                  |
| 21-Sep   | 0.222         | 29-Oct  | 0.304         | 6-Dec  | 0.614                 |
| 22-Sep   | 0.698         | 30-Oct  | 0.532         | 7-Dec  | 3.23                  |
| 23-Sep   | 0.358         | 31-Oct  | 0.552         | 8-Dec  | 3.9                   |
| 24-Sep   | 0.324         | 1-Nov   | 0.96          | 9-Dec  | 1.996                 |
| 25-Sep   | 0.612         | 2-Nov   | 0.704         | 10-Dec | 0.57                  |
| 26-Sep Ü | 0.238         | 3-Nov   | 1.536         | 11-Dec | 0.442                 |
| 27-Sep   | 0.17          | 4-Nov   | 0.276         | 12-Dec | 0.556                 |
| 28-Sep   | 0.204         | 5-Nov   | 0.59          | 13-Dec | 0.26                  |
| 29-Sep   | 0.34          | 6-Nov   | 0.384         | 14-Dec | 0.476                 |
| 30-Sep   | 0.34          | 7-Nov   | 4.37          | 15-Dec | 1.236                 |
| 1-Oct    | 0.408         | · 8-Nov | 4.75          | 16-Dec | 0.856                 |
| 2-Oct    | 0.358         | 9-Nov   | 3.072         | 17-Dec | 0.666                 |
| 3-Oct    | 2.88          | 10-Nov  | 0.556         | 18-Dec | 1.14                  |
| 4-0ct ·  | · 1.98        | 11-Nov  | 0.384         | 19-Dec | 0.308                 |
| 5-Oct    | 0.476         | 12-Nov  | 0.57          | 20-Dec | 2.09                  |
| 6-Oct    | 0.72          | 13-Nov  | 0.48          | 21-Dec | 3.23                  |
| 7-Oct    | 0.442         | 14-Nov  | 0.346         | 22-Dec | 1.33                  |
| 8-Oct    | 0.712         | 15-Nov  | 1.52          | 23-Dec | 2.28                  |
| 9-Oct    | 0.204         | 16-Nov  | 0.95          | 24-Dec | 2.28                  |
| 10-Oct   | 0.392         | 17-Nov  | 0.308         | 25-Dec | 0.76                  |
| 11-Oct   | 0.494         | 18-Nov  | 0.556         | 26-Dec | 0.596                 |
| 2-Oct    | · 2.8         | 19-Nov  | 0.326         | 27-Dec | 0.384                 |
| l3-Oct   | 0.426         | 20-Nov. | 1.14          | 28-Dec | 1.632                 |
| l4-Oct   | 0.442         | 21-Nov  | 1.9           | 29-Dec | 0.96                  |
| 15-Oct   | 0.374         | 22-Nov  | 0.556         | 31-Dec | 5.51                  |
| 16-Oct   | 0.426         | 23-Nov  | 0.556         |        |                       |
| l7-Oct   | 0.324         | 24-Nov  | 0.288         |        |                       |
| 18-Oct   | 0.19          | 25-Nov  | 1.9           | •      |                       |
| 19-Oct   | 0.4           | 26-Nov  | 1.71          |        |                       |
| 20-Oct   | 0.742         | 27-Nov  | 0.538         | Avg    | 0.86                  |
| 21-Oct   | 0.456         | 28-Nov  | 0.346         | StdDev | 0.95                  |
| 22-Oct   | 1.9           | 29-Nov  | 0.76          | Max    | 7.92                  |
| 23-Oct   | 0.576         | 30-Nov  | 1.248         | Min    | 0.036                 |

<sup>a</sup> From NLCO 1956; all samples taken at lift station.

Radiological Assessments Corporation "Setting the standard in environmental health"

: :

:

. .

NY.

A Restriction

.

and she in the state.

1.32

NAMES OF T

.

nen sol e gate te set

| 1957     | of the OutFall | Lift Station    |
|----------|----------------|-----------------|
| Date     | U (mg L-1)     | $U (mg L^{-1})$ |
| 1-Feb    | 0.76           | 1,06            |
| 9-Feb    | 2.56           | 4.6             |
| 3-Apr    | 3.86           | 2.02            |
| 22-May   | 1.326          | 1.1             |
| 25-May   | 1.428          | 7.46            |
| . 31-May | 2              | 0.96            |
| . 27-Jun | 1.28           | 1.34            |
| 28-Jun   | 0.76           | 1.54            |
| 27-Jul   | 0.28           | 3.16            |
| 8-Nov    | 1.64           | 3.22            |
| 14-Nov   | 1.24           | 2.3             |
| 18-Nov   | 1.14           | 1.8             |
| 7-Dec    | 1.52           | 1.96            |
| 8-Dec    | 0.16           | 0.78            |
| Average  | 1.43           | 2.38            |
| Stdev    | 0.94           | 1.81            |
| Max .    | 3.86           | 7.46            |
| Min      | 0.16           | 0.78            |

ł

# Table L1-17, Uraniu

<sup>a</sup> From NLCO 1957.

1.5

| Appendix L          |       |
|---------------------|-------|
| Surface Water Disch | arges |

.

ر رم

100 .

|      |             | <u>Outtall 1</u> | n 1902, 1903 | and 1904 | <u>.</u>                  |       |
|------|-------------|------------------|--------------|----------|---------------------------|-------|
| 1000 | Conc. Img L | 1004             |              | 1000     | Lone. Img L               | 1004  |
| 1962 | 1963        | 1964             | Summary      | 1962     | 1963                      | 1964  |
| 35   | 41          | 16.4             |              | 6        | 3.4                       | 4.8   |
| 29.5 | 28          | 16.2             |              | 5.5.     | 3.4                       | 4.8   |
| 18.5 | 16          | 15.6 .           |              | 5.5      | 3.3                       | 4.8   |
| 17.5 | 15.2        | 13.4             |              | 5.5      | 3.2                       | 4.6   |
| 15.5 | 14.5        | 13.2             |              | 5.5      | 3                         | 4.6   |
| 15   | 8           | 12.6             |              | 5.5      | · <b>3</b>                | 4.6   |
| 12.5 | 7.5         | 12.2             |              | 5.5      | 3                         | 4.4   |
| 11   | 7.5         | 12               |              | 5.5      | 2.8                       | 4.4   |
| 10.5 | 7.5         | 11.8             |              | 5.5      | 2.8                       | 4.4   |
| 10.5 | 6           | 10               |              | 5.5      | 2.2 ·                     | 4.2   |
| 10   | 6           | 10               |              | 5.5      | 2                         | 4     |
| 9.5  | 6 ·         | 9                |              | 5        | 2                         | 4     |
| 9    | 6           | 8.6              |              | 5        |                           | 4     |
| 5    | 6.2         | 8.4              |              | 5        |                           | 3.8   |
| 9.5  | 5.5         | 8.2              |              | 4.5      |                           | 3.8   |
| 8.5  | 5.5         | 7.6              |              | 4.5      |                           | 3.8   |
| 8.5  | 5.4         | 7.4              |              | 4.5      |                           | 3.8   |
| 8.5  | 5.2         | 7                |              | 4.5      | •                         | 3.8   |
| 8    | 5           | 6.8              |              | 4.5      |                           | 3.6   |
| 8    | 5           | 6.8              |              | 4        |                           | 3.1   |
| 7.5  | 4.8         | 6.6              |              | 4        |                           | 3     |
| 7    | 4.6         | 6.6              |              | 2.3      |                           | 2.8   |
| 7    | 4.6         | 6.4              |              | 1.9      | •                         | . 2.6 |
| 7    | 4.5         | 6.4              |              | 0.8      |                           | 2.4   |
| 7    | 4.5         | 6                |              |          |                           | 2.4   |
| 6.5  | 4.5         | 5.8              |              |          |                           | 2     |
| 6.5  | 4.4         | 5.8              |              |          |                           | 1.4   |
| 6.5  | 4.4         | 5.6              | ••           |          |                           | 0.3   |
| 6.5  | 4.2         | 5.4              |              |          |                           |       |
| 6.5  | · 4         | 5.4              | Average      | 8.06     | 6.65                      | 6.39  |
| 6    | 3.6         | 5                | StdDev       | 5.86     | 7.02                      | 3.73  |
| 6    | 3.4         | 4.8              | Max          | 35       | <b>41</b> <sup>····</sup> | 16    |
| 6    | 3.4         | 4.8              | Min          | 0.80     | 2.00                      | 0.30  |
|      |             |                  |              |          |                           |       |

|                | •          |                 |            |              |       |
|----------------|------------|-----------------|------------|--------------|-------|
| fable L1–18. I | Uranium Co | ncentrations    | Measured a | at the Storm | Sewer |
|                | Outfal     | l in 1962, 1963 | and 1964 a | L            |       |

<sup>a</sup> From Rathgens, 1965; handwritten ledger sheets summarizing uranium measurements taken throughout the year for frequency distribution. The data for 1962 and 1963 were used to calculate total uranium to Paddy's Run from storm sewer outfall assuming 250, 000 gallons per day (See Figure L-3). For 1964, data from analytical data sheets are given in Table L1-21 in the annex.

| Page | L-108 |
|------|-------|
|------|-------|

12.11.12

1.1.10

| -1960     | # Outfall           |             | <u> </u>      | Volume   | Uranium       | DLWb                                                                                                            | MLRC |
|-----------|---------------------|-------------|---------------|----------|---------------|-----------------------------------------------------------------------------------------------------------------|------|
| Month     | Events <sup>a</sup> | Date        | $(mg L^{-1})$ | (gal)    | (kg)          | (kg)                                                                                                            | (kg) |
| Jan-60    | ?                   | 27          | 6.0           | 44400    | 1             | 1 .                                                                                                             | 128  |
| Feb-60    | 7                   | 4           | 6.0           | 72000    | 2             | 45                                                                                                              |      |
| •         |                     | 5           | 5.0           | 5124000  | 96            |                                                                                                                 |      |
|           |                     | 6           | 1.8           | 79800    | 1             |                                                                                                                 | •    |
|           | •                   | 9           | 6.0           | 98160    | 2             |                                                                                                                 |      |
|           | •                   | 10          | 4.5           | 1770750  | 30            |                                                                                                                 |      |
| •         |                     | 11          | 0.6           | 30000    | 0.1           |                                                                                                                 |      |
|           |                     | 25          | 1.5           | 400420   | 2             |                                                                                                                 |      |
| Mar-60    | • . 3               | 14          | 2.3           | 24000    | 0.2           | 3                                                                                                               |      |
|           |                     | 16          | 2.4           | 3150     | <0.1          |                                                                                                                 |      |
|           |                     | 17          | 6.4           | 12000    | 0.3           |                                                                                                                 |      |
| Apr-60    | . 3                 | 3           | 9.8           | 269800   | 10            | 10                                                                                                              | 10   |
|           | •                   | 26          | 9.5           | 264000   | 9             |                                                                                                                 |      |
|           |                     | <b>30</b> . | 19.5          | 109560   | 8             |                                                                                                                 |      |
|           |                     | -           | ÷ .           |          |               |                                                                                                                 |      |
| May-60    | 3                   | 12          | <b>8.5</b>    | 18500    | 1             | 125                                                                                                             | 125  |
| • •.      |                     | <b>16</b> · | 48.0          | 100500   | 18            | 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - 1997 - |      |
| _         |                     | 20          | 14.5          | 64800    | 4             |                                                                                                                 |      |
| Jun-60    | ?                   | 27          | <b>4.1</b> a  | 66730    | 1             | 64                                                                                                              | 176  |
| Jul-60    | · ?                 | 3           | 13.5          | 2174000  | 111           | 137                                                                                                             | 138  |
|           | •.                  | 13          | 8.5           | 500000   | 16            |                                                                                                                 |      |
|           |                     | 18          | 6.0           | 447900   | 10            |                                                                                                                 |      |
| A         | <b>9</b>            | 00          | 10.5          | 40000    |               | 70                                                                                                              |      |
| Aug-ou    | :                   | 29          | 18.5          | 42000    | 3             | 13                                                                                                              |      |
| Sec. (0)  | · •                 | 30 .        | 30.0          | 621000   | 10            | •                                                                                                               |      |
| Sep-60    | 0                   | F           | 10.0          | 100000   | 10            | 0                                                                                                               | 73   |
| 001-00    | . 4                 | 0 ·         | 18.0          | 198000   | 13            | 81 .                                                                                                            | 87   |
|           | *                   | 0           | 15.0          | 210000   |               |                                                                                                                 |      |
|           |                     | 10          | 35.0 -        | 48000    | 6             |                                                                                                                 |      |
|           |                     | 19          | 14.0          | 1050000  | 30            |                                                                                                                 |      |
| Nov-60    | 5                   | 9           | 14.0          | 546000   | 29            | 50                                                                                                              |      |
|           | U                   | 16          | 0.0           | 31200    | -01           | 00                                                                                                              |      |
|           | •                   | 22          | • 13.5        | 402720   | 21            |                                                                                                                 |      |
|           |                     | 23          | 11.5          | 24480    | 1             | •                                                                                                               |      |
| •         |                     | 28          | 16.0          | 109600   | $\frac{1}{7}$ | · .                                                                                                             |      |
| Dec-60    | · 3                 | 6           | 10.5          | 580000   | 23            | 40                                                                                                              | 40   |
|           | · ·                 | 11          | 9.0           | 316300   | 11            |                                                                                                                 | ••   |
|           |                     | 26          | 5.5           | 259200   | 5             |                                                                                                                 |      |
| •         |                     |             | ·, ·          |          |               |                                                                                                                 |      |
| Totals    |                     |             |               | 16112970 | 579           | 635                                                                                                             | 770  |
| Avg/Event | •                   |             |               | 460371   | 17            |                                                                                                                 |      |

<sup>a</sup> Records were not complete to verify number of events for all months. These events refer only to material lost to Paddy's Run through the storm sewer outfall ditch. Additional quantities were lost to Paddy's Run through runoff from the west side of the facility. These additional quantities are included in our final source term estimates reported in Table L-8. <sup>b</sup> From Starkey 1960-1961. <sup>c</sup> From Cuthbert 1960, 1961. - Card Dolentik Roll (Schernlich) -- -

. . . .

•

| lonth . | # Events a | 1. Date |       | Vol. (gal) | U(kg) | DLW (kgi <sup>b</sup> | MLR (kg) |
|---------|------------|---------|-------|------------|-------|-----------------------|----------|
| Jan-61  | 2          | 6       | 6.5   | 1632000    | 40    | 81                    | 86       |
|         |            | 15      | 11.5  | 948000     | 41    |                       |          |
| Feb-61  | 7          | 10      | 13.0  | 24(000)    | 12    | 82                    | 41       |
|         |            | 17      | 17.0  | 126000     | 8     |                       |          |
|         |            | 18      | 13.5  | 333000     | 17    |                       |          |
|         |            | 22      | 7.0   | 157200     | 4     | 1.                    | •        |
|         |            | 25      | 7.0   | 1026000    | 27    |                       |          |
|         |            | 26      | 4.5   | 168000     | 3     |                       |          |
|         |            | 28      | 4.5   | 639600     | 11    |                       |          |
| Mar-61  | 9          | 4       | 6.5   | 472500     | 12    | 179                   | 219      |
|         |            | 5       | 5.0   | 2382000    | 45    | 1                     |          |
|         |            | 6       | 6.5   | 478500     | 12    | 1                     |          |
|         |            | 8       | 6.5   | 1452100    | 36    | }                     |          |
|         |            | 12      | 4.5   | 2054200    | 35    | 1                     |          |
|         |            | 13      | 4.5   | 1141100    | 19    | }                     |          |
|         |            | 19      | 7.5   | 264000     | 7.    | ·                     |          |
|         |            | 21      | 6.0   | 336000     | ´ 8   | 1.                    |          |
|         |            | 22      | 5.5   | 252000     | 5     | 1                     |          |
| Apr-61  | 8          | 9       | 8.5   | 534000     | 17    | 94                    | 75       |
|         |            | 10      | 2.6   | 36000      | 1     |                       |          |
|         |            | 12      | 7.0   | 786200     | 21    | · ·                   |          |
|         | •          | 13      | 5.5   | 600000     | 12    |                       |          |
|         |            | 15      | 9.0   | 567000     | 19    |                       |          |
|         |            | 16      | 6.0   | 216000     | 5     |                       |          |
|         |            | 25      | 10.5  | 433000     | 17    |                       |          |
|         |            | 28      | 6.5   | 84000      | 2     | 1                     |          |
| May-61  | 6          | 5       | 8.5   | 94500      | 3     | 89                    | 108      |
|         |            | 6       | 11.5  | 126000     | 5     |                       | •        |
|         |            | 7       | . 6.5 | 1238400    | 30    |                       |          |
|         |            | 8       | 8.5   | 1368000    | . 44  |                       |          |
|         |            | 9       | 4.5   | 336000     | 6     | }                     |          |
|         |            | 18      | 8.0   | 96000      | 3     | Í                     |          |
| Jun-61  | 4          | · 2     | 9.5   | 66000      | 2     | 64                    | 64       |
|         |            | 8       | 21.5  | 300000     | 24    |                       |          |
|         |            | 9       | 25.0  | 132000     | 12    |                       |          |
|         |            | 14      | 7.5   | 876000     | 25    |                       |          |
| Jul-61  | 7          | · .     | 75    | 547800     | 16    | 91                    | 89       |

<sup>a</sup> Records for individual outfall events located for January to August 1961.

7.5

10.5

5.5

10.5

9.5

4.0

15.5

17.5

9.0

8.7

25

2.6

547800

564600

739200

363000

528000

125200

42000

144000 90000

560,000

2,380,000

36,000

16

22

15

14

19

2

2

10

3

15.4

45

0.5

.

<sup>b</sup> From Starkey 1960–1961 (DLW) and Cuthbert 1960,1961 (MLR).

4

5

15

20

21

22

30

1

24

•

Jul-61

Aug-61

Totals

Avg/Event Max

. Min

7

2

Radiological Assessments Corporation "Setting the standard in environmental health"

13

693

15

| Page | L-1 | 10 |
|------|-----|----|
|------|-----|----|

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

5 · .

¥.\*

**5**.

Sr-10

Konstant and Antonia

Sec. 1

5. S. S. A.

あま どうしょう

.....

 ÷.,

| 1964        | # Outfall                              | ······      | Volume   | U Conc.       | U/Event   | U/Month    |
|-------------|----------------------------------------|-------------|----------|---------------|-----------|------------|
| Mon         | Events                                 | Date        | (gallon) | $(mg L^{-1})$ | (kg)      | (kg)       |
| Jan-64      | . 9                                    | 2           | 214500   | 4.4           | 4         | 58         |
|             |                                        | 3           | 288000   | 10.0          | 11        |            |
|             | •                                      | 5           | 336000   | 7.4           | 9         |            |
|             |                                        | 9           | 132000   | 8.4           | 4 ·       |            |
|             |                                        | 15          | 8400     | 1.4           | 0.04      | •          |
|             | -                                      | <b>19</b> ' | 168000   | 10.0          | · 6       | • <b>2</b> |
|             |                                        | 20          | 564000   | 9.0           | 19        |            |
|             | •                                      | 24          | 12000    | 15.6          | 1         |            |
|             | · ·                                    | 25          | 132000   | - 6.4         | 3         |            |
| Feb-64      | ´. 9                                   | 5           | 1374000  | 16.4          | 85        | 98         |
|             |                                        | 15          | 312000   | 8.2           | 10        | - <b>-</b> |
|             |                                        | 16          | 64800    | 13.4          | 3         |            |
| Mar-64      | 10                                     | 2           | 66000    | 16.2          | 4         | 506        |
|             | •                                      | 4           | 7152000  | 6.8           | 184       |            |
|             | 3                                      | 5           | 150000   | 4.8           | 3         |            |
|             | · •                                    | 8           | 823000   | 11.8          | 37        |            |
|             |                                        | 9           | 9288000  | 3.8           | 133       |            |
|             |                                        | 10          | 1764000  | 4.4           | 29        | ÷.         |
| · · · · · · | í                                      | 12          | 350640   | 6.6           | 9         |            |
| • .         |                                        | 14          | 1560000  | 12.6          | 74        | · ·        |
| e e e       | •••••••••••••••••••••••••••••••••••••• | 21 (        | 112000   | 6.0           | 3         |            |
| · · · · ·   | · · · · · ·                            | 25          | 660000   | 12.0          | 30 .      |            |
| Apr-64      | 12                                     | 2           | 1992000  | 6.4           | 48        | 338        |
| •           |                                        | 3           | 3702000  | 3.8           | 53        |            |
|             |                                        | 5           | 1200000  | 4.2           | 19        | •          |
| •           |                                        | 6           | 2148000  | 3.8           | 31        |            |
|             |                                        | 13          | 3120     | 3.8           | 0.05      |            |
|             |                                        | 19          | 3144000  | 4.0           | 48        | • •        |
|             |                                        | 20          | 360000   | 4.8           | 7         |            |
|             |                                        | 21          | 7800000  | 3.6           | 106       |            |
|             |                                        | 22          | 792000   | 3.0           | •0        |            |
|             | ,                                      | 24          | 325700   | 4.0           | 5         |            |
|             |                                        | 26          | 378000   | 7.6           | 11        |            |
|             |                                        | 27          | 90000    | 4.6           |           |            |
| May-64      | • 1                                    | 11          | 5200     | 0.3           | 0.01      | 0.01       |
| Jun-64      | 5                                      | 2           | 144000   | - 4 8         | 3         | 190        |
|             | <b>.</b>                               | - A         | 306000   | 66            | 8         |            |
|             |                                        | 12          | 13000000 | · 26          | 128       |            |
|             |                                        | 13          | 1920000  | 2.0           | 15        |            |
|             |                                        | 18          | 2256000  | 2.0<br>4 A    | 38        |            |
| Jul-64      | 4                                      | 10<br>6-    | 66000    | <br>9 /       | 1         | 36         |
|             | 4                                      | 7           | 540000   | 50            | 10        | 00         |
|             | • •                                    | 12          | 960000   | 6.9           | <u>95</u> | •          |
|             |                                        | - <i>64</i> | 200000 · | 0.0           | 04        |            |

(Continued on next page)

.**.**•

n. .

| Table   | Table L1–21. Uranium Concentrations and Volume of Effluent to               |      |            |               |         |         |  |  |
|---------|-----------------------------------------------------------------------------|------|------------|---------------|---------|---------|--|--|
| Padd    | Paddy's Run Via the Storm Sewer Outfall Ditch in 1964 <sup>a</sup> (cont'd) |      |            |               |         |         |  |  |
| 1964    | # Outfall                                                                   | •    | Volume     | U Conc.       | U/Event | U/Month |  |  |
| Mon     | Events                                                                      | Date | (gallon)   | $(mg L^{-1})$ | (kg)    | (kg)    |  |  |
| Aug-64  | . 3                                                                         | 11   | 312000     | 5.6           | . 7     | 30      |  |  |
|         |                                                                             | 21   | 360000     | 13.2          | 18      | •       |  |  |
| •       |                                                                             | 22   | 216000     | 7.0           | 6       |         |  |  |
| Sep-64  | 2                                                                           | 18   | 720000     | 5.8           | 16      | 37      |  |  |
|         |                                                                             | 19   | 960000     | 5.8           | 21      |         |  |  |
| Oct-64  | 1                                                                           | 18   | 492000     | 8.6           | 16      | 16      |  |  |
| Nov-64  | 4                                                                           | 18   | 511200     | 12.2          | 24      | 73      |  |  |
|         |                                                                             | 19   | 1320000    | 5.4           | 27      |         |  |  |
|         |                                                                             | 25   | 210000     | 4.6           | 4       |         |  |  |
|         |                                                                             | 28   | 1080000    | 4.6           | 19      |         |  |  |
| Dec-64  | · 6                                                                         | 2    | . 248400   | <b>3.1</b> ·  | 3       | 78      |  |  |
|         |                                                                             | 3    | 1134000    | 5.8           | 25      |         |  |  |
| •       |                                                                             | 4    | 1302000    | 4.0           | 20      |         |  |  |
|         |                                                                             | 11   | 2600000    | 2.4           | 24      |         |  |  |
|         |                                                                             | 16   | 216000     | 2.9           | 2       |         |  |  |
|         |                                                                             | 24   | 204000     | 5.4           | 4       |         |  |  |
| Totals  |                                                                             |      | 70,000,000 |               | 1458    | 1458    |  |  |
| Average | ,                                                                           |      | 1,300,000  | 6             | 24      | 122     |  |  |
| Max     | •                                                                           |      | 13,000,000 | 16.4          | 180     | 506     |  |  |
| Min     | •                                                                           |      | 3100       | 0.3           | 0.01    | 0.01    |  |  |

<sup>a</sup> These events refer only to material to Paddy's Run through the storm sewer outfall ditch. Additional quantities were lost to Paddy's Run through runoff from the west side of the facility. These additional quantities are included in our final source term estimates that are reported in Table L-8.

## Radiological Assessments Corporation "Setting the standard in environmental health"

......

5

| Page I | L-112 | 2 |
|--------|-------|---|
|--------|-------|---|

-1654(343)

Were and the second

Sealer Sealer

. • :

•

. . . · · .

| : · · ·  | Paddy            | s Run Via t   | he Storm  | Sewer Out | fall Ditch | in 1966 <sup>a</sup> | )          |
|----------|------------------|---------------|-----------|-----------|------------|----------------------|------------|
| 1966     | Outfall          | Lift Station  | Outfall   | 1966      | Outfall    | Lift Station         | Outfall    |
| Date     | U Conc.          | $(mg L^{-1})$ | Vol.(gal) | Date      | U Conc     | $(mg L^{-1})$        | Vol. (gal) |
| 1-Jan    | 4.2              | . 3.4         | 546000    | 13-Jul    | 5          | 1.24                 | 2808000    |
| 2-Jan    | 2.4              | 2             | 3105000 🖞 | ें 23-Jul | 8.8        | 6.4                  |            |
| 5-Jan    | 0.96             | 2.8           | • • •     | 26-Jul    | 0.3        | 0.54                 |            |
| 6-Jan    | 2.4              | 3 (           |           | - 28-Jul  | 14         | 1.6                  |            |
| 7-Feb    | 3.8              | 5.8           | 92400     | 7-Aug     | 7.2        | 2.6                  |            |
| 8-Feb    | 3.6              | 7.2           |           | 🗄 8-Aug   | 3.8        | 2.8                  | •          |
| 10-Feb   | 5.6              | 8.2           | 4200000   | 1 9-Aug   | 1.14       | 11                   |            |
| 11-Feb   | · 4.8            | 14.8          | · 、 、     | 10-Aug    | 4.2        | 2.4                  | 423000     |
| 13-Feb   | <b>3.2</b> .     | 5.4           | 708000    | 11-Aug    | 5          | 4                    |            |
| 14-Feb   | •                | 220           | , '       | 13-Aug    | 6.2        | 3.4                  |            |
| 8:00 AM  | 1.8              | •             | 13 gpm    | 14-Aug    | 4.8        | 3.4                  |            |
| 10:00 AM | <b>1</b> `       |               | 200 gpm   | - 15-Aug  | 3          | 2.6                  | •          |
| 10:15 AM | 1600             |               | 200 gpm   | 20-Aug    | 3.8        | 2.4                  |            |
| 11:15 AM | 490              | •             | 75 gpm    | 3-Sep     | 3.6        | 2.4                  |            |
| 1:15 PM  | 43               | ` 1i          | 130 gpm   | · 15-Sep  | 5.2        | 5.4                  |            |
| 2:30 PM  | 16               | Ĩ             | 116 gpm   | 19-Sep    | 4          | 6.4                  |            |
| 16-Feb   | 6.5 <sup>1</sup> | 7.5           |           | 20-Sep    | 4.8        | 3.8                  | 756000     |
| 28-Feb   | 8.2              | 6.2           |           | 25-Sep    | 7.6        | 6.6                  | 327600     |
| 12-Mar   | 4.               | 3.4           |           | 15-Oct    | 3          | 3.6                  | 1120000    |
| 21-Mar   | 16               | 2.8           |           | 2-Nov     | . 5        | 4.6                  | 1264500    |
| 23-Mar   | 2.6              | 3.6           |           | 3-Nov     | 4.8        | <b>4.4</b> .:        | 320400     |
| 3-Apr    | 0.22             | 3.8           |           | 4-Nov     | 3.8        | 3.8                  | 108000     |
| 4-Apr    | 0.42             | 1.72          |           | 5-Nov     | 3.8        | 4                    | 247440     |
| 11-Apr   | 4.2              | 7.4           | • *       | 8-Nov     | 4          | 3.6                  |            |
| 12-Apr   | 4.4              | 4.6           | ٤         | 10-Nov    | 2.4        | <b>,3</b> .          |            |
| 24-Apr   | 6.               | <b>4</b> e    | 765,000   | 25-Nov    | 8.2        | 3                    |            |
| 27-Apr   | 5                | 4             |           | 6-Dec     | 5.4        | 4.4                  |            |
| 28-Apr   | 8                | 9             |           | 7-Dec     | 5.8        | 3.2                  |            |
| 30-Apr   | 3.6              | 2.6           |           | 🔅 8-Dec   | •          | 2.8                  | •          |
| 9-May    | 3.4              | 3             |           | 9-Dec     | .3.4       | 4                    |            |
| 11-May   | 4.2              | <b>.4</b> -€. | ·         | 10-Dec    | 2.6        | 2.6                  |            |
| 28-May   | 7.6              | 2.6           | ·• ·      |           | •          | •                    |            |
| 6-Jun    | 162              | 400           |           | Avg/event | 7.31       | 10.78                | 1052583.8  |
| 9-Jun    | 2.6              | 5.2           |           | Stdev     | 20.67      | 51.16                | 1230753.3  |
| 6-Jul    | 2.4              | 1.04          | ť         | Max       | 1600       | 400                  | .4200000   |
| 10-Jul   | 4.4              | 2             | 147-0006  | Min 🐳     | 0.22       | 0.54                 | 50000      |

Table L1-22, IIr

<sup>a</sup> From NLCO 1966, analytical data sheets; total volume was not given for all outfall events. an average value was used to calculate the total quantity of uranium to Paddy's Run. These events refer only to material to Paddy's Run through the storm sewer outfall ditch. Additional quantities were lost to Paddy's Run through runoff from the west side of the facility. These additional quantities are included in our final source term estimates that are reported in Table L-8.

. . .

مرد. مرد ا

| Table L1-23. Reported | <b>Quantities of Uranium Disch</b> | arged to | the Storm Sewer                       |
|-----------------------|------------------------------------|----------|---------------------------------------|
|                       | Suctom at the EMDCa                |          | · · · · · · · · · · · · · · · · · · · |

|             | _ L               | Total U to Storm   | Storm Se | ewer Lift   |        | •        |
|-------------|-------------------|--------------------|----------|-------------|--------|----------|
| _           | Rain <sup>D</sup> | Sewer              | Stat     | tion        | Paddy  | 's Run   |
| Date        | (inches)          | (kg)               | (kg)     | <b>%</b>    | (kg)   | <b>%</b> |
| Jan-60      | 2.5               | 330                | 200      | 61          | 130    | 39       |
| Feb-60      | · 3               | 3405               | 210      | 61          | 130    | 39       |
| Mar-60      | 0.5               | 180 <sup>b</sup>   | 180      | 99          | 3      | 2        |
| Apr-60      | 1                 | 425                | 400      | 93          | 10     | 7        |
| May-60      | 3.5               | 510                | 385      | 75          | 125    | 25       |
| Jun-60      | 5.5               | 650                | 470      | 73          | 175    | 27       |
| Jul-60      | 4.5               | 395                | 260      | 65          | 137    | 35       |
| Aug-60      | 1.5               | . 490 <sup>b</sup> | 415      | 85          | 73     | 15       |
| Sep-60      | 1                 | 355                | 280      | •           | 0      | d        |
| Oct-60      | 2                 | 480                | 395      | · 82        | 90     | 18       |
| Nov-60      | 2                 | 475 <sup>b</sup>   | 420      | 88          | 50     | 12       |
| Dec-60      | 1.5               | 500                | 460      | 92          | 40     | 8        |
| 1960 Totals |                   | 5200               | 4100     |             | 1000 . |          |
| Jan-61      | 1                 | 422                | 341      | · 81        | 80     | 19       |
| Feb-61      | 3.5               | 475                | 393      | 83          | 82     | 17       |
| Mar-61      | 4.5               | 642                | 463      | 72          | 179    | 28       |
| Apr-61      | 3.5               | 396                | 302      | 76          | 94     | 24       |
| May-61      | 6                 | 500                | 408      | 82          | 90     | 18       |
| Jun-61      | 3.5               | 319                | 255      | 80          | 65     | 20       |
| Jul-61      | 8.5               | 359                | 268      | 75          | 90     | 25       |
| Aug-61      | 2                 | 609                | 596      | 98 -        | 15     | 2        |
| Sep-61      | 3.2               | 740 <sup>c</sup>   | 479      | 65          | 261    | 35       |
| Oct-61      | 1.5               | 230 <sup>b</sup>   | 184      | 80          | 46     | 20       |
| Nov-61      | 3.5               | 400 <sup>b</sup>   | 294      | 73          | 106    | 27       |
| Dec-61      | 3                 | 310 <sup>b</sup>   | 288      | 93          | 22     | 7        |
| 1961 Totals |                   | 5400               | 4300     |             | 1100   |          |
| Jan-62      | 3.5               | 590 <sup>b</sup>   | 457      | 77          | 135    | 23       |
| Feb-62      | 4.5               | 700                | 574      | 82          | 126    | 18       |
| Mar-62      | 3                 | 550 <sup>D</sup>   | 243      | 44          | 310    | 56       |
| Apr-62      | 0.5               | 425 <sup>b</sup>   | 340      | 80          | 85     | 20       |
| May-62      | 4                 | 615 <sup>D</sup>   | 486      |             | 129    | c        |
| Jun-62      | 1                 | . 320 <sup>b</sup> | 190      | <b>59</b> · | 130    | 41       |
| Jul-62      | 6.5               | 450 <sup>b</sup>   | 378      | 84          | 72 ·   | 16       |
| Aug-62      | 2                 | 425 <sup>b</sup>   | 380      | 89.         | 45     | 11       |
| Sep-62      | . <b>0.5</b>      | 1383°              | 1378     | 99          | 5      | Ъ        |
| Oct-62      | 3                 | 480 <sup>b</sup>   | 404      | 84          | 76     | 16       |
| Nov-62      | 1.5               | 376 <sup>c</sup>   | 317      | 84          | 59     | Ъ        |
| Dec-62      | 1                 | 505 <sup>b</sup>   | 399      | Ъ           | 106    | c        |
| 1962 Totals |                   | 6800               | 5500     |             | 1300   |          |

<sup>a</sup> From Cuthbert 1960-1962 and Starkey 1960-1961 unless otherwise noted. For our source term estimates, additional material was assumed to be lost to Paddy's Run through runoff from the west side of the site. <sup>b</sup> From Fischoff 1960--1962.

<sup>c</sup> Uranium loss was calculated as 21% of the loss to the storm sewer system. <sup>d</sup> No losses were reported to Paddy's Run through the storm sewer outfall ditch.

1.0X2

The star of the second second second

|                                                                              | •      | · · · · • |          | an 1 - 17 21 |              | 1        |                | <u></u>         | •         |
|------------------------------------------------------------------------------|--------|-----------|----------|--------------|--------------|----------|----------------|-----------------|-----------|
| Table L1–24A. Daily Measurements of Total Suspended Solids (TSS) in Liquid   |        |           |          |              |              |          |                |                 |           |
| Effluents Discharged to the River in 1957 (mg L <sup>-1</sup> ) <sup>a</sup> |        |           |          |              |              |          |                |                 |           |
| Date                                                                         | TSS    | Date      | TSS      | Date         | TSS          | Date     | TSS            | Date            | TSS       |
| 1-Jan                                                                        | 982    | 12-Feb    | 1029 '   | 26-Mar       | 1427         | 7-May    | 88             | 19-Jun          | 121       |
| 2-Jan                                                                        | 1105   | 13-Feb    | 1375     | 27-Mar       | 177          | 8-May    | 242            | 20-Jun          | 159       |
| 3-Jan                                                                        | 982    | 14-Feb    | 1374     | 28-Mar       | 731          | 9-May    | 47             | 21-Jun          | 150       |
| 4-Jan                                                                        | 1490   | 15-Feb    | 1055     | 29-Mar       | 726 ·        | 11-May   | 191            | 22-Jun          | 122       |
| 5-Jan                                                                        | 762    | 16-Feb    | 253      | 30-Mar       | 392          | 12-May   | 159            | 23-Jun          | 87        |
| 6-Jan                                                                        | 651    | 17-Feb    | 1524     | 31-Mar       | 548          | 13-May . | 129            | 24-Jun          | 242       |
| 7-Jan                                                                        | • 517  | 18-Feb    | 1016     | 1-Apr        | 130          | 14-May   | 192            | . 25-Jun        | 225       |
| 8-Jan                                                                        | - 1271 | 19-Feb    | 177      | 2-Apr        | 110          | 15-May   | 86             | . 26-Jun        | 46        |
| 9-Jan                                                                        | 904    | 20-Feb    | 76       | 3-Apr        | 89           | 16-May   | 45             | 27-Jun          | 139       |
| 10-Jan                                                                       | 1093   | 21-Feb    | 214      | 4-Apr        | 299          | 17-May   | 139            | 28-Jun          | 45        |
| 11-Jan                                                                       | 1049   | 22-Feb    | 117      | 5-Apr        | 439          | 18-May   | 86 🚊           | 29-Jun          | 141       |
| 12-Jan                                                                       | 2374   | 23-Feb    | -75 🗧    | 6-Apr        | 2318         | 19-May   | 162            | 30-Jun          | <u>48</u> |
| 13-Jan                                                                       | 1608   | 24-Feb    | 306      | 7-Apr        | 1209         | 20-May   | 816            | 1-Jul           | 539       |
| 14-Jan                                                                       | 1283   | 25-Feb    | 598      | 8-Apr        | 1230         | 21-May   | 1621           | 2-Jul           | 539       |
| 15-Jan                                                                       | 2021   | 26-Feb    | 413      | 9-Apr        | 261          | 22-May   | <b>195</b> e   | ʻ3-Jul          | 111       |
| 16-Jan                                                                       | 1403   | 27-Feb    | 407      | 10-Apr       | 926          | 23-May   | 742            | 4-Jul           | 76        |
| 17-Jan                                                                       | 1241   | 28-Feb    | 466      | 11-Apr       | 919          | 24-May : | 274            | . <b>5-Ju</b> ] | 524       |
| 18-Jan                                                                       | 746    | · 1-Mar   | 95       | 12-Apr       | 300          | 25-May   | 458            | - 6-Jul         | 413       |
| 19-Jan                                                                       | 1261   | 2-Mar     | 163      | 13-Apr       | 120          | 26-May   | 2609           | 7-Jul           | 142       |
| 20-Jan                                                                       | 881    | 3-Mar     | 85       | 14-Apr       | 412          | 27-May   | 1235           | : 8-Jul         | 103       |
| 21-lan                                                                       | 37     | 4-Mar     | ··71 ·   | 15-Apr       | 379          | 28-May   | 357 ·          | 9-Jul           | 438       |
| 22-Jan                                                                       | 476    | 5-Mar     | 98       | 16-Apr       | 483          | 29-May   | 172            | 10-Jul          | 271       |
| 23-Jan                                                                       | 253    | 6-Mar     | 101      | 17-Apr       | 165          | 30-May   | 426            | 11-Jul          | . 150     |
| 24-Jan                                                                       | 537    | 7-Mar     | 262      | 18-Apr       | 653          | 31-May   | 306            | 12-Jul          | 41        |
| 25-Jan                                                                       | - 281  | 8-Mar     | 261      | 19-Apr       | 837          | 1-Jun    | 50 🗇           | 13-Jul          | -411      |
| 26-Jan                                                                       | 631    | 9-Mar     | 121      | 20-Apr       | 1649         | 2-Jun    | 57 ·           | 14-Jul          | 598       |
| 27-Jan                                                                       | 1144   | 10-Mar    | 395      | 21-Apr       | 162          | 3-Jun    | 52             | 15-Jul          | 442       |
| 28-Jan                                                                       | 1167   | 11-Mar    | 109      | 22-Apr       | 73           | 4-Jun    | 583 ·          | '16-Jul         | 607       |
| 29-Jan                                                                       | 1293   | 12-Mar    | 803      | 23-Apr       | <b>9</b> 9 ` | 5-Jun    | 132 ·          | 17-Jul          | 92        |
| 30-Jan                                                                       | 854    | 13-Mar    | 509      | 24-Apr       | 76           | 6-Jun    | <b>526</b> : 2 | 18-Jul          | 397       |
| 31-Jan                                                                       | 1120   | 14-Mar    | 470      | 25-Apr       | 110          | 7-Jun    | 99             | : 19-Jul        | 328 ·     |
| 1-Feb                                                                        | 1000   | 15-Mar    | 315      | 26-Apr       | 156          | 8-Jun    | 130            | 20-Jul          | 483       |
| 2-Feb                                                                        | 1491   | 16-Mar    | 1286     | 27-Apr       | 260          | 9-Jun    | 233            | 21-Jul          | 48        |
| 3-Feb                                                                        | 965    | 17-Mar    | 509      | 28-Apr       | 78           | 10-Jun   | 166            | 22-Jul          | 953       |
| 4-Feb                                                                        | 1027   | 18-Mar    | 1263     | 29-Apr       | 106          | 11-Jun   | 1197           | 23-Jul          | 110       |
| 5-Feb                                                                        | 1192   | 19-Mar    | 366      | 30-Apr       | 709          | 12-Jun   | 456            | -24-Jul         | 381       |
| 6-Feb                                                                        | 1394   | 20-Mar    | 206      | 1-May        | 463          | 13-Jun   | 240            | 25-Jul          | 272       |
| 7-Feb                                                                        | 1154   | 21-Mar    | ·· 532 ① | 2-May        | 176          | 14-Jun   | 32 -           | 26-Jul          | 84        |
| 8-Feb                                                                        | 702    | 22-Mar    | 404      | 3-Mav        | 110          | 15-Jun   | 153 🗟          | 27-Jul          | 83        |
| 9-Feb                                                                        | 829    | 23-Mar    | 253      | 4-Mav        | 115          | 16-Jun   | 577            | 28-Jul          | 57        |
| 10-Feb                                                                       | . 262  | 24-Mar    | 539      | 5-Mav        | 658          | 17-Jun   | 95             | 29-Jul          | 182       |
| 11-Feb                                                                       | 354    | 25-Mar    | 205      | 6-May        | 140          | 18-Jun   | 610            | 30-Jul          | 195       |

(continued on next page)

......

· · ·

-, 7

...:

...

| Table L1-24B. | . Daily Measurements of Total Suspended     | Solids (TSS) in Liquid         |
|---------------|---------------------------------------------|--------------------------------|
| Efflu         | uents Discharged to the River in 1957 (mg.) | $L^{-1}$ <sup>a</sup> (cont'd) |

| · ·    | <u>Effluents D</u> | ischarge | <u>ed to the </u> | River in 1 | <u>957 (mg L</u> | ,-1) <sup>a</sup> (cont | <u>'d)</u> |
|--------|--------------------|----------|-------------------|------------|------------------|-------------------------|------------|
| Date   | TSS                | Date     | TSS               | Date       | TSS              | Date                    | TSS        |
| 31-Jul | 333 ·              | 11-Sep   | 221               | 22-Oct     | 105              | 1-Dec                   | 148        |
| 1-Aug  | 221                | 12-Sep   | 618               | 23-Oct     | 124              | 2-Dec                   | 58         |
| 2 Aug  | . 373              | 13-Sep   | 116               | 22-Oct     | 105              | 3-Dec                   | 299        |
| 3-Aug  | 272                | 14-Sep   | 86                | 23-Oct     | ·124             | 4-Dec                   | 121        |
| 4-Aug  | 756 ·              | 15-Sep   | 108               | 26-Oct     | 69               | 5-Dec                   | 52         |
| 5-Aug  | 788                | 16-Sep   | 87                | 27-Oct     | . 60             | 6-Dec                   | 157        |
| 6-Aug  | 227                | 17-Sep   | 73                | 28-Oct     | 33               | 7-Dec                   | 87         |
| 7-Aug  | 424                | 18-Sep   | 247               | 29-Oct     | 51               | 8-Dec                   | 183        |
| 8-Aug  | 194                | 19-Sep   | 58                | 30-Oct     | 792.             | 9-Dec                   | 525        |
| 9-Aug  | 963                | 20-Sep   | 87                | 31-Oct     | 387              | 10-Dec                  | 251        |
| 10-Aug | 854                | 21-Sep   | 89                | 1-Nov      | . 34             | 11-Dec                  | 158        |
| 11-Aug | 806                | 22-Sep   | 54                | 2-Nov      | 62               | 12-Dec                  | 539        |
| 12-Aug | 665                | 23-Sep   | 109               | 3-Nov      | 65               | 13-Dec                  | 85         |
| 13-Aug | 1213               | 24-Sep   | 50                | 4-Nov      | 104              | 14-Dec                  | 238        |
| 14-Aug | 288                | 25-Sep   | 62                | 5-Nov      | 2154             | 15-Dec                  | 698        |
| 15-Aug | 471 、              | 26-Sep   | 46                | 6-Nov      | 1102             | 16-Dec                  | 94         |
| 16-Aug | 391                | 27-Sep   | 49                | 7-Nov      | 324              | 17-Dec                  | 117        |
| 17-Aug | 165                | 28-Sep   | 148               | · 8-Nov    | 278              | 18-Dec                  | <b>79</b>  |
| 18-Aug | 455                | 29-Sep   | 71                | 9-Nov      | 338              | 19-Dec                  | 298        |
| 19-Aug | 294                | 30-Sep   | 5 <del>8</del>    | 10-Nov     | 53               | 20-Dec                  | 88         |
| 20-Aug | 74                 | 1-Oct    | 54                | 11-Nov     | 43               | 21-Dec                  | 62         |
| 21-Aug | 330                | . 2-Oct  | 264               | 12-Nov     | 40               | 22-Dec                  | 173        |
| 22-Aug | 590                | 3-Oct    | 317               | 13-Nov     | 95 .             | 23-Dec                  | 142        |
| 23-Aug | 214                | 4-Oct    | 73                | 14-Nov     | 101              | 24-Dec                  | 53         |
| 24-Aug | 342                | 5-Oct    | 53                | 15-Nov     | 92               | 25-Dec                  | 127        |
| 25-Aug | 1222               | 6-Oct    | 41                | 16-Nov     | 145              | 26-Dec                  | 81         |
| 26-Aug | 155                | 7-Oct    | 82                | 17-Nov     | 82               | 27-Dec                  | 92         |
| 27-Aug | 137                | 9-Oct    | 68                | , 18-Nov   | 272              | 28-Dec                  | 120        |
| 28-Aug | 166                | 10-Oct   | 497               | 19-Nov     | , 121            | 29-Dec                  | 89         |
| 29-Aug | 546                | 11-Oct   | 85                | 20-Nov     | 147              | 30-Dec                  | 127        |
| 30-Aug | <b>66</b>          | 12-Oct   | 4591              | 21-Nov     | 94               | 31-Dec                  | 11         |
| 31-Aug | 280                | ·13-Oct  | 194               | 22-Nov     | 110              |                         |            |
| 1-Sep  | 76                 | 14-Oct   | 208               | 23-Nov     | 258              |                         | •          |
| 2-Sep  | 57                 | 15-Oct   | 76,               | 24-Nov     | 185              | _* <b>s</b> ·           |            |
| 3-Sep  | 57                 | 16-Oct   | 45                | · 25-Nov   | 106              | •                       |            |
| 4-Sep  | 45                 | 17-Oct   | 165               | 26-Nov     | 102              | · ·                     |            |
| 5-Sep  | 65                 | 18-Oct   | 146               | 27-Nov     | .81              |                         |            |
| 6-Sep  | ·92                | 19-Oct   | 42                | 28-Nov     | 137              | Average                 | 400        |
| 7-Sep  | 335                | 20-Oct   | 32                | 29-Nov     | <b>66</b>        | Мах                     | 4600       |
| 8-Sep  | 69                 | 21-Oct   | 43                | 30-Nov     | 103              | Min                     | 11         |

<sup>a</sup> From NLCO 1957; original analytical data sheets from the Bioassay Department at the FMPC.

| Page L-116 | The Fernald Dosimetry Reconstruction Project  |
|------------|-----------------------------------------------|
| _          | Tasks 2 and 3. Source Terms and Uncertainties |

|         |      | Discu | argeu to t | de niver ( | mg L - /- |      |      |
|---------|------|-------|------------|------------|-----------|------|------|
|         | 1957 | 1958  | 1959       | 1960       | 1961      | 1964 | 1966 |
| Jan     | 1010 | 140   | 140        | 79         | 110       | 270  | 78   |
| Feb     | 740  | 145   | 105        | 74         | 110       | 270  | 76   |
| Mar     | 430  | 100   | 63         | 93         | 72        | 150  | 57   |
| Apr     | 490  | 180   | 65         | 55         | 55        | 180  | 55   |
| May     | 400  | 180   | 170        | 58         | 89        | 140  | 31   |
| Jun     | 230  | 170   | 140        | 45         | 64        | 96   | 40   |
| Jul     | 290  | 190   | 93         | 72         | 65        | 72   | 150  |
| Aug     | 450  | 320   | 51         | 58         | 50        | 59   | 61   |
| Sep     | 110  | 76    | 57         | 44         | 57        | 38   | · 28 |
| Oct     | 290  | 59    | <b>60</b>  | 54         | 63        | 33   |      |
| Nov     | 230  | 150   | 91 🗇       | 60         | 140       | 55   | 49   |
| Dec     | 175  | 190   | 72         | • 98       | 150       | 63   | 42   |
| Average | 404  | 158   | 92         | 66         | 85        | 119  | 61   |
| StdDev  | 255  | 67    | 39         | 18         | 34        | 84   | 34   |
| Max     | 1010 | 320   | 170        | 98         | 150       | 270  | 150  |
| Min     | 110  | 59    | 51         | · 44       | 50        | 33   | 28   |

Contract the second

A State of the second se

(1999) .....

Table L1-25. Monthly Average Total Suspended Solids (TSS) in Liquid Effluents Discharged to the River (mg L<sup>-1</sup>)<sup>a</sup>

<sup>a</sup> From NLCO 1957, NLCO 1958, NLCO 1959, NLCO 1960, NLCO 1961, NLCO 1964, NLCO 1966; daily measurements of total suspended solids made on 24 hour composite samples from the discharge point at MH 175 to the river.

: \*\*\*; • :: <u>:</u> : •

and the second second second strategy and

|         | at Manhole 175 in      | 1955            |
|---------|------------------------|-----------------|
| 1955    | Total l                | Radium          |
| Date    | μμg mL <sup>-1 a</sup> | mg <sup>h</sup> |
| 16-Sep  | 0.79435                | 3.30            |
| 24-Sep  | 1.4522                 | 6.04            |
| 3-Oct ` | 0.781                  | 3.25            |
| 6-Oct   | 0.0875                 | 0.36            |
| 30-Oct  | 3.141                  | 13.06           |
| 2-Nov   | 0.7114                 | 2.96            |
| 12-Nov  | 3.093                  | 12.86           |
| 15-Nov  | 0.8728                 | 3.63            |
| 3-Dec   | 6.0765                 | 25.27           |
| 6-Dec   | 6.4279                 | 26.73           |
| 9-Dec   | . 2.15                 | 8.94            |
| Mean    | 2.33                   | 9.67            |
| StdDev  | 2.18                   | 9.05            |
| Max     | 6.43                   | 26.73           |
| Min     | 0.09                   | 0.36            |

# Table L1-26. Radium Quantities Measured at Manhole 175 in 1955

<sup>a</sup> NLCO 1955b, analytical data sheets; uug is an outdated unit, equivalent 0.00000000001 g.
 <sup>b</sup> Calculated quantities using same methods for U quantities,

Calculated quantities using same methods for U quantities, assuming effluent flow of 1 million gallons per day to river via Manhole 175, see Figure L-3.

### Radiological Assessments Corporation "Setting the standard in environmental health"

F

ALC: WALL

And Antonia Maria

SOF ST

4 ÷

.:

- ; **-**

| Table L1-27. Measured               | <b>Concentrations and Calculated</b> | Quantities of Radium at |
|-------------------------------------|--------------------------------------|-------------------------|
| and the second second second second | Manhole 175 in 1956                  | •                       |

|                     |                           |         | 11010 110 II          | 1 1000   | ·         |                        | ·      |
|---------------------|---------------------------|---------|-----------------------|----------|-----------|------------------------|--------|
| 1956                | Total Radium              | 1956 -  | <u>93.)</u> (iTotal R | adium    | 1956      | Total Ra               | ıdium  |
| Date                | µµg mL <sup>-1 a</sup> mg | Date    | µµg mL-1 a            | nıg h    | Date      | µµg mL <sup>-1</sup> a | mg h   |
| 7-Jan               | 0.8528 3.55               | 21-May  | 0.737                 | 3.06     | 29-Jun    | 0.1429                 | 0.59   |
| 19-Jan              | 0.9254 3.85               | 22-May  | 0.2447                | 1.02     | 30-Jun    | 0.2608                 | 1.08   |
| 22-Jan              | 0.1153 0.48               | 23-May  | 0.4164                | 1.73     | 1-Jul i   | 0.387                  | 1.61   |
| 15-Apr              | 0.22 0.91                 | 24-May  | 0.0209                | 0.09     | 2-Jul     | 0.9033                 | 3.76   |
| . 16-Apr            | 0.3905 1.62               | 25-May  | 0.1474                | 0.61     | 3-Jul     | 0.3218                 | 1.34   |
| 17-Apr              | 0.27731 1.15              | 26-May  | 0.1262                | 0.52     | 4-Jul     | 0.3609                 | 1.50   |
| 18-Apr              | 0.2751 1.14               | 27-May  | 0.2336                | 0.97     | ี่ 5-Jul∴ | 0.5036                 | 2.09   |
| 19-Apr              | 0.5894 2.45               | 28-May  | 0.2031                | 0.84     | 6-Jul     | 0.155                  | 0.64   |
| 20-Apr              | : 0.1836 0.76             | 29-May  | 0.0811                | 0.34     | 7-Jul     | 0.1532                 | · 0.64 |
| 21-Apr              | 0.1535 0.64               | 30-May  | 0.0999                | 0.42     | 8-Jul     | 0.7199                 | 2.99   |
| 22-Apr              | 0.3286 1.37               | 31-May  | 0.0658                | 0.27     | 9-Jul     | 0.3747                 | 1.56   |
| 23-Apr              | 0.8205 3.41               | · 1-Jun | 0.1051                | 0.44     | 10-Jul    | 1.568                  | 6.52   |
| 24-Apr <sup>-</sup> | 0.5295 2.20               | 2-Jun   | 0.0126                | 0.05     | 11-Jul    | 0.0409                 | 0.17   |
| 25-Apr -            | 0.08 0.33                 | 3-Jun   | 0.3367                | 1.40 /   | 12-Jul    | )i 0.1318              | 0.55   |
| 26-Apr              | 1.25 5.24                 | 4-Jun   | 0.1625                | 0.68     | 13-Jul    | 0.79                   | 3.28   |
| 27-Apr              | 01.48 0 <b>.2</b> 0       | 5-Jun   | 0.4047                | 1.68     | 14-Jul    | 0.047                  | 0.20   |
| 28-Apr              | 0.0975 0.41               | 6-Jun   | 0.4254                | 1.77     | 15-Jul    | 1.1217                 | 4.66   |
| 29-Apr              | 0.221 0.92                | 7-Jun   | 0.5095                | 2.12     | 16-Jul    | 0.4374                 | 1.82   |
| 30-Apr              | 0.03 0.12                 | ∘ 8-Jun | 0.2462                | 1.02     | 17-Jul    | 0 <u>.</u> 9541        | 3.97   |
| 1-May               | 0.154 0.64                | 9-Jun   | 0.5136                | 2.14     | 18-Jul    | 0.1292                 | 0.54   |
| 2-May               | 0.2237 0.93               | 10-Jun  | 0.3551                | 1.48     | 19-Jul    | 0 <b>.996</b>          | 4.14   |
| 3-May               | 0.0938 0.39               | 11-Jun  | 0.1242                | 0.52     | 20-Jul    | . 0.5295               | 2.20   |
| 4-May               | 0.079 0.33                | 12-Jun  | 0.0049                | 0.02     | 21-Jul    | 0.6789                 | · 2.82 |
| 5-May               | 0.0854 0.36               | 13-Jun  | · 0.0249              | 0.10     | 22-Jul    | 0.9204                 | 3.83   |
| 6-May               | 0.0602 0.25               | 14-Jun  | 0.0205                | 0.09     | 23-Jul    | 0.298                  | 1.24   |
| 7-May               | 0.0729 0.30               | 15-Jun  | 0.0481                | 0.20     | 24-Jul    | 0.109                  | 0.45   |
| 8-May               | 0.0175 • 0.07             | 16-Jun  | 0.0146                | 0.06     | 25-Jul    | 11 0 <b>.1</b> 59      | 0.66   |
| 9-May               | 0.0153 0.06               | 17-Jun  | 0.0258                | 0.11     | 26-Jul    | 0.1015                 | 0.42   |
| 10-May              | 0.241 1.00                | 18-Jun' | 0.1534                | 0.64     | 27-Jul    | 0.0858                 | 0.36   |
| 11-May              | 0.23 0.96                 | 19-Jun  | 0.1307                | 0.54     | 28-Jul    | 0.0737                 | 0.31 · |
| 12-May              | 0.2131 0.89               | 20-Jun  | 0.2636                | 1.10     | 29-Jul    | 0.5831                 | 2.42   |
| 13-May              | 0.3951 1.64               | 21-Jun  | 0.2782                | 1.16     | 30-Jul    | 2.5701                 | 10.69  |
| . 14-May            | 0.0555 0.23               | 22-Jun  | 0.4937                | 2.05     | 31-Jul    | 2.9258                 | 12.17  |
| 15-May              | 0.0082 0.03               | 23-Jun  | 0.2965                | . 1.23 . | · ·       |                        |        |
| 16-May              | 0.0063 0.03               | 24-Jun  | 0.1615                | 0.67     |           | •                      |        |
| 17-May              | 0.075 0.31                | 25-Jun  | 0.2475                | 1.03     | Mean      | 0.35                   | 1.44   |
| 18-May              | 0.1775 0.74               | 26-Jun  | 0.172                 | 0.72     | StdDev    | 0.44                   | 1.84   |
| 19-May              | 0.4683 1.95               | 27-Jun  | 0.1076                | 0.45     | Max       | 2.93                   | 12.17  |
| 20-May              | 0.2295 0.95               | 28-Jun  | 0.5067                | 2.11     | Min       | 0.0049                 | 0.02   |

<sup>a</sup> NLCO 1956. Values from original analytical data sheets; *uug* is an outdated unit, equivalent to 0.000000000001 gram.

<sup>b</sup> Calculated quantities using same methods for U quantities, assuming effluent flow of 1 million gallons per day to river via Manhole 175, see Figure L-3.

|          | of Rad                 | ium at Ma | nhole 175 i | in 1957                | quantities  |  |
|----------|------------------------|-----------|-------------|------------------------|-------------|--|
| 1957     | Total Ra               | adium     | 1957        | Total Radium           |             |  |
| Date .   | μμg mL <sup>-1 a</sup> | nig h     | Date        | μμg mL <sup>-1 a</sup> | mgb         |  |
| 1-Jan    | 0.3873                 | 2         | 4-Feb       | 2.043                  | 8.49        |  |
| 2-Jan 🖉  | 1.0107                 | . 4       | 5-Feb       | 1.0436                 | 4.34        |  |
| 3-Jan    | 0.9892                 | 4         | 6-Feb       | 0.9294                 | 3.86        |  |
| 4-Jan    | 5.1073                 | 21        | 7-Feb       | 1.7832                 | 7.41        |  |
| 5-Jan    | 0.9014                 | 4         | 8-Feb       | 1.8905                 | 7.86        |  |
| 6-Jan    | 0.309                  | 1         | 9-Feb       | 2.1296                 | 8.85        |  |
| 7-Jan    | 0.4164                 | 2         | 10-Feb      | 1.9407                 | 8.07        |  |
| 8-Jan    | 0.5862                 | ·<br>2    | 11-Feb      | 0.3313                 | 1.38        |  |
| 9-Jan    | 0.3549                 | 1         | 12-Feb      | 2.0535                 | 8.54        |  |
| 10-Jan   | 0.5732                 | 2         | 13-Feb      | <b>2.6339</b> ·        | 10.95       |  |
| 11-Jan   | 0.3                    | 1         | 14-Feb      | 0.2927                 | 1.22        |  |
| 12-Jan   | 0.8751                 | 4         | 15-Feb      | 1.8532                 | 7.71        |  |
| 13-Jan   | 0.6343                 | . 3       | 16-Feb      | 1.6025                 | 6.66        |  |
| 14-Jan   | 0.2397                 | 1         | 17-Feb      | 0.1939                 | 0.81        |  |
| 15-Jan   | 0.344                  | 1         | 18-Feb      | 1.4565                 | 6.06        |  |
| 16-Jan   | 1.1787                 | 5         | 19-Feb      | 1.3825                 | 5.75        |  |
| 17-Jan   | 0.7535                 | 3         | 20-Feb      | 2.0049                 | 8.34        |  |
| 18-Jan   | 0.4709                 | 2         | 21-Feb      | 0.3253                 | 1.35        |  |
| 19-Jan   | 0.8058                 | 3         | 22-Feb      | 0.0961                 | 0.40        |  |
| 20-Jan   | 0.5284                 | 2         | 23-Feb      | 0.1069                 | <b>0.44</b> |  |
| 21-Jan + | 0.0064                 | 0         | 24-Feb      | 0.0845                 | 0.35        |  |
| 22-Jan   | 0.3082                 | 1.        | 25-Feb      | 1.515                  | 6.30        |  |
| 23-Jan   | 0.0221                 | 0         | 26-Feb      | 1.6653                 | 6.92        |  |
| 24-Jan   | 0.1167                 | 0         | 27-Feb      | 2.2093                 | 9.19        |  |
| 25-Jan   | 0.1868                 | 1         | 28-Feb      | 0.5988                 | 2.49        |  |
| 26-Jan   | 0.8341                 | 3         | 1-Mar       | 1.6952                 | 7.05        |  |
| 27-Jan   | 0.7516                 | 3         | 3-Mar       | 0.4304                 | 1.79        |  |
| 28-Jan   | 1.4341                 | 6         |             |                        |             |  |
| 29-Jan   | 2.5368                 | 11        |             |                        |             |  |
| 30-Jan   | 1.269                  | 5         | Average     | 1.1                    | 4.90        |  |
| 31-Jan   | 0.9171                 | 4         | StdDev      | 1.1                    | 5.10        |  |
| 2-Feb    | 6.4124                 | 26.66     | Max         | 6.41                   | 26.66       |  |
| 3-Feb    | 4.8745                 | 20.27     | Min         | 0.01                   | 0.03        |  |

Table L1-28, Measured Co ations and Calculated Quantities

a NLCO 1957, original analytical data sheets; uug is an outdated unit, equivalent to 0.000000000001 gram. <sup>b</sup> Calculated quantities using same methods for U quantities, assuming effluent

flow of I million gallons per day to river via Manhole 175, see Figure L-3.

Radiological Assessments Corporation "Setting the standard in environmental health"

.....

57.5

| Page I | -120 |
|--------|------|
|--------|------|

1.13 Parts

Colorador.

.

۱,

| and Calculated Activities to the River in 1969 and 1970 |                        |         |                  |                    |            |                                  |                  |  |  |
|---------------------------------------------------------|------------------------|---------|------------------|--------------------|------------|----------------------------------|------------------|--|--|
| 1969 a .                                                | dpm mL <sup>-1 h</sup> | pCi L−l | uCi <sup>e</sup> | : 1970 h           | dpm mL-1 h | <sup>⊥</sup> pCi L <sup>−1</sup> | uCi <sup>c</sup> |  |  |
| 13-Apr                                                  | 4.95                   | 2200    | 44000            | 5-Jan .            | 1.45       | 653                              | 2832             |  |  |
| 20-Apr                                                  | 2.01                   | 900     | 18000            | 12-Jan             | 1.06       | 477                              | 2070             |  |  |
| 4-May                                                   | 4.18                   | 1900    | 37000            | °                  | 1.39       | 626                              | 2715             |  |  |
| 11-May                                                  | 3.32                   | 1500    | 30000            | 26-Jan             | 1.23       | 554                              | 2402             |  |  |
| 18-May                                                  | 2.58                   | 1200    | 23000            | : Feb              | . 1.16     | 522                              | 9709             |  |  |
| 25-May                                                  | 0.70                   | 320     | 6300             | ' Mar              | 1.52       | 684                              | 12722 .          |  |  |
| 8-Jun                                                   | 0.64                   | 290     | <b>~</b> 5700    | Apr                | 2.82       | 1269                             | 23603            |  |  |
| 15-Jun                                                  | 1.16                   | 520     | P10000           | 81 May             | . 3.3      | 1485                             | 27621            |  |  |
| · 22-Jun                                                | 2.09                   | 940     | 18700            | June               | 0.11       | 50                               | 921              |  |  |
| 29-Jun                                                  | 0.33                   | 150     | 2900             | िJuly              | 0.19       | 86                               | 1590             |  |  |
| 6-Jul                                                   | 0.18                   | 83      | 1600             | <sup>°</sup> 3-Aug | 0.048      | 22                               | 187              |  |  |
| 13-Jul                                                  | 0.53                   | 240     | 4700             | 17-Aug             | 0.054      | 24                               | 211              |  |  |
| 20-Jul                                                  | . '0.03                | 13      | 250              | 31-Aug             | 0.069      | 31                               | 270              |  |  |
| 27-Jul                                                  | -0.19                  | ´ 87    | 1700             | 7-Sep              | .''0.08    | .36                              | 312              |  |  |
| 3-Aug                                                   | 0.05                   | 23      | <sup></sup> 460  | '14-Sep            | 0.018      | 8                                | 70               |  |  |
| 10-Aug                                                  | 0.18                   | 80      | 1600             | 28-Sep             | 0.03       | 14                               | 117              |  |  |
| 17-Aug                                                  | 2.08                   | 940     | 18600            | 12-Oct             | < 0.01     | <5                               | <40              |  |  |
| 24-Aug                                                  | 3.08                   | 1400    | · 28000          | 30-Nov             | 0.029      | 13                               | 113              |  |  |
| 31-Aug                                                  | 3.32                   | 1500    | 30000            | 14-Dec             | 0.02       | 9                                | - 78             |  |  |
| 12-Oct                                                  | 4.86                   | 2200    | 43000            |                    |            | · .                              |                  |  |  |
| 19-Oct                                                  | 2.84                   | 1300    | 25000            | •                  | ŧ.         | ·                                | •                |  |  |
| Nov                                                     | 2.56                   | 1200    | ×98000           | ,                  |            | . •                              | •                |  |  |
| Dec                                                     | 3.2                    | 1400    | 122000           | i i                |            | r * .                            |                  |  |  |
| <b>***</b>                                              |                        | •       |                  |                    |            |                                  |                  |  |  |
| Total                                                   |                        |         | 660,000          | Total              | 13.1       | · · · ·                          | 88,000           |  |  |
| Average                                                 | 1.90                   | 870     | 20387            | Average            | 0.81       | 364                              | 4864             |  |  |
| StdDev                                                  | 1.61                   | 726     | 22449            | StdDev             | 1.01       | 456                              | 8330             |  |  |
| Max                                                     | 4.95                   | 2200    | 98000            | Max                | 3.30       | 1485                             | 27621            |  |  |
| Min                                                     | . 0.03                 | 13      | 250              | Min                | 0.02       | 8                                | 70               |  |  |

 Table L1-29. Concentration of 228 Ra Measured at Manhole 175

 and Calculated Activities to the River in 1969 and 1970

<sup>a</sup> NLCO 1969. In 1969, the date represents the beginning of a two-week composite sampling period; Nov and Dec represent monthly composites. All values were taken from original analytical data sheets.

<sup>b</sup> NLCO 1970. In 1970, composite samples were taken weekly in January, biweekly from Aug to Dec, and monthly from Feb to July. All values are from original analytical data sheets.

<sup>c</sup> Calculated quantities using same methods for U quantities, assuming effluent flow of 750,000 gallons per day to river via Manhole 175, see Figure L-3.

. .;.

· .

13

| and Calculated Activities to the River in 1971 |                        |                     |           |                        |                                         |                  |  |  |  |
|------------------------------------------------|------------------------|---------------------|-----------|------------------------|-----------------------------------------|------------------|--|--|--|
| -1971                                          |                        | <sup>226</sup> Ra   |           | <sup>228</sup> Ra      |                                         |                  |  |  |  |
| Date <sup>a</sup>                              | dpm mL <sup>-1 b</sup> | pCi L <sup>-1</sup> | · · uCi ° | dpm mL <sup>-1 b</sup> | pCi L <sup>-1</sup>                     | uCi <sup>e</sup> |  |  |  |
| 17-May                                         | 0.6                    | 270                 | 8900      | 0.06                   | 27                                      | 890              |  |  |  |
| 31-May                                         | 0.3                    | 135                 | 4400      | 0.12                   | 54                                      | 1800             |  |  |  |
| 14-Jun                                         | 0.75                   | 338                 | 11000     | 0.23                   | 104                                     | 3400             |  |  |  |
| 28-Jun                                         | 0.4                    | 180                 | · 5900    | 0.07                   | 32                                      | 1040             |  |  |  |
| 12-Jul                                         | 0.28                   | 126                 | 4100      | 0.01                   | 5                                       | 150              |  |  |  |
| 26-Jul                                         | 0.14                   | 63                  | 2100      | 0.03                   | - 14                                    | 440              |  |  |  |
| 16-Aug                                         | 0.42                   | 189                 | 6200      | 0.08                   | . 36                                    | 1200             |  |  |  |
| 30-Aug                                         | 0.41                   | 185                 | 62100     | 0.14                   | 63                                      | 2100             |  |  |  |
| 13-Sep                                         | 0.09                   | 41                  | 1300      | 0.01                   | 5                                       | 150              |  |  |  |
| 27-Sep                                         | 0.02                   | 9                   | 300       | 0.03                   | 14                                      | 440              |  |  |  |
| 11-Oct                                         | 0.02                   | 9                   | 300       | 0.03                   | 14                                      | 440 .            |  |  |  |
| 1-Nov                                          | 0.06                   | 27                  | 890       | 0.04                   | 18                                      | 590              |  |  |  |
| 15-Nov                                         | 0.02                   | 9                   | 300       | 0.05                   | 23                                      | 740              |  |  |  |
| 29-Nov                                         | . 0.06                 | 27                  | 890       | 0.02                   | 9                                       | 300 .            |  |  |  |
| 13-Dec                                         | 0.46                   | 207                 | 6800      | <0.01                  | _<4.5                                   | <10              |  |  |  |
|                                                |                        |                     |           |                        | ••••••••••••••••••••••••••••••••••••••• | •                |  |  |  |
| Average                                        | • 0.27                 | 121                 | 4000      | 0.07                   | . 30                                    | 970              |  |  |  |
| StdDev                                         | 0.23                   | 105                 | 3400      | 0.06                   | 28                                      | 910              |  |  |  |
| Max                                            | 0.75                   | 338                 | 11,000    | 0.23                   | 104                                     | 3400             |  |  |  |
| Min                                            | 0.02                   | 9                   | 300       | 0.01                   | 5                                       | 150              |  |  |  |

Table L1-30. Concentration of <sup>226</sup>Ra and <sup>228</sup>Ra Measured at Manhole 175 and Calculated Activities to the River in 1971

<sup>a</sup> Beginning date of sampling period; two-week composites. Average, Max and Min values represent a two-week period.

<sup>b</sup> NLCO 1971. Values from original analytical data sheets; reported as disintegrations per minute per milliliter, dpm/mL.

<sup>c</sup> Calculated quantities using same methods for U quantities, assuming effluent flow of 620,000 gallons per day to river via Manhole 175, see Figure L-3.

| Page I | L-122 |
|--------|-------|
|--------|-------|

South States

and the part

Notes and a second

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainties

| and Calculated Activities to the River in 1972 |                                       |                     |                    |                        |                     |        |  |  |  |
|------------------------------------------------|---------------------------------------|---------------------|--------------------|------------------------|---------------------|--------|--|--|--|
| 1972                                           | · · · · · · · · · · · · · · · · · · · | <sup>226</sup> Ra   |                    |                        | <sup>228</sup> Ra   |        |  |  |  |
| Date <sup>a</sup>                              | dpm mL <sup>-1 b</sup>                | pCi L <sup>-1</sup> | uCi <sup>e</sup>   | dpm mL <sup>-1 h</sup> | pCi L <sup>-1</sup> | uCi c  |  |  |  |
| 3-Jan                                          | 0.51                                  | 230                 | 7500               | <0.01                  | <4.5                |        |  |  |  |
| 17-Jan                                         | 0.44                                  | 198                 | 6500               | <0.01                  | <4.0                | •      |  |  |  |
| 31-Jan                                         | 0.35                                  | 158                 | 5200               | 0.06                   | 27                  | 890    |  |  |  |
| 14-Feb                                         | 0.4                                   | 180 · · ·           | 5900               | 0.12                   | 54                  | 1800   |  |  |  |
| 28-Feb                                         | 0.12                                  | 54                  | 1800               | 0.02                   | 9                   | 300    |  |  |  |
| 13-Mar                                         | 0.08                                  | 36                  | 1200               | <0.01                  | <4.5                |        |  |  |  |
| 3-Apr                                          | 0.05                                  | 23 👘                | 740                | 0.02                   | · 9                 | 300    |  |  |  |
| 17-Apr                                         | 0.04                                  | 18                  | 590                | 0.02                   | • •9                | 300    |  |  |  |
| 1-May                                          | 0.09                                  | 41                  | 1300               | 0.02                   | 9                   | - 300  |  |  |  |
| 15-May                                         | 0.15                                  | <b>68</b> 200       | 2200               | 0.07                   | 32                  | 1040   |  |  |  |
| 29-May                                         | 0.13                                  | .59                 | 1900               | 0.13                   | 59                  | 1900   |  |  |  |
| 12-Jun                                         | 0.11                                  | <b>50</b>           | 1600               | 0.15                   | 68                  | 2200   |  |  |  |
| 3-Jul                                          | 0.01                                  | 5                   | 150 <sup>- 5</sup> | 0.02                   | 9                   | 300    |  |  |  |
| 17-Jul                                         | 0.06                                  | 27                  | 890                | 0.02                   | -9                  | 300    |  |  |  |
| 31-Jul                                         | 0.04                                  | 18 🍧 🛸              | 590                | 0.02                   | • 9                 | 300    |  |  |  |
| 14-Aug                                         | 0.08                                  | <b>36</b>           | 1200               | 0.01                   | 5                   | 150    |  |  |  |
| 4-Sep                                          | 0.05                                  | 23                  | 740                | 0.01                   | 5.                  | 150    |  |  |  |
| 18-Sep                                         | 0.02                                  | 9                   | 300                | 0.01                   | 5                   | 150    |  |  |  |
| 2-Oct                                          | 0.02                                  | 9                   | 300                | 0.01                   | 5                   | - 150  |  |  |  |
| · 16-Oct                                       | 0.02                                  | 9                   | 300                | <0.01                  | <4.5                | ·· <10 |  |  |  |
| 30-Oct                                         | 0.07                                  | 32                  | 1000               | 0.01                   | 5                   | 150    |  |  |  |
| 13-Nov                                         | 0.08                                  | 36                  | 1200               | 0.01                   | 5                   | 150    |  |  |  |
| 27-Nov                                         | 0.1                                   | 45                  | 1500               | <0.01                  | <4.5                | <10    |  |  |  |
| 11-Dec                                         | 0.08                                  | 36                  | 1200               | · <0.01                | <4.5                | · <10  |  |  |  |
|                                                |                                       |                     |                    |                        |                     |        |  |  |  |
| Average                                        | 0.13                                  | 58 <sup>11</sup>    | 1900               | 0.04                   | 19                  | 600    |  |  |  |
| StdDev                                         | 0.14                                  | <b>64</b>           | 2100               | 0.05                   | 21                  | 680    |  |  |  |
| Max                                            | 0.51                                  | 230                 | 7500               | 0.15                   | 68                  | 2200   |  |  |  |
| Min                                            | 0.01                                  | 5                   | 150                | 0.01                   | 5                   | 150    |  |  |  |

# Table L1-31. Concentration of <sup>226</sup>Ra and <sup>228</sup>Ra Measured at Manhole 175

Beginning date of sampling period; two-week composite. Average, Max and Min

values represent a two-week period, two week temposite. Inverage, Max and Min NLCO 1972. Values from original analytical data sheets; reported as disintegrations per minute per milliliter, dpm per mL. Ь

<sup>c</sup> Calculated quantities using same methods for U quantities, assuming effluent flow of 620,000 gallons per day to river via Manhole 175, see Figure L-3.

| Page L | -123 |
|--------|------|
|--------|------|

|                   | and Calculated Activities to the River in 1973 |                                  |                  |          |          |       |                      |                       |  |
|-------------------|------------------------------------------------|----------------------------------|------------------|----------|----------|-------|----------------------|-----------------------|--|
| 1973              | <sup>226</sup> Ra                              |                                  |                  | `        | 228Ra    |       |                      | Total Radium          |  |
| Date <sup>a</sup> | dpm mL-11                                      | <sup>h</sup> pCi L <sup>-1</sup> | uCi <sup>e</sup> | dpm mL-1 | h pCiL-1 | uCi " | dpm mL <sup>-1</sup> | h pCi L <sup>-1</sup> |  |
| 1-Jan             | 0.03                                           | 14                               | 440              | 0.03     | 14       | 440   | 0.06                 | 27                    |  |
| 15-Jan            | 0.05                                           | 23                               | 740              | 0.01     | 5        | 150   | 0.06                 | 27                    |  |
| 29-Jan            | 0.06                                           | 27                               | 890              | 0.01     | 5        | 150   | 0.07                 | 32                    |  |
| 12-Feb            | 0.04                                           | 18                               | 590              | 0.02     | 9        | 300   | 0.06                 | 27                    |  |
| 26-Feb            | 0.02                                           | 9                                | 300              | 0.01     | 5        | 150   | 0.03                 | 14                    |  |
| 19-Mar            | 0.01                                           | 5                                | 150              | 0.02     | 9        | 300   | 0.03                 | 14                    |  |
| 2-Apr             | 0.01                                           | 5                                | 150              | 0.02     | 9        | 300   | 0.03                 | 14                    |  |
| 16-Apr            | 0.01                                           | 5                                | 150              | 0.03     | 14       | 440   | 0.04                 | 18                    |  |
| 30-Apr            | 0.01                                           | 5                                | 150              | 0.01     | 5        | 150   | 0.02                 | 9                     |  |
| 14-May            | 0.01                                           | 5                                | 150              | 0.01     | 5        | 150   | 0.02                 | 9                     |  |
| 28-May            | 0.01                                           | 5                                | 150              | 0.03     | 14       | 440   | 0.04                 | 18                    |  |
| 11-Jun            | 0.01                                           | 5                                | 150              | 0.02     | 9        | 300   | 0.03                 | 14                    |  |
| 2-Jul             | 0.02                                           | 9                                | 300              | 0.02     | 9        | 300   | 0.04                 | 18                    |  |
| 16-Jul            | 0.11                                           | 50                               | 1600             | 0.01 -   | 5        | 150   | 0.12                 | 54 ·                  |  |
| 30-Jul            | 0.49                                           | 221                              | 7200             | <0.01    | <4.5     |       | 0.5                  | 225                   |  |
| 13-Aug            | 0.18                                           | 81                               | 2700             | <0.01    | <4.5     |       | 0.19                 | 86                    |  |
| 3-Sep             | 0.07                                           | 32                               | 1000             | <0.01    | <4.5     |       | 0.08                 | 36                    |  |
| 17-Sep            | . 0.04                                         | 18                               | 590 ·            | <0.01    | <4.5     |       | 0.05                 | 23                    |  |
| 1-Oct             | 0.03                                           | 14                               | 440              | 0.02     | 9        | 300   | 0.05                 | 23                    |  |
| 15-Oct            | 0.03                                           | 14                               | 440              | <0.01    | <4.5     |       | 0.04                 | 18                    |  |
| 29-Oct            | 0.02                                           | 9                                | 300              | <0.01    | <4.5     |       | 0.03                 | 14                    |  |
| 12-Nov            | 0.02                                           | . 9                              | 300              | 0.01     | 5        | 150   | 0.03                 | 14                    |  |
| 3-Dec             | 0.04                                           | 18                               | 590              | 0.01     | 5        | 150   | 0.05                 | 23                    |  |
| 17-Dec            | 0.04                                           | 18                               | . 590            | <0.01    | <4.5     |       | 0.05                 | 23                    |  |
|                   | •                                              |                                  |                  |          |          |       |                      |                       |  |
| Average           | 0.06                                           | 26                               | 840              | 0.02     | 8        | 262   | 0.07                 | 32                    |  |
| StdDev            | 0.10                                           | 45                               | 1500             | 0.01     | . 3      | 8     | 0.10                 | 44                    |  |
| Max               | 0.49                                           | 221                              | 7200             | 0.03     | • 14     | 31    | 0.5                  | 225                   |  |
| Min               | 0.01                                           | · 5                              | 150              | 0.01     | 5        | 10    | 0.02                 | 9                     |  |

÷

...

. . . .

### Table L1-32. Concentration of <sup>226</sup>Ra and <sup>228</sup>Ra Measured at Manhole 175 and Calculated Activities to the River in 1973

<sup>a</sup> Beginning date of sampling period; two-week composite. Average; Max and Min values represent a two-week period.

<sup>b</sup> NLCO 1973. Values from original analytical data sheets; reported as disintegrations per minute per milliliter, dpm per mL.

<sup>c</sup> Calculated quantities using same methods for U quantities, assuming effluent flow of 620,000 gallons per day to river via Manhole 175, see Figure L-3.
| Page L–124 | The Fernald Dosimetry Reconstruction Project  |
|------------|-----------------------------------------------|
|            | Tasks 2 and 3. Source Terms and Uncertainties |

|   |            |            | •                 | and Calc   | ulated .            | Activities to                   | the Rive | er in 1974            | , •, r. |
|---|------------|------------|-------------------|------------|---------------------|---------------------------------|----------|-----------------------|---------|
|   | ·•         |            | 1974              | • •        | <sup>226</sup> Ra   |                                 |          | <sup>228</sup> Ra     |         |
|   |            |            | Date <sup>a</sup> | dpm mL-1 b | pCi L <sup>-1</sup> | uCi °                           | dpm mL-1 | b pCi L <sup>-1</sup> | uCi     |
|   |            |            | - 13-Jan          | 0.04       | 18                  | 590                             | 0.01     | 5                     | 150     |
|   |            |            | 27-Jan            | 0.04       | 18                  | 91.0 <b>590</b> A               | 0.01     | 5                     | 150     |
|   | . <i>•</i> |            | 10-Feb            | 0.02       | 9                   | 300                             | 0.01     | .: 5                  | 150     |
|   | •          |            | 24-Feb            | 0.04       | 18                  | 590                             | 0.02     | · 9 ·                 | 300     |
|   | 14         | ••         | 10-Mar            | 0.04       | 18                  | 590                             | 0.03     | '14                   | 440 ï   |
|   |            | · ·        | 28-Mar            | 0.04       | 18                  | 590                             | 0.06     | 27                    | 890     |
|   |            | 2          | 14-Apr            | 0.02       | 9                   | 300                             | 0.04     | 18                    | 590     |
|   |            | •          | 28-Apr            | 0.02       | <b>9</b> '          | 300                             | 0.02     | - 9                   | .300    |
|   |            | · • ·      | 12-May            | 0.02       | 9                   | 300                             | 0.01     | 5                     | 150     |
|   | ••         |            | 2-Jun             | 0.02       | 9                   | 300                             | 0.01     | 5                     | 150     |
|   |            | ,<br>, , , | 16-Jun            | 0.02       | 9                   | 300                             | 0.01     | 1. 4 <b>5</b>         | 150     |
|   | ·          | · · · ·    | 30-Jun            | 0.02       | 9                   | 300                             | 0.01     | 5                     | 150     |
|   |            | ··· 、      | 14-Jul            | 0.02       | 9                   | <b>300</b> , ET                 | 0.02     | 9                     | 20      |
|   | t .        | ં કેલ્લ મ  | 28-Jul            | 0.02       | · 9 ,               | - SN 300 - A                    | 0.01     | 5                     | 150     |
|   | : : :      |            | 11-Aug            | 0.02       | : 9 :               | <sup>° °</sup> 300 <sup>°</sup> | 0.01     | 5                     | 150     |
|   | 3          |            | 1-Sep             | 0.01       | 5                   | <sup>t</sup> 150                | 0.01     | 5                     | 150     |
|   | •          | 173.       | 15-Sep            | 0.02       | 9                   | <b>300</b>                      | 0.01     | 5                     | 150     |
|   | •          |            | 29-Sep            | 0.02       | <b>``9</b> ```      | 300                             | 0.01     | - 5                   | 150     |
| • |            |            | 13-Oct            | 0.02       | 9                   | 300                             | 0.01     | 5                     | - 150   |
|   |            |            | 28-Oct            | 0.01       | 5                   | 150                             | 0.01     | - 5                   | 150     |
|   | •          | ÷.,        | 11-Nov            | 0.03       | 14                  | 440                             | 0.04     | · <b>18</b>           | : 590   |
|   |            |            | 25-Nov            | 0.01       | 5.                  | 150                             | 0.02     | 9                     | 300     |
|   |            |            | 9-Dec             | 0.01       | 5                   | 150                             | 0.02     | - 9                   | 300     |
|   | • .'       |            | . 30-Dec          | 0.02       | 9 -                 | 300                             | 0.02     | 9                     | 300     |
|   |            |            | · · ·             |            | ÷                   |                                 |          | •                     |         |
|   | . •        | · -        | Average           | 0.02       | 10                  | 340                             | 0.02     | 8                     | 260     |
|   |            |            | StdDev            | 0.01       | 5                   | 150                             | 0.01     | 6                     | 190     |
|   |            | •          | Max               | 0.04       | 18                  | 590                             | 0.06     | 27                    | 890     |
|   |            | · · ·      | Min               | . 0.01     | _ 5                 | ( <b>150</b>                    | 0.01     | , 5                   | 150     |

# Table L1-33. Concentration of <sup>226</sup>Ra and <sup>228</sup>Ra Measured at Manhole 175

<sup>a</sup> Beginning date of sampling period for two-week composite. Average, Max and Min values represent a two-week period.
<sup>b</sup> NLCO 1974, original analytical data sheets; reported as disintegrations per minute per milliliter, dpm per mL.

per milliliter, dpm per mL. <sup>c</sup> Calculated quantities using same methods for U quantities, assuming effluent flow of 620,000 gallons per day to river via Manhole 175, see Figure L-3.

1. -1

11.000

 $\dot{\gamma}$  h

1

# Appendix L Surface Water Discharges

10.17

į

| Table L1-34. Quanti | y of Thorium (m | L <sup>-1</sup> ) Measured | l at Manhole | 175 in 1956 <sup>a</sup> |
|---------------------|-----------------|----------------------------|--------------|--------------------------|
|---------------------|-----------------|----------------------------|--------------|--------------------------|

|        | <br>  | L' Dett |            |        | <b>T</b> |        |        |        | (T).    | Det     |       |
|--------|-------|---------|------------|--------|----------|--------|--------|--------|---------|---------|-------|
|        | 10    |         | <u></u>    | Date   | <u></u>  | Date   | Th     | Date   | <u></u> | Date    | Th    |
| 18-Apr | 0.4   | 9-Jun   | 0.22       | 21-Jul | 0.82     | 3-Sep  | 0.54   | 15-Oct | 0.06    | 20-NOV  | 2.82  |
| 19-Apr | 0.4   | 10-Jun  | 0.52       | 22-Jul | 0.76     | 4-Sep  | 0.1    | 16-Uct | 0.23    | 21-NOV  | 0.87  |
| 20-Apr | 0.45  |         | 0.51       | 23-JU  | 0.64     | 5-Sep  | 0.14   | 17-Uct | 0.76    | 28-INOV | 2.06  |
| 21-Apr | 0.46  | 12-Jun  | 0.48       | 24-JUI | 0.5      | 6-Sep  | 0.13   | 18-Uct | 0.97    | 29-NOV  | 0.34  |
| 22-Apr | 0.27  | 13-Jun  | 0.23       | 25-Jui | 0.38     | 7-Sep  | nd     | 19-0ct | 0.27    | 30-Nov  | 1.94  |
| 23-Apr | 0.32  | 14-Jun  | 0.19       | 26-Jul | 0.4      | 8-Sep  | nd     | 20-Oct | 0.61    | 1-Dec   | 1.58  |
| 24-Apr | 0.34  | 15-Jun  | 0.58       | 27-Jul | nd       | 9-Sep  | 0.008  | 21-Oct | 1.2     | 2-Dec   | 0.8   |
| 25-Apr | 0.24  | 16-Jun  | 0.34       | 28-Jul | nd       | 10-Sep | nd     | 22-Oct | 0.11    | 3-Dec   | 1.07  |
| 26-Apr | . 0.3 | 17-Jun  | 0.27       | 29-Jul | 0.16     | 11-Sep | 0.003  | 23-Oct | 0.34    | 4-Dec   | nd    |
| 27-Apr | 0.64  | 18-Jun  | 0.5        | 30-Jul | 0.61     | 12-Sep | 0.61   | 24-Oct | 0.4     | 5-Dec   | 0.02  |
| 28-Apr | 0.32  | 19-Jun  | 0.66       | 31-Jul | 0.28     | 13-Sep | 1.16   | 25-Oct | nd      | 6-Dec   | 0.36  |
| 29-Apr | 0.34  | 20-Jun  | 0.1        | 2-Aug  | 0.21     | 14-Sep | 0.36   | 26-Oct | 0.15    | 7-Dec   | 0.12  |
| 30-Apr | 0.52  | 21-Jun  | 0.32       | 3-Aug  | 0.74     | 15-Sep | · 0.32 | 27-Oct | 0.34    | 8-Dec   | nd    |
| 1-May  | 0.18  | 22-Jun  | 0.52       | 4-Aug  | 0.58     | 16-Sep | 0.94   | 28-Oct | 0.47    | 9-Dec   | 1.03  |
| 5-May  | 0.23  | 23-Jun  | 0.42       | 5-Aug  | 0.3      | 17-Sep | 0.66   | 29-Oct | 0.54    | 10-Dec  | 1.03  |
| 6-May  | 0.42  | 24-Jun  | 0.72       | 6-Aug  | 0.34     | 18-Sep | 0.2    | 30-Oct | 0.1     | 11-Dec  | 0.74  |
| 7-May  | 0.32  | 25-Jun  | 0.79       | 7-Aug  | , 0.51   | 19-Sep | 0.59   | 31-Oct | 0.1     | 12-Dec  | nd    |
| 8-May  | 0.15  | 26-Jun  | 0.51       | 8-Aug  | 0.2      | 20-Sep | 0.85   | 1-Nov  | 0.85    | 13-Dec  | nd    |
| 9-May  | 0.44  | 27-Jun  | 0.11       | 9-Aug  | 0.5      | 21-Sep | 1.6    | 2-Nov  | 0.49    | 14-Dec  | 0.85  |
| 10-May | nd    | 28-Jun  | 0.74       | 10-Aug | 0.22     | 22-Sep | 0.46   | 3-Nov  | 0.71    | 15-Dec  | 5.72  |
| 11-May | 0.27  | 29-Jun  | <b>1.3</b> | 11-Aug | 0.19     | 23-Sep | 0.54   | 4-Nov  | 0.79    | 16-Dec  | 4.12  |
| 12-May | 0.47  | 30-Jun  | 0.51       | 12-Aug | 0.25     | 24-Sep | 0.2    | 5-Nov  | 0.88    | 17-Dec  | 4.76  |
| 13-May | 0.3   | 1-Jul   | 0.9        | 13-Aug | 0.4      | 25-Sep | 0.67   | 6-Nov  | 0.61    | 18-Dec  | 1.8   |
| 14-May | 0.64  | · 2-Jul | 0.61       | 14-Aug | nd       | 26-Sep | 0.74   | 7-Nov  | 1.1     | 19-Dec  | 3.66  |
| 15-May | 0.72  | 3-Jul   | 1.1        | 15-Aug | 0.09     | 27-Sep | 1 '    | 8-Nov  | 0.79    | 20-Dec  | 3.8   |
| 16-May | 0.24  | 4-Jul   | 0.64       | 16-Aug | 0.2      | 28-Sep | 0.7    | 9-Nov  | 0.29    | 21-Dec  | 2.92  |
| 17-May | 0.04  | 5-Jul   | 0.72       | 17-Aug | nd       | 29-Sep | 1.15   | 10-Nov | 0.84    | 22-Dec  | 1.92  |
| 18-May | 0.38  | 6-Jul   | 0.47       | 18-Aug | 0.27     | 30-Sep | 0.54   | 11-Nov | 0.59    | 23-Dec  | 1.8   |
| 19-May | 0.48  | 7-Jul   | 0.12       | 19-Aug | 0.51     | 1-Oct  | 0.49   | 12-Nov | 0.25    | 24-Dec  | 1.54  |
| 20-May | 0.58  | 8-Jul   | 0.34       | 20-Aug | 0.09     | 2-Oct  | 0.14   | 13-Nov | nd      | 25-Dec  | 1.09  |
| 21-May | 1.06  | 9-Jul   | 0.4        | 21-Aug | 0.4      | 3-Oct  | 0.49   | 14-Nov | 1.6     | 26-Dec  | 0.8   |
| 22-May | 0.92  | 10-Jul  | 0.9        | 22-Aug | 0.09     | 4-Oct  | 0.58   | 15-Nov | 0.71    | 27-Dec  | 0.91  |
| 23-May | 0.84  | 11-Jul  | 1.4        | 23-Aug | 0.1      | 5-Oct  | 0.38   | 16-Nov | · 1.3   | 28-Dec  | 1.92  |
| 24-May | 0.48  | 12-Jul  | 0.27       | 24-Aug | 0.44     | 6-Oct  | nd     | 17-Nov | 1.28    | 29-Dec  | 2.18  |
| 25-May | 0.38  | 13-Jul  | 0.36       | 25-Aug | nd       | 7-Oct  | 0.016  | 18-Nov | 1.32    | 30-Dec  | 2.51  |
| 26-Mav | 0.14  | 14-Jul  | 0.76       | 26-Aug | 0.42     | 8-Oct  | nd     | 19-Nov | 0.61    | 1       |       |
| 27-Mav | 0.24  | 15-Jul  | 0.2        | 27-Aug | 0.36     | 9-Oct  | 0.36   | 20-Nov | 1.56    | · ·     |       |
| 28-Mav | 0.6   | 16-Jul  | 0.64       | 28-Aug | nd       | 10-Oct | 0.27   | 21-Nov | 0.56    |         |       |
| 29-May | 0.34  | 17-Jul  | 0.44       | 29-Aug | 0.18     | 11-Oct | 0.31   | 22-Nov | 0.71    | Avg     | 0.70  |
| 30-Mav | 0.56  | 18-Jul  | 0.36       | 30-Aug | 0.2      | 12-Oct | 0.1    | 23-Nov | 2.22    | StdDev  | 0.77  |
| 7-Jun  | 0.74  | 19-Jul  | 0.31       | 31-Aug | 0.1      | 13-Oct | 0.57   | 24-Nov | 0.81    | Max     | 5.7 · |
| 8-Jun  | 0.34  | 20-Jul  | 1.14       | 1-Sep  | 0.2      | 14-Oct | 0.32   | 25-Nov | 3.3     | Min     | 0.003 |

<sup>a</sup> From NLCO 1956.

: .

nd none detected

.

Radiological Assessments Corporation "Setting the standard in environmental health"

÷

٠.

· . · · · · · · · · · · ·

# Page L-126

| able L1-35. Quantity of Thorium (mg L <sup>-1</sup> ) Measured |         |          |              |  |  |  |
|----------------------------------------------------------------|---------|----------|--------------|--|--|--|
| Date                                                           | Thorium | Date     | Thorium      |  |  |  |
| l-Jan                                                          | 2.75    | 3-Feb    | 0.66         |  |  |  |
| 2-Jan                                                          | 2.07    | 4-Feb    | 0.3          |  |  |  |
| 3-Jan                                                          | 13.08   | 5-Feb    | 0.56         |  |  |  |
| 4-Jan                                                          | 2.46    | 6-Feb    | 0.42         |  |  |  |
| 5-Jan                                                          | 2.73    | 7-Feb    | 0.7          |  |  |  |
| 6-Jan                                                          | 2.28    | 8-Feb    | 0.74         |  |  |  |
| 7-Jan                                                          | 1.48    | 9-Feb    | 0.84         |  |  |  |
| 8-Jan                                                          | 2.28    | 10-Feb   | <b>40.26</b> |  |  |  |
| 9-Jan                                                          | 1.76 🐧  | 11-Feb   | 1.76         |  |  |  |
| 10-Jan                                                         | 1.12    | 12-Feb   | 1:22         |  |  |  |
| 11-Jan                                                         | 1.42    | 13-Feb   | 1.65         |  |  |  |
| 12-Jan                                                         | 2.6     | 14-Feb   | 1.34         |  |  |  |
| 13-Jan                                                         | 1.96    | 15-Feb   | 0.88         |  |  |  |
| 14-Jan                                                         | 0.48    | 16-Feb   | 0.18         |  |  |  |
| 15-Jan                                                         | 1.24    | 17-Feb   | 1.16         |  |  |  |
| 16-Jan                                                         | 0.62    | 18-Feb   | 1.02         |  |  |  |
| 17-Jan                                                         | 0.26    | 19-Feb   | 0.34         |  |  |  |
| 18-Jan                                                         | 0.28    | . 20-Feb | 0.24         |  |  |  |
| 19-Jan                                                         | 0.14    | 21-Feb   | 178          |  |  |  |
| 20-Jan                                                         | 0.16    | 22-Feb   | <b>4</b> ,02 |  |  |  |
| 21-Jan                                                         | 0.14    | 23-Feb   | đ.07         |  |  |  |
| 22-Jan                                                         | 0.48    | 24-Feb   | 0.21         |  |  |  |
| 23-Jan                                                         | 0.06    | 25-Feb   | 0.95         |  |  |  |
| 24-Jan                                                         | 0.2     | 26-Feb   | 0.28         |  |  |  |
| 25-Jan                                                         | 0.14    | 27-Feb   | 0.21         |  |  |  |
| 26-Jan                                                         | 0.16    | 28-Feb   | nd           |  |  |  |
| 27-Jan                                                         | 0.42    | 1-Mar    | 0.12         |  |  |  |
| 28-Jan                                                         | 0.42    | •        |              |  |  |  |
| 29-Jan                                                         | 1       |          |              |  |  |  |
| 30-Jan                                                         | 0.88    | Average  | 0.60         |  |  |  |
| 31-Jan                                                         | 0.7     | StdDev   | 0.42         |  |  |  |
| 1-Feb                                                          | 0.88    | Max      | 178          |  |  |  |
| 2-Feb                                                          | 0.86    | Min      | 0.02         |  |  |  |

<sup>a</sup> From NLCO 1957. nd - none detected

· · .

. . . .

Appendix L Surface Water Discharges

٠,

•.\*

:

5

٠,

......

|      | Effluent Volume ( | million gallons)         |
|------|-------------------|--------------------------|
| Year | Great Miami River | Paddy's Run <sup>b</sup> |
| 1959 | . 371             | 26                       |
| 1960 | 397               | 28                       |
| 1961 | 465               | 41                       |
| 1962 | 343               | 60                       |
| 1963 | 303               | 70                       |
| 1964 | 330               | 78                       |
| 1965 | 261               | 66                       |
| 1966 | . 299             | 87                       |
| 1967 | 313               | 35                       |
| 1968 | <b>324</b> .      | 22                       |
| 1969 | 274               | 36                       |
| 1970 | - 270             | 28                       |
| 1971 | 249               | 24                       |
| 1972 | 189               | 31                       |
| 1973 | 242               | 17                       |
| 1974 | 212               | 34                       |
| 1975 | 221               | 19                       |
| 1976 | 183               | 10                       |
| 1977 | 169               | 11                       |
| 1978 | 180               | 12`                      |
| 1979 | 199               | 17                       |
| 1980 | 149               | 5                        |
| 1981 | 163               | 2                        |
| 1982 | 179               | 11                       |
| 1983 | 172               | 14                       |
| 1984 | 213               | 15                       |

<sup>a</sup> From Cuthbert 1960–1961, Flowers 1959–1962, Marshall 1963, Rathgens 1974, Ross 1958, Shwan 1967–1983, Starkey 1958b, Starkey 1960–1961, WMCO 1989.

<sup>b</sup> Through the Storm Sewer Outfall Ditch.

Radiological Assessments Corporation "Setting the standard in environmental health"

Page L-127

# APPENDIX M

#### GROUNDWATER CONTAMINATION OUTSIDE THE FMPC

#### INTRODUCTION

.

1

Byrne et al. (1991) provides a brief history of the measurement of offsite uranium contamination in groundwater around the FMPC. Sampling by the State of Ohio in late 1981 indicated elevated levels of gross beta radioactivity in three wells south of the FMPC. Subsequent sampling by the FMPC showed that the activity was due to naturally-occurring <sup>40</sup>K, and thus not associated with the FMPC. However, the FMPC sampling showed significantly elevated concentrations of uranium in other wells near the site. Because of the elevated uranium concentrations, the FMPC groundwater monitoring program was expanded in 1982 to include many private wells around the site. Since then the private well monitoring program has continued, with frequent expansions to include other wells.

The significant offsite uranium contamination in groundwater is south of the site, and is now called the "South Plume." Uranium concentrations in wells in the South Plume remain elevated. There are additional known areas of groundwater contamination on the FMPC site, but only the South Plume area extends outside the site boundary at this time (Byrne et al. 1991; FERMCO 1993). Since this dose reconstruction project is concerned with past doses to people around the site, the groundwater contamination to be considered in this Project is limited to the South Plume. Figure M-1 shows the estimated areal extent of the South Plume uranium contamination as of the end of 1991, as well as the locations of the private wells monitored (discussed later). The area of the South Plume has been estimated by the FMPC (Schwarzman 1992b), based on monitoring results from the private wells and from other monitoring wells, not shown in Figure M-1. The area shown includes the area where uranium concentrations are estimated to be greater than 20  $\mu$ g L<sup>-1</sup> (or about 13.5 pCi L<sup>-1</sup>). Of the private wells monitored by the FMPC, only three, numbers 12, 15, and 17, have shown uranium concentrations above the range of background (Fleming and Ross 1983; Fleming and Ross 1984; Facemire et al. 1985; Aas et al. 1986; WMCO 1987; WMCO 1988; WMCO 1989; Dugan et al. 1990; Byrne et al. 1991). Although well 26 is within the area of groundwater contamination, it is screened deeper in the aquifer, and the uranium concentrations are at background levels.

In our report of Task 4 of this Project (Killough et al. 1993), we concluded that because of the limited area of the South Plume, only a small number of people would have potentially received radiation doses from contaminated groundwater. Toward the main objective of this Project, the determination of the feasibility of an epidemiological study, doses to these people would be less important than doses through other pathways. For this reason, we further concluded that a detailed assessment of the groundwater transport of radionuclides and detailed assessments of doses to individuals potentially exposed through groundwater pathways, are not warranted. For other project objectives, it is still important to estimate potential doses through the groundwater pathway, so instead we use simple



# The Fernald Dosimetry Reconstruction Project management Tasks 2 and 3, Source Terms and Uncertainty



Figure M-1. Approximate area of uranium-contaminated groundwater in the South Plume, as of the end of 1991, as estimated by the FMPC (Schwarzman 1992b). The area shown includes the area where uranium concentrations are estimated to be greater than 20  $\mu$ g L<sup>-1</sup> (or about 13.5 pCi L<sup>-1</sup>). Locations of the private wells around the FMPC sampled in the FMPC routine monitoring program are also shown, based on annual environmental monitoring reports (Fleming and Ross 1983; Fleming and Ross 1984; Facemire et al. 1985; Aas et al. 1986; WMCO 1987; WMCO 1988; WMCO 1989; Dugan et al. 1990; Byrne et al. 1991). Although well 26 is within the area of groundwater contamination, it is screened deeper in the aquifer, and the uranium concentrations are at background levels. Sampling point W7 is a location for sampling the surface water in Paddy's Run, at the Willey Road bridge.

#### General provident provident.

· ' ,

methods to estimate concentrations of uranium in the three contaminated wells. For the small group of people exposed to the contaminated groundwater, doses will be calculated later, in Task 6 of this Project.

For those years for which groundwater uranium monitoring data are available, the measured concentrations in private wells around the FMPC will be used directly in

#### Appendix M

.

ः

÷.

#### Groundwater Contamination Outside the FMPC

exposure assessments. Measurements have been obtained for late 1981 through 1992, and will be used to estimate annual average concentrations for 1982–1988 (the scope of this Project includes assessing doses through 1988 only).

For years when groundwater monitoring data are not available, we estimate uranium concentrations that might have existed in the three contaminated wells. In this Appendix, we investigate the lateral movement of contaminated groundwater to offsite locations of groundwater use. Based on that analysis, we conclude that uranium contamination in the groundwater had not migrated outside the FMPC boundary by 1962. However, sometime between 1962 and the end of 1981, uranium contamination in the South Plume had migrated offsite and into private wells. Recent studies of the groundwater around the FMPC site (Dames and Moore 1985; DOE 1990a) have concluded that the primary source of the uranium contamination in the groundwater is uranium in waters released to the storm sewer outfall ditch (SSOD) and to Paddy's Run (see Figure M-1). The soils in parts of the outfall ditch and Paddy's Run are very permeable, and apparently allow contaminated water to move directly downward into the aquifer. For 1963-1981, we first calculate an upper bound on uranium concentrations in the three contaminated wells in the South Plume. For a more realistic assessment, uranium concentrations are calculated using an empirical model, that uses the available measured concentrations in the wells and the quantities of uranium released from the FMPC into Paddy's Run and the SSOD.

There are three annexes to this Appendix. The first includes tables of data that support calculations described in the text. Annex 2 includes information about quantities of uranium discarded to the waste pits on the FMPC. Information about the transport of uranium deposited on the ground surface may be useful to other parts of this Project. A special study of this transport was performed for this Project, and is summarized in Annex 3.

In this Appendix, concentrations of uranium in water are generally presented as total uranium concentrations using activity units (pCi L<sup>-1</sup>). However, in some cases we retain the units of the original information source. To convert from activity units to mass units (or vice versa), the specific activity of natural uranium has been assumed to apply. The value of  $6.75 \times 10^{-7}$  Ci g<sup>-1</sup> (Rich et al. 1988) has been used.

#### POTENTIAL SOURCES OF GROUNDWATER CONTAMINATION FROM FMPC

The status of groundwater contamination in the vicinity of the FMPC has been investigated (Dames and Moore 1985; Solow and Phoenix 1987; DOE 1990a; WMCO 1990). These studies indicate there are two potential sources of groundwater contamination originating on the FMPC site (see Figure M-1): (1) historical releases of uraniumcontaminated water to Paddy's Run and to the Storm Sewer Outfall Ditch (SSOD), and (2) possible releases from the solid and liquid waste pits in the waste storage area.

Paddy's Run is a small stream which generally flows only during January to May (Pennak 1973). The flow rate ranges from 0.2 to 4.0 ft<sup>3</sup> s<sup>-1</sup>. For the balance of the year it may be considered a dry bed stream with occasional flash flows of a few hours duration following heavy rains. The bottom sediments of Paddy's Run and the SSOD are very permeable in the area north and west of the South Plume, so these areas are recharge areas

7

š

17.13.1 H

1. N. N. N.

10/0.04

for the regional aquifer (DOE 1990a). Thus, uranium contamination in Paddy's Run and the SSOD percolates downward through the permeable sediments to ultimately reach the groundwater. As discussed in Appendix L of this report, releases of uranium directly to Paddy's Run were due to storm water runoff across contaminated ground on the FMPC, primarily areas on the western part of the site. Releases to the SSOD were primarily from overflows of the site storm sewer system, when heavy rains exceeded the storm sewer lift station capacity.

Of the potential sources, the principal source of uranium contamination in the South Plume has been determined to be the historical releases to Paddy's Run and the SSOD (DOE 1990a). The waste pits probably have not been significant direct contributors to the uranium contamination outside the site boundary. Runoff from contamination in and around the waste pits, however, probably contributed to releases to Paddy's Run. While it appears the waste pits are not of great concern relative to the groundwater contamination, Annex 2 of this Appendix provides some information about materials disposed of in the waste pits. Additional discussion regarding the waste pits can be found in Appendix K.

### RADIONUCLIDES OF CONCERN IN THE SOUTH PLUME GROUNDWATER

The radionuclide of primary concern in the South Plume has been uranium (see, for example, DOE 1990a; Dames and Moore 1985; Byrne et al. 1991). However, other radionuclides were also released into surface waters, so the potential exists for other radionuclides to be present in the South Plume groundwater. Appendix D of this report discusses releases of radionuclides other than uranium from the FMPC to air and to surface waters. In Appendix D we performed a screening-level assessment of the relative importance of radionuclide releases to surface waters, based primarily on information about releases to the Great Miami River. From this assessment, the radium isotopes <sup>226</sup>Ra and <sup>228</sup>Ra were determined to be of primary importance (see Appendix D).

However, this determination only applies to radionuclides in surface waters. For radionuclides in groundwater, the environmental transport is different, and different exposure pathways may be pertinent. Since large quantities of these two radium isotopes were released to surface waters, they would be of concern in the groundwater if they migrated into the South Plume along with the uranium.

From recent environmental monitoring reports for the FMPC, it appears that the private, offsite wells have not been routinely monitored for radionuclides other than uranium (Dugan et al. 1990; Byrne et al. 1991; WEMCO 1992; FERMCO 1993). In the 1989 report, radionuclides other than uranium were not discussed (Dugan et al. 1990). The 1990 report summarized results from the comprehensive groundwater program (which involves wells in addition to the routine monitoring wells), which monitored for <sup>90</sup>Sr, <sup>99</sup>Tc, <sup>226</sup>Ra, <sup>228</sup>Ra, and <sup>232</sup>Th (Byrne et al. 1991). This report only provided those results that were above the Department of Energy (DOE) concentration guidelines for drinking water. For these other radionuclides, none of the wells in the South Plume area exceeded the guidelines. In the 1991 and 1992 reports, no results for other radionuclides were presented, due to problems with data validation (WEMCO 1992; FERMCO 1993).

# Appendix M Groundwater Contamination Outside the FMPC

.

لغذائ

.

As part of the Remedial Investigation/Feasibility Study (RI/FS) of the environmental restoration work at the FMPC, a study of the South Plume groundwater included installation of additional groundwater monitoring wells, followed by sampling and analysis of these new wells and the existing monitoring wells in the late 1980s and 1990 (DOE 1990a). The radionuclide analyses of the well samples included total uranium, total thorium, isotopic uranium, isotopic thorium, isotopic plutonium, <sup>226</sup>Ra, <sup>223</sup>Ra, <sup>237</sup>Np, <sup>99</sup>Tc, <sup>90</sup>Sr, and gamma-emitting radionuclides by gamma spectroscopy. Except for uranium, none of these

Another report prepared for the RI/FS work included a comprehensive compilation of groundwater contamination monitoring data from August 1987 through April 1990, as well as descriptions of the nature and extent of groundwater contamination at the FMPC (DOE 1990b). Some results from that report are summarized here. Outside the FMPC boundary, the only recurrent detections of radionuclides other than uranium were for <sup>226</sup>Ra and <sup>228</sup>Ra, both at a monitoring well (not one of the private wells) near the town of Fernald, south of New Haven Road (see Figure M-1 for general location). These measured concentrations were low and were spatially isolated. It was concluded that the presence of radium in this well was probably not due to the South Plume. No other radionuclides (other than uranium and radium) were recurrently detected in the wells of the South Plume area. Thus, for all radionuclides other than uranium, it was concluded that the FMPC was not contributing significant quantities to the South Plume.

radionuclides were found at concentrations above natural background (DOE 1990a).

Based on these studies of other radionuclides, there are no indications that other radionuclides are present in offsite groundwater in concentrations above background. It appears that radium and other radionuclides have not migrated into the South Plume groundwater in significant quantities. We note that the sampling for other radionuclides was limited to a few, recent years, with no results for private wells. We conclude that uranium is the primary radionuclide of concern in the South Plume groundwater. Thus, uranium is the only radionuclide considered in the remainder of this Appendix.

# • PRELIMINARY INVESTIGATION OF LATERAL MOVEMENT OF CONTAMINATED GROUNDWATER TO OFFSITE LOCATIONS

The migration of contamination in the aquifer to offsite locations is a critical factor in the assessment of potential doses from groundwater. The time of arrival of the contaminated plume at wells, primarily located south of the FMPC, determines the time of first potential exposure of individuals using well water for various purposes. A special study, that is summarized below, was conducted to determine whether the contaminated water had migrated to offsite locations from the FMPC prior to 1962 (Ichimura 1991a). That date was chosen because the period of interest for the preliminary report of Tasks 2 and 3 of this Project was 1960-1962 (Voillequé et al. 1991).

The purpose of the analysis was to estimate the time of possible exposure to contaminated groundwater using published information. To accomplish this objective, it was necessary to estimate horizontal movement of the plume and its position relative to the southern boundary of the FMPC. We use "groundwater velocity" to mean the horizontal rate

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page M-5

- · · ·

of movement of the groundwater, and "solute velocity" or "plume velocity" for the effective rate of movement of the contaminant (or the contaminant plume front) in the aquifer.

The published information used for this analysis of groundwater movement comes from reports by Advanced Sciences, Inc., and International Technology Corp. (ASI-IT 1990), and GeoTrans (1985). These reports assimilate large quantities of geologic, hydrologic, chemical, and source term data to construct a model of the south groundwater plume.

## Analysis of the ASI-IT Model

Groundwater travel time estimates can be based on the provisionally calibrated groundwater flow and transport model described in the report "Engineering Evaluation/Cost Analysis South Plume" that was prepared by ASI-IT (1990). Appendix A of that report describes a three-dimensional solute transport model. Results of calculations made using this model show the projected plume would carry uranium beneath New Haven Road near Highway 128 and eventually to the Great Miami River just upstream of the confluence with Paddy's Run. The velocity of groundwater along the plume is about 1,300 ft  $y^{-1}$ .

At the present time (actually, for 1989), plume geometry, as calculated by the computer model, is an elongated ellipse oriented in the northwest-southeast direction (Figure M-2). Analytical data from the Remedial Investigation/Feasibility Study (RI/FS) program, available as of September 15, 1989, were utilized for the evaluation of the South Plume by ASI-IT (1990). This orientation is due to the channeling of groundwater through a narrow north-south buried aquifer. Areas of maximum predicted uranium concentrations, for 1989, are located approximately 800 ft south of Willey Road. The maximum uranium concentration predicted by the model is 600  $\mu$ g L<sup>-1</sup>. The area occupied by the plume exceeding 30  $\mu$ g L<sup>-1</sup> is approximately 100 acres.

The northern boundary of the plume is defined by a curved line, through the storm sewer outfall ditch and Paddy's Run, in which uranium loading occurs. The groundwater recharge rate along this boundary is 32 in  $y^{-1}$ . The loading concentration is variable and unspecified in the ASI-IT (1990) report.

Another parameter assumed in the model is a distribution coefficient of 0.016 ft<sup>3</sup> lb<sup>-1</sup> (1.0 mL g<sup>-1</sup>). According to the ASI-IT report, the corresponding retardation factor is 9. The best model calibration for a retardation factor of 9 was attained using a longitudinal dispersivity of 50 ft and a transverse dispersivity of 1 ft.

According to the ASI-IT report, the model of the South Plume gives an approximate plume length of 4,200 ft at 1990 conditions. Furthermore, the groundwater solute transport model indicates that the horizontal plume velocity is 220 ft  $y^{-1}$ . Therefore, the estimated horizontal spread of the plume has occurred for the time: (4,200 ft)/(220 ft  $y^{-1}$ ) = 19 y. This number means that the plume would have begun migrating laterally away from the point where the contaminants entered the aquifer roughly 19 years ago. Assuming that current conditions refer to January, 1990, the initial entry of uranium into the sand and gravel aquifer must have occurred by 1971. Prior to that time, the contaminants would have been moving downward from the surface to the aquifer. According to this model, no contaminants would have reached the aquifer or been transported laterally away from the point of entry in the early sixties.



20

Figure M-2. Model-calculated estimate of the extent of the groundwater plume as of 1989. The boundary shown represents a calculated concentration of 30  $\mu$ g L<sup>-1</sup> (about 20 pCi L<sup>-1</sup>). Redrawn from ASI-IT (1990).

The foregoing analysis is based on information reported for the ASI-IT model of the South Plume. According to the ASI-IT report, the groundwater flow model is considered to be well calibrated because the model has successfully reproduced flow conditions throughout the South Plume area. However, the calibration of the solute transport is considered to be provisional because of uncertainty with calibration of retardation and dispersivity. Decreasing the retardation factor will increase the rate of movement of the plume. Similarly, increasing the dispersivity will increase the rate of plume spreading.

To estimate the plume boundary using the solute transport model, ASI-IT had to estimate the contaminant source term loading rates. Contaminant loading time periods and source areas were fixed. However, the time rate of contaminant release was varied as part of the model calibration and was originally derived from literature reviews. Finally, ASI-IT did not provide the source term data in its report.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

The model produces a horizontal projection of the South Plume. Because the distance traveled by the plume is measured in the horizontal plane, the travel time analysis does not include time required for transport in the vertical direction. This component of the total travel time can be significant because low permeability materials underlie areas around the FMPC. Therefore, only a minimum travel time can be determined using this analysis.

GeoTrans Groundwater Modeling Analysis

Other estimates of groundwater velocities were reported as part of an earlier groundwater modeling study (GeoTrans 1985). In that study, the reported groundwater velocity was 800 ft  $y^{-1}$ . Assuming that the plume velocity has the same relationship to the groundwater velocity as in the ASI-IT (1990) report, the velocity of the plume is estimated to be (800/1300)×(220), or about 135 ft  $y^{-1}$ . Using this estimate for the plume velocity and the current plume length of 4200 ft, the initial release of uranium to the aquifer is estimated to have occurred 31 years before 1990, or prior to 1959.

Groundwater particle tracing studies conducted by GeoTrans (1985) showed a groundwater travel time of 3.4 years to the FMPC southern boundary. The uranium migration rate is expected to be less than that of the groundwater because of retardation effects. If the GeoTrans estimate is accurate, the South Plume would have been about 400 ft in length, or just at the southern border of the FMPC at year 1962. Therefore, it is unlikely that the significant part of the South Plume was offsite and impacting wells in 1962 based on this model.

### **Conclusions About Lateral Movement of Groundwater Contamination**

Because the recent ASI-IT (1990) study uses more current data and additional model refinements, its results should be more reliable and are preferred for that reason. The width of the aquifer varies near the FMPC, and consequently the groundwater flow velocity also varies. The ASI-IT study shows the slower horizontal flow near the FMPC (the aquifer is relatively wide there), in the recharge area, and the faster flow near the village of Fernald, south of the site (the aquifer narrows between two outcrops of bedrock).

Based on results provided by ASI-IT (1990), the estimated initial release of uranium into the sand and gravel aquifer occurred by 1971. However, earlier more conservative estimates, based on a report by GeoTrans (1985) indicate that the horizontal South Plume development occurred by 1959 and may have barely reached the southern border of the FMPC in 1962. These preliminary estimates indicate that the plume of uranium contaminated water did not impact offsite groundwater users until after 1962.

#### **URANIUM CONCENTRATIONS IN PRIVATE WELL WATER FOR 1982–1988**

As discussed in our Task 5 Report (Shleien et al. 1993), the most important program for monitoring uranium concentrations in private well water around the FMPC has been the FMPC monitoring program. The FMPC began its routine monitoring of private wells around the site in early 1982 (Byrne et al. 1991), although results were not reported in the annual environmental report for 1982 (Fleming and Ross 1983). Since the wells sampled were not

#### Appendix M

1

÷.,

#### Groundwater Contamination Outside the FMPC

under the control of the FMPC, inclusion in the program was based on the well owner's request. Samples were generally taken on a monthly frequency, although a few of the wells were sampled less frequently. The annual environmental reports for 1983-1990 (Fleming and Ross 1983; Fleming and Ross 1984; Facemire et al. 1985; Aas et al. 1986; WMCO 1987; WMCO 1988; WMCO 1989; Dugan et al. 1990; Byrne et al. 1991) generally provide the minimum, maximum, and annual average uranium concentrations for each well in the monitoring program.

The locations of the private wells sampled in the FMPC program are shown in Figure M-1. The well locations were obtained from the annual environmental reports and from a detailed drawing obtained from the FMPC (Schwarzman 1992a). In our Task 5 Report (Shleien et al. 1993), we presented annual average concentrations for wells 1 through 38 for years 1983 through 1990, obtained from the annual environmental monitoring reports. We also presented monthly measurement results for the three contaminated wells, wells 12, 15, and 17 for November 1981 through February 1985, obtained from a compilation by the groundwater study of Dames and Moore (1985).

Also in our Task 5 Report, we examined the annual average concentrations for the 1983-1990 period to estimate a range of background concentrations. We concluded that a reasonable estimate of the range of long-term average, background concentrations of uranium in private well water around the FMPC, for individual wells, is 0.09 to 1.3 pCi L<sup>-1</sup> (total uranium). This range compares well with background concentrations estimated by the FMPC (Byrne et al. 1991) to be 0.068-2.2 pCi L<sup>-1</sup>. These background concentrations can be used for comparisons to the concentrations in the contaminated wells.

Additional, detailed results of the FMPC monitoring have been obtained. Kraps (1993) provides results of the monthly results for the private well sampling, for 1984 through 1992. The monthly results for the three contaminated wells, wells 12, 15, and 17, are compiled in Table M1-1, in Annex 1 of this Appendix. In Table M1-1 we also repeat the monthly results for these three wells for 1981 through 1983, from a compilation in Dames and Moore (1985).

From the monthly concentrations, annual average concentrations for 1982–1992 for the three contaminated wells are calculated, with the results shown in Table M-1. Here we convert the mass concentrations to radioactivity concentrations, with units of pCi  $L^{-1}$ . Since only one or two results were available in 1981 for these wells, we do not calculate annual averages for 1981. The annual average concentrations are also plotted in Figure M-3. These annual average concentrations, for 1982–1988, will be used as the basis of dosimetry calculations for these years, in Task 6 of this Project (the scope of this Project includes calculating doses through only 1988).

# ESTIMATED UPPER BOUND ON URANIUM CONCENTRATIONS IN PRIVATE WELL WATER IN THE SOUTH PLUME FOR 1963–1981

In this section we describe preliminary calculations, to develop an upper bound estimate of the concentrations of uranium that might have existed for 1963–1981 in the South Plume groundwater, prior to the start of monitoring.

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

| ·. · ·                                                                                                           | Year | Well 12       | Well 15 | Well 17 |   |
|------------------------------------------------------------------------------------------------------------------|------|---------------|---------|---------|---|
| •                                                                                                                | 1982 | 170           | 320     | 45      | _ |
| • • •                                                                                                            | 1983 | - <b>180</b>  | .290    | -39     |   |
| •                                                                                                                | 1984 | 170 .         | 220     | 36      |   |
| •                                                                                                                | 1985 | 140           | 200     | 31 .:   |   |
| and the second | 1986 | 150           | 190     | 31      |   |
| A Green Hotel                                                                                                    | 1987 | 200           | 200     | 40.     |   |
|                                                                                                                  | 1988 | 170           | 190     | 38      |   |
| •                                                                                                                | 1989 | 170 s at 1 75 | 190     | 27      |   |
| · · · ·                                                                                                          | 1990 | 130 ·         | 180     | 30.     | • |
|                                                                                                                  | 1991 | 100           | 170     | 27      |   |
|                                                                                                                  | 1992 | 100           | 150     |         |   |



Figure M-3. Annual average concentrations of uranium in well water for the three contaminated private wells, for 1982 through 1992.

**Basis for Upper Bound Estimate** 

As discussed earlier in this Appendix, it has been determined that the principal source of uranium contamination in the South Plume is the historical releases to Paddy's Run and the SSOD. Because of the finite velocity of the uranium plume in the groundwater, there would be a time lag between the release of uranium to Paddy's Run and the SSOD, and the appearance of the contamination in downgradient wells in the aquifer, such as wells 12, 15, and 17 in the South Plume. Uranium concentrations at these downgradient wells due to surface water releases from a particular time should not exceed concentrations measured in surface water runoff from Paddy's Run and the SSOD. Therefore, we use surface water concentrations as an upper bound on uranium concentrations that might have existed in wells 12, 15, and 17 for the period 1963-1981.

Appendix M.

÷7.

.

#### Groundwater Contamination Outside the FMPC

Page M–11

This use of surface water concentrations to bound groundwater concentrations is applicable for the following reasons. Sources of groundwater that eventually flow into the South Plume area of the aquifer include groundwater flowing from the west and the north, in two branches of the same aquifer, water from bedrock, and recharge sources (DOE 1990a). Recharge sources in the area include precipitation recharge and recharge by stream infiltration through Paddy's Run, the SSOD, and other streams (DOE 1990a). Surface waters which recharge from Paddy's Run and the SSOD will be diluted by groundwater from the other sources. Therefore, groundwater concentrations of uranium could be as high as surface water concentrations only when a large quantity of recharge from infiltration in Paddy's Run and the SSOD occur, and when there is no mixing with existing groundwater from other sources.

-- : : :

#### Applicable Uranium Concentration Data for Paddy's Run and the SSOD

In our Task 5 Report (Shleien et al. 1993), we compiled measured concentrations of uranium in Paddy's Run, sampled by the FMPC at sampling point W7, the Willey Road bridge (Figure M-1). Results for 1955-1965 and 1975-1991 were obtained, and are shown in Table M-2. Because this location was downstream from the confluence of the SSOD and Paddy's Run, uranium concentrations here are diluted by clean water from north of the site.

Concentrations of uranium in the SSOD are obtained both from measurements and from estimates based on release quantities and release volumes. Measurement results for 1954– 1957, 1960–1964, and 1966 are presented in Appendix L. These measurements were made at the overflow outfall from the storm sewer lift station. When sufficient measurement data for effluent volumes were available, we calculated the annual average uranium concentration as the volume-weighted average of the individual concentration values. For other cases, an unweighted average was used. Additional measurement results, for 1975–1984, are compiled in Dames and Moore (1985). All of these results were from FMPC measurements. The annual average concentrations measured in the SSOD are shown in Table M-2.

In Appendix L of this report, estimates of the quantities of uranium released to Paddy's Run were developed. The majority of uranium released was to the SSOD, with a smaller quantity going directly into Paddy's Run. In Appendix L we also compiled data on the water volumes released in the SSOD. The uranium release quantities and release volumes can be used to estimate the concentrations released to the SSOD. These estimates will generally be biased somewhat high, since not all of the uranium released was through the SSOD. However, the estimates should be adequate for our purposes. Table M1-2 shows the release quantities; release volumes, for years for which complete data were obtained; and estimated release concentrations of uranium. The estimated release concentrations (in the SSOD) are also shown in Table M-2. For 1963, 1966, and 1982, the estimated concentrations are significantly less than the measured concentrations, by factors of about 2 to 3. These discrepancies are not readily explained, though for 1963 and 1966 the effluent volume data were incomplete, thus not allowing a volume-weighted average of the measured values.

For comparison, Table M-2 also shows the annual average uranium concentrations in well 15, from Table M-1. We use well 15 for comparison purposes because it has had the highest uranium concentrations of the contaminated wells, for the periods measured.

Page M–12

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

# Table M-2. Comparison of Uranium Concentrations in Well 15 with Those in Paddy's Run and the SSOD

.....

.....

-----

. .

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | ,            | Uranium d                             | oncentrations                                 | in water (p                           | Ci L <sup>-1</sup> ) |                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|---------------------------------------|-----------------------------------------------|---------------------------------------|----------------------|--------------------|
| 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | lear         | Paddy's Run at<br>Willey Road         | Measured 2.                                   | Estimated<br>SSOD                     | Well 1               | .5                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 952          |                                       | a the states of the                           | <br>                                  | · · ·                | · · ·              |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 953          |                                       | ಸ್ಟರ್ಷ-೧೮೮೪                                   | ан 1 <sup>3</sup>                     | · , .                | ÷.,                |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 954          | 1. Sec. 4. 4.                         | 230                                           | ·                                     |                      | . 11 -             |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 955          | 100                                   | 290                                           |                                       | i ,                  |                    |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 956          | 240                                   |                                               | *,i                                   | ·                    | •                  |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 957          | 100                                   | 970                                           |                                       | · .                  |                    |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 958          | 480                                   |                                               |                                       |                      |                    |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 959          | 780                                   | , <u>, , , , , , , , , , , , , , , , , , </u> | 5800                                  | •                    | •                  |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 960          | · 1100                                | 6400                                          | 8300                                  |                      |                    |
| 1 <b>1</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 961          | <b>470</b>                            | <b>4900</b>                                   | 6100                                  | 27                   |                    |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 962          | 367                                   | <u>(* 5400</u> a. 7                           | 4500                                  | <b>`</b> . ·         | Sec. 3.            |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 963          | 690                                   | 4500                                          | 2300                                  | · · · •              | · , · · .          |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 964          | 720                                   | ຸຼ3700                                        | 3900                                  | • • •                |                    |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 965          | 580                                   | au 1. 1.                                      | 1700                                  | 2                    | on or the          |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 966          | ; · · ·                               | 4900                                          | 1600                                  | •                    |                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 967          |                                       |                                               | 3800                                  |                      | · ·                |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 968          | 1                                     | 41 49, 411 1<br>10                            | 2900                                  |                      | •                  |
| r state for the state of the st | 969          | i i terreta dest                      | e de la Calendaria                            | 1400                                  | •••                  | · · ·              |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 970,         | 1                                     |                                               | 2200                                  |                      | - 1 - <i>1</i> - 1 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 971          |                                       | l spoke to the                                | 3700                                  | · · ·                | ta a tela          |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 912          | · ·                                   | er en     | 1900                                  | •                    |                    |
| 11                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 313<br>171 - |                                       | •                                             | 2400                                  |                      | 2 18 J.L.          |
| 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 914<br>075   | 01                                    | EOF                                           | 1300                                  |                      | · · · · · · · · ·  |
| 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 970<br>976   | 160                                   | - 120.<br>1200 <sup>4</sup>                   | 4800                                  |                      |                    |
| 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 570.<br>577  |                                       |                                               | 4000                                  | ·                    |                    |
| 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 478 .        | 63                                    | 2.1.25.00 - 1.1.<br>2.30                      | 1000                                  | •                    |                    |
| 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 270          | 11                                    | 790                                           | 280                                   |                      |                    |
| 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 980          | 10 •                                  | 500                                           | 1800                                  |                      | -                  |
| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 981          | · 21 · · · ·                          | 230                                           | 1800                                  | • •                  |                    |
| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 982          | 12                                    | 560                                           | 320                                   | 320                  | •                  |
| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 983          |                                       | 320                                           | × 690                                 | 290                  | 1932 - 1           |
| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 984          | 15                                    | 420                                           | 680                                   | 220                  |                    |
| . 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 985          | 43                                    |                                               | 000                                   | 200                  |                    |
| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 986          | 49                                    | and a second second                           |                                       | 190                  | p. ~               |
| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 987          | 5.8                                   | an tratic de la para la<br>Anticipat          | , , , , , , , , , , , , , , , , , , , | 200                  |                    |
| - 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 988          | 7                                     |                                               |                                       | 190                  | a a stat           |
| - 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 989          | 6.4                                   |                                               | •                                     | 190                  |                    |
| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 9 <b>90</b>  | 6.5 ar                                | ment and an                                   | ·                                     | 180                  |                    |
| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 91           | 5                                     | tetter at the                                 | 5. re 3                               | 170                  |                    |
| 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 992          | · · · · · · · · · · · · · · · ·       |                                               | · · · ·                               | 150                  | γ.                 |
| and a second                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |              | · · · · · · · · · · · · · · · · · · · |                                               |                                       |                      |                    |

and the second 
and the second 
•

.

.

.

÷.,

3

### Estimated Upper Bound Uranium Concentration

For the short length of time that monitoring of private wells has been performed, the concentrations of uranium in well 15 are seen to be generally lower than concentrations in the SSOD, but higher than concentrations in Paddy's Run at the Willey Road bridge (Table M-2). This relationship is consistent with (though it does not prove) waters from both Paddy's Run and the SSOD being the sources of the groundwater contamination. It seems reasonable that this relationship would also have generally existed in earlier years (before well measurements were made, starting in late 1981). However, when the plume first reached the well, concentrations in the well water may have initially been much lower.

We thus conclude that an upper bound on the annual average concentrations of uranium in the three contaminated wells for 1963-1981 is the maximum annual average concentration in the SSOD for earlier years. Based on the data in Table M-2, this upper bound is 8300 pCi  $L^{-1}$ , for releases in 1960. For this upper bound we use the estimated concentration, because the measurement data were available only for part of the year (see Appendix L), and because the estimated value was similar to the average of the available measured results.

We recognize that this upper bound on uranium concentrations that might have existed in private wells in the South Plume area for 1963-1981 is an extremely conservative (i.e. the estimated value is too high) estimate of uranium concentrations in the wells. The upper bound is conservative for at least three important reasons. First, of the measured and estimated uranium concentrations in the SSOD, for 1952–1988, we used the highest annual average value, and assumed it applied to the whole period 1963–1981. Second, the uranium that infiltrated into the groundwater came from both the SSOD and Paddy's Run. In Table M-2, uranium concentrations in the SSOD and in Paddy's Run are shown, with concentrations in Paddy's Run lower than in the SSOD. The combined source would have had uranium concentrations between those of the two sources, which would have been lower than concentrations in the SSOD. And third, dilution of the uranium infiltrating into the groundwater from the SSOD and Paddy's Run was not considered. As discussed earlier (see page M-11), sources of groundwater that eventually flow into the South Plume area of the aquifer include groundwater flowing into the area from the west and the north, in two branches of the same aquifer, water from bedrock, and recharge sources (DOE 1990a). Surface water recharge from Paddy's Run and the SSOD would be diluted by uncontaminated groundwater from the other sources, thus reducing the concentrations of uranium in the aquifer.

# ESTIMATED URANIUM CONCENTRATIONS IN PRIVATE WELL WATER IN THE SOUTH PLUME FOR 1963–1988, BASED ON AN EMPIRICAL MODEL

We believe the use of the upper bound uranium concentration of 8300 pCi  $L^{-1}$ , to represent uranium concentrations in water at private wells in the South Plume for the complete period 1963-1981, is unrealistically conservative. In this section we describe a ratio model used to determine a more realistic, though still somewhat conservative, estimate of uranium concentrations in the private wells during 1963-1981.

# Linear, Empirical Model with Travel Time

Historical releases of uranium from the FMPC into Paddy's Run or the SSOD did not immediately move into the offsite part of the South Plume groundwater. The uranium had to move downstream, to the area where the aquifer outcrops in the stream bottoms, infiltrate vertically through the stream bed and underlying soil to reach the aquifer, and then migrate horizontally, in the aquifer, southward into the South Plume area. We use a model to describe this movement of uranium from historical releases into the South Plume groundwater.

General model. Figure M-4 shows the steps involved in the transport of uranium from FMPC releases to wells in the South Plume. The general model we use is based on an assumption that uranium concentrations in the water at each point in the transport are directly related to concentrations (or releases quantities) at the previous point, and that this relationship is multiplicative, by a constant factor. For each of the three transport steps, this assumption seems a reasonable first approximation. The solubility of the uranium is important in determining how much uranium migrates into the aquifer. Our assumption of a constant multiplicative factor implicitly includes an assumption of a constant ratio of soluble uranium to insoluble uranium in the surface water releases, for all years of releases.



Figure M-4. Generalized description of the transport of uranium from historical FMPC releases into the SSOD and Paddy's Run to groundwater wells in the South Plume area. The arrows represent the three steps involved in the transport. The boxes show the different endpoints of each step.

Given that each step of the transport can be represented by such constant, multiplicative factors, the model is described by the following set of equations.

o de la seguidad de la companya de l La companya de la comp Appendix M Groundwater Contamination Outside the FMPC

 $C_1 = R_1 Q$   $C_2 = R_2 C_1 \qquad (M-1)$   $C = R_3 C_2$ 

where  $C_1$  is the concentration of uranium in surface water,  $C_2$  is the concentration in groundwater in vertical flow, C is the concentration at wells in the South Plume, Q is the annual quantity of uranium released from the FMPC to the SSOD and Paddy's Run, and  $R_1$ ,  $R_2$ , and  $R_3$  are constant ratio factors.

C

These equations can be rewritten as:

$$= RQ \qquad (M-2)$$

where the overall ratio factor is

.

. در ۲۰

1

$$R = R_1 R_2 R_3 \tag{M-3}$$

Measured uranium concentrations (C) in South Plume wells are available for some years, and quantities of uranium released from the FMPC into the SSOD and Paddy's Run (Q) have been estimated for all operating years. These data can be used to estimate the ratio factor R by calculating values of C/Q.

The general model given by equation M-2 will be developed further for application to the available data. To summarize, this model assumes that there is a linear relationship between annual quantities of uranium released (Q) and annual average concentrations of uranium in the wells in the South Plume (C), and the relationship can be represented by a constant factor R. The model is empirical in that available data for release quantities and measured well concentrations will be used to estimate the ratio factor R, which will then be used to estimate the concentrations C for which measurements do not exist.

Specific model. The discussion of the general model neglected the time required for transport of the uranium through each step. This transport time is referred to as travel time. In Figure M-4 we have shown travel times  $T_1$ ,  $T_2$ , and  $T_3$ , associated with each transport step. The total travel time T, from the stream water to the groundwater in the South Plume area, is the sum of the three individual travel times. From studies of the lateral movement of uranium contamination in groundwater (summarized on page M-8), we concluded that by 1962 the uranium contamination had not extended outside the FMPC boundary. Since uranium releases to Paddy's Run and the SSOD began in 1952, the travel time for uranium to move from these surface waters to reach the nearest private wells in the South Plume area is many years. Thus, travel time is accounted for in the specific implementation of the empirical model.

The travel times for the vertical transport into the aquifer  $(T_2)$  and horizontal transport in the aquifer  $(T_3)$  are at least a few years (as discussed later). However, the travel time in surface waters  $(T_1)$  is very much shorter, because the distance from the uranium release points to the area where infiltration into the aquifer occurred is very short. We thus ignore the travel time  $T_1$ .

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

and the second 
and the first first state of the

To account for travel time between uranium releases and arrival of contamination at wells, we use the following empirical model. Here we have added the subscript i to indicate that calculations are performed on an annual basis.

$$C_i = R_{i,T}Q_{i-T}$$

(M-4)

where

 $C_i$  = estimated annual average concentration of uranium in groundwater at private wells in the South Plume area, for year *i* (pCi L<sup>-1</sup>).

- $R_{i,T}$  = ratio factor, to relate uranium release quantities to estimated concentrations in the South Plume groundwater (pCi L<sup>-1</sup> per kg). The subscript *T* indicates that the ratio factors may be different for different travel times. For a given travel time, *T*, a single distribution of ratio factors will be applied to each year *i*. The subscript *i* is used because the uncertainties in the ratio factors for individual years are considered independent.
- $Q_{i-T}$  = the quantity of uranium (kg) released from the FMPC to Paddy's Run and the SSOD in year *i*-T. Here we use the uranium quantity for year *i*-T so that the concentration for a given year (*i*) is based on the release T years earlier (hence *i*-T). This accounts for the travel time T.
- $T_{...}$  = the total travel time (lag time) (y) for uranium to move from surface waters of Paddy's Run and the SSOD into groundwater in the South Plume area. T is the sum of the vertical travel time  $T_2$  and the horizontal travel time  $T_3$ .

Groundwater and solute transport modeling involve large uncertainties, some of which may not be adequately accounted for in our parameter uncertainty analysis. Because of this, and because only a small number of people were potentially exposed to the contaminated groundwater, we make some conservative assumptions for the model calculations. For estimating the travel time, we use as receptor point the offsite private well that is closest to the source of the groundwater contamination. For determining the ratio factors, we use the uranium concentrations from the contaminated well with the highest concentrations.

Parameters and Calculations

.

et als groups of the sector way of the because of a

As for the majority of the source term calculations presented in this report, for these calculations of uranium concentrations in groundwater we use Monte Carlo simulations, for a concurrent parameter uncertainty analysis. The rest of this section describes the parameter distributions used and the implementation of the calculations.

Uranium released and measured concentrations in groundwater. The quantities for of uranium released from the FMPC into Paddy's Run and the SSOD are calculated in Appendix L of this report. The values used here are the best estimates (medians of the distributions), from that Appendix, of the annual total mass of uranium released into Paddy's Run and the SSOD. Table M-3 shows these release quantities.

For the development of the ratio factors,  $R_{i,T}$ , annual average measured concentrations of uranium in the groundwater of the South Plume are also required. Table M-1 shows these concentrations, for the three contaminated wells in the South Plume area. For developing the ratios, we use data from the well with the highest concentrations, well 15.

# Appendix M Groundwater Contamination Outside the FMPC

3

| Released from the FMPC into Paddy's Run and the SSOD |                          |               |                          |      |                          |  |  |  |
|------------------------------------------------------|--------------------------|---------------|--------------------------|------|--------------------------|--|--|--|
| Year                                                 | Uranium<br>released (kg) | Year          | Uranium<br>released (kg) | Year | Uranium<br>released (kg) |  |  |  |
| 1952                                                 | 522                      | 1965          | 622                      | 1978 | 68                       |  |  |  |
| 1953                                                 | 522                      | <b>1966</b> . | 771                      | 1979 | 84                       |  |  |  |
| 1954                                                 | 522                      | 1967          | 753                      | 1980 | 50                       |  |  |  |
| 1955                                                 | 300                      | 1968          | 358                      | 1981 | 20                       |  |  |  |
| 1956                                                 | 270                      | 1969          | 290                      | 1982 | 20                       |  |  |  |
| 1957                                                 | 340                      | 1970          | 349                      | 1983 | 54                       |  |  |  |
| 1958                                                 | 630                      | 1971          | 499                      | 1984 | 57                       |  |  |  |
| 1959                                                 | 840                      | 1972          | 322                      | 1985 | 39                       |  |  |  |
| 1960                                                 | 1300                     | 1973          | 231                      | 1986 | 17                       |  |  |  |
| 1961                                                 | 1400                     | 1974          | 255                      | 1987 | <0.5                     |  |  |  |
| 1962                                                 | 1500                     | 1975          | 245                      | 1988 | <0.5                     |  |  |  |
| 1963                                                 | 901                      | 1976          | 272                      | ,    |                          |  |  |  |
| 1964                                                 | 1722                     | 1977          | 204                      |      |                          |  |  |  |

Table M-3. Median Estimated Annual Quantities of Uranium Released from the FMPC into Paddy's Run and the SSOD

**Travel time.** The travel time T is estimated based on the preliminary investigation of lateral movement of contaminated groundwater to offsite locations (Ichimura 1991a), which was summarized earlier in this Appendix (see page M-5). That investigation reviewed two main studies of the groundwater around the FMPC: (1) a study by GeoTrans, Inc. (GeoTrans 1985), and (2) a study by Advanced Sciences, Inc. and International Technology, Inc. (ASI-IT 1990). The two groundwater studies include information about the plume velocity, which is the velocity at which the uranium contamination moves horizontally in the aquifer. The plume velocity can be used to help estimate travel time.

From the GeoTrans study, we estimated the uranium contamination entered the aquifer in about 1959 (see page M-8), at which time horizontal spreading of the plume would have begun. Since uranium was first released into Paddy's Run and the SSOD in 1952, the vertical travel time (time for the uranium to infiltrate into the aquifer) is estimated to be about 7 y. The location where the uranium is thought to have infiltrated from surface waters into the aquifer is Paddy's Run and the SSOD, in the area near their confluence. The distance from this area to the closest offsite well, well 12, is about 500 ft (see Figure M-1). The uranium plume velocity was estimated to be 135 ft  $y^{-1}$  (see page M-8). So, the horizontal travel time to well 12 is estimated to be (500 ft/135 ft  $y^{-1}$ ) = 3.7 y.

From the ASI-IT study, we estimated that the uranium contamination entered the aquifer in about 1971 (see page M-6). Since uranium was first released into Paddy's Run and the SSOD in 1952, the vertical travel time is estimated to be about 19 y. For this study, the plume velocity was estimated to be 220 ft  $y^{-1}$ . Thus, the horizontal travel time to well 12 is estimated to be (500 ft/220 ft  $y^{-1}$ ) = 2.3 y.

The plume velocities from the two studies result in different estimates of vertical and horizontal travel times to the nearest offsite well. The total travel time of uranium from surface waters of Paddy's Run and the SSOD to groundwater at well 12 is the sum of the vertical and horizontal travel times. The travel times are summarized in Table M-4.

| •, •               | Estimated travel time (y)              |                           |                          |          |  |  |
|--------------------|----------------------------------------|---------------------------|--------------------------|----------|--|--|
| Study              | Plume velocit<br>(ft y <sup>-1</sup> ) | ty Vertical to<br>aquifer | Horizontal to<br>well 12 | Total    |  |  |
| GeoTrans<br>ASI-IT | 135<br>220                             | 7                         | 3.7<br>2.3               | 11<br>21 |  |  |

| Table M-4. Summary of Uraniu | um Travel ' | Time from   | Surface  | Waters |
|------------------------------|-------------|-------------|----------|--------|
| of Paddy's Run and the SS    | OD to Well  | 12 in the S | outh Plu | me     |

From Table M-4, estimated total travel times to well 12, based on the two studies, are 11 and 21 y. From our reviews of the two basis reports (GeoTrans 1985 and ASI-IT 1990), the uncertainties in the uranium plume velocities are large. In general terms, we expect the ASI-IT report to be of higher quality, because it was based on additional and more recent data. But, we have no strong evidence to indicate this, and no justifiable way to quantify any difference in the data quality from the two reports (GeoTrans and ASI-IT). Thus, with only two estimates of travel time, we assume that all travel times within the range 11-21 y are equally likely. Since T is a whole number, we assume that T has a discrete probability distribution over the range 11-21 y, inclusive, with each value having equal probability. (This is similar to a uniform distribution, but is discrete, rather than continuous.)

Ratio factors. We determine distributions of  $R_{i,T}$  from the measured uranium concentrations in well water and the estimated uranium quantities released to Paddy's Run and the SSOD. For each T, in the range 11-21, we calculate, for all possible years j, the ratio  $C_{j,15}/Q_{j-T}$ , where  $Q_{j-T}$  is as defined earlier, and  $C_{j,15}$  is the measured uranium concentration in well 15 for year j. The subscript j has the same meaning as the index i, but is used here for calculations to determine the ratios  $R_{i,T}$ , while i is used in equation M-4 to determine  $C_i$ . Here we use well 15 concentrations because they are the highest of concentrations from the three contaminated wells. Because only eleven years of uranium concentration data are available, we can form only eleven of these ratios for each travel time T. Thus, for each travel time T, a distribution of ratios is developed.

To illustrate the construction of the distribution of ratios for a particular travel time, we use the example of travel time 13 y. Table M-5 shows the concentrations and release quantities used for T = 13 y, and the ratios calculated, for the available data. The ratios range from 0.44 to 2.5 pCi L<sup>-1</sup>, with geometric mean 0.908 and geometric standard deviation 1.62. The cumulative distribution of calculated ratios for travel time 13 y is plotted in Figure M-5. As seen in Figure M-5, the distribution of ratios, for 13-year travel time, is reasonably well represented by a lognormal distribution. This lognormal representation is superior to that of a normal distribution (though the normal distribution is not shown here).

This same procedure was used to develop distributions of the ratios for each travel time. Eleven distributions are developed (one for each travel time, of 11-21 y). Upon examination, the resulting eleven distributions of these ratios are adequately represented by lognormal distributions, and, overall, the distributions appear more lognormal in shape than normal. (We note that many of the other distributions appear closer to a lognormal distribution than does the distribution for 13-y travel time, and a few appear farther from a lognormal

# Appendix M Groundwater Contamination Outside the FMPC

....

35

distribution.) We thus assume that all  $R_{i,T}$  will be represented by lognormal distributions, described by a geometric mean and geometric standard deviation. Table M-6 summarizes information about the eleven distributions of ratios, showing the minimum and maximum ratios computed for each travel time, and the geometric means and geometric standard deviations which will be used to represent the distributions of  $R_{i,T}$ .

| Year j           | C <sub>j</sub><br>(pCi L <sup>-1</sup> ) | Year j-T | <i>Q<sub>j-T</sub></i><br>(kg) | Ratio $C_j/Q_{j-T}$<br>(pCi L <sup>-1</sup> per kg) |  |  |  |  |  |
|------------------|------------------------------------------|----------|--------------------------------|-----------------------------------------------------|--|--|--|--|--|
| 1982             | 320                                      | . 1969   | 290                            | 1.10                                                |  |  |  |  |  |
| · 1983           | 290                                      | 1970     | 349                            | 0.831                                               |  |  |  |  |  |
| 1984             | 220                                      | 1971     | <b>499</b> - 1                 | · 0.441                                             |  |  |  |  |  |
| 1985             | 200                                      | 1972     | 322                            | 0.621                                               |  |  |  |  |  |
| 1986             | 190                                      | . 1973   | 231                            | 0.823                                               |  |  |  |  |  |
| 1987             | 200                                      | 1974     | 255                            | 0.784                                               |  |  |  |  |  |
| 1988             | 190                                      | 1975     | 245                            | 0.776                                               |  |  |  |  |  |
| 198 <del>9</del> | 190                                      | 1976     | 272                            | 0.699                                               |  |  |  |  |  |
| 1990             | 180                                      | 1977     | 204                            | 0.882                                               |  |  |  |  |  |
| 1991             | 170                                      | 1978     | 68                             | 2.50                                                |  |  |  |  |  |
| 1992             | 150                                      | 1979     | 84                             | 1.79                                                |  |  |  |  |  |

# Table M-5. Construction of the Frequency Distribution ofRatio Factors for Travel Time 13 Years a

<sup>i</sup> The subscript *j* has the same meaning as the index *i*, but is used for calculating the ratios R<sub>i,T</sub>, while *i* is used in equation M-4 to determine C<sub>i</sub>.



Figure M-5. Log-probability plot of the cumulative distribution of calculated ratios for travel time 13 y. The line indicates the lognormal distribution chosen to represent the distribution.

2000

| Travel time T | Minimum<br>ratio | Maximum<br>ratio     | GM      | GSD  |
|---------------|------------------|----------------------|---------|------|
| 11            | 0.641            | 7.50                 | 1.38    | 2.24 |
| 12            | 0.581            | <b>3.00</b>          | 1.07    | 1.78 |
| 13            | 0.441            | 2.50                 | 0.908   | 1.62 |
| 14            | 0.401            | 2.21                 | 0.796   | 1.52 |
| 15            | 0.381 -          | 0.823                | · 0.640 | 1.29 |
| 16            | 0.385            | Aston <b>0.823</b> h | 0.567   | 1.29 |
| 17            | 0.292            | 0.779                | 0.526   | 1.34 |
| 18            | 0.186            | 0.736                | 0.440   | 1.55 |
| 19            | 0.168            | 0.655                | 0.393   | 1.55 |
| . 20          | 0.128            | 0.655                | 0.331   | 1.61 |
| 21            | 0.116            | .0.321               | 0.290   | 1.62 |

Table M-6. Development of Ratio Factors  $R_{i,T}$  (pCi L<sup>-1</sup> per kg): Range of Computed Ratios, and Geometric Mean (GM) and Geometric Standard Deviation (GSD) of Distributions Used to Represent Ratio Factors

For a given T,  $R_{i,T}$  is represented by a single distribution that is dependent only on T. We retain the index *i* only to indicate that, for a given T, we will consider the  $R_{i,T}$  for the different years *i* to be independent. This is explained further below.

Implementation of calculations. As indicated earlier, the calculations are performed as a Monte Carlo simulation. The Monte Carlo calculations for this analysis were performed using spreadsheet and forecasting software on an IBM-compatible microcomputer. Ten thousand iterations of the calculations were performed. The parameter distributions were generated using Crystal Ball<sup>®</sup>, version 3.0 for Windows (Decisioneering 1993). In Crystal Ball<sup>®</sup>, uniform distributions are generated using a multiplicative congruential generator which has a period of length 2<sup>31</sup>-2, and lognormal distributions are generated using the Polar Marsaglia method (Decisioneering 1993).

For each iteration of the calculations, a value of T is first chosen at random from the discrete distribution described above. Then, for each year *i*, a value of  $R_{i,T}$  is independently chosen from the distribution for travel time T, as described by parameters in Table M-6. The values of  $R_{i,T}$  for different years (different *i*) would presumably not actually be independent. However, for these calculations we assume they are independent so that uncertainties are conservatively estimated. Then, for each year *i*,  $C_i$  is calculated using equation M-4. Because the assumed minimum travel time is 11 y, and the first releases of uranium from the FMPC to Paddy's Run and the SSOD occurred in 1952, equation M-4 can only be used to calculate concentrations for years starting in 1963, at the earliest (depending on T, the earliest possible year could be later). Thus, calculations of  $C_i$  are performed only for years 1963-1988. This procedure is repeated for each iteration.

#### Results

The predicted annual average concentrations of uranium in private well water in the South Plume area,  $C_i$ , are summarized in Table M-7, in terms of percentiles of the distributions of results. In Figure M-6 the predicted uranium concentrations in the South

Appendix M

9

4

Z

# Groundwater Contamination Outside the FMPC

Plume are compared with measured concentrations in well 15, measured concentrations in Paddy's Run, measured and estimated concentrations in the SSOD, and estimated quantities of uranium released to the SSOD and Paddy's Run. The shapes of all the curves are generally similar, with an increase followed by a gradual decrease over time, but the estimated well concentrations curve is shifted later in time (as expected).

| Year (i)    | 5th percentile | median       | 95th percentile |
|-------------|----------------|--------------|-----------------|
| 1963        | 0              | · 0          | 640             |
| 1964        | 0              | . 0          | 930             |
| 1965        | 0              | 0            | 1000            |
| 1966        | 0              | 0            | 870             |
| 1967        | 0              | 0            | 730             |
| 1968        | 0              | 180          | 680             |
| 1969        | · 0            | 230          | 890             |
| 1970        | 0              | · <b>230</b> | 1400            |
| 1971        | . 0            | 230          | 2000            |
| 1972        | 0              | 240          | 2400            |
| 1973        | 93             | 290          | 2800            |
| 1974        | 83             | 370          | 2400            |
| 1975        | 73             | 490          | 2700            |
| <b>1976</b> | 64             | 580          | 2300            |
| 1977        | 73             | 620          | 2100            |
| 1978        | 100            | 620          | 1900            |
| 1979        | ·· 160         | 570          | .1400           |
| 1980        | 180            | 510          | 1200            |
| 1981        | 180            | 460          | 1100            |
| 1982        | 170            | 410          | . 1100          |
| 1983        | 150            | 360          | 990             |
| 1984        | . 130          | 300          | 810             |
| 1985        | 120            | <b>260</b> · | · 740           |
| 1986        | . 100          | 230          | 560             |
| 1987        | 90.            | 210          | 550             |
| 1988        | 78             | 190          | 490             |

## Table M-7. Summary of Frequency Distributions of Predicted Uranium Concentration, C<sub>i</sub>, (pCi L<sup>-1</sup>) in Private Well Water in the South Plume Area

The median prediction of the uranium concentration is zero prior to 1968 (Table M-7). This indicates that, given the assumptions that have been made about travel times, it is likely that uranium contamination in the groundwater would not have reached offsite wells" prior to 1968.



11.200

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty



Figure M-6. Comparison of the predicted and measured uranium concentrations in the South Plume (well 15) with measured concentrations in Paddy's Run, and measured and estimated concentrations in the SSOD. The median predicted well concentrations are zero prior to 1968; these zero values are not plotted. The Paddy's Run concentrations were measured at the Willey Road bridge, sampling point W7. All concentrations are annual 'averages. For comparison, the annual quantities of uranium released to the SSOD and Paddy's Run are shown (note the separate scale).

and a star of the second se

# SUMMARY AND CONCLUSIONS

Routine monitoring of the three contaminated wells in the South Plume has been performed by the FMPC since 1982. The annual average measured concentrations are suitable for use in the dosimetry calculations for 1982–1988. Our evaluation of the lateral movement of uranium in the groundwater indicated that the uranium plume had not reached the FMPC boundary by 1962. Thus, uranium concentrations in the South Plume wells were estimated for 1963–1981. We first estimated an upper bound on uranium concentrations that might have existed in these wells for this period, based on the maximum concentration in the source surface waters. But, we believe the upper bound is too

# Appendix M Groundwater Contamination Outside the FMPC

conservative to use for the dosimetry calculations. An empirical model, which uses the measured well concentrations for 1982–1992 and the estimated quantities of uranium released to Paddy's Run and the SSOD, was then developed. The empirical model allows more realistic, though still somewhat conservative, estimates of uranium concentrations in the South Plume wells for 1963–1981. These estimated concentrations are thus preferred over the upper bound estimate.

For the dosimetry calculations of Task 6, we will employ a single best estimate, for each year, of the annual average concentration of uranium in the South Plume to which people may have been exposed. For those years for which measurements are available, 1982–1988, the measured values from well 15 will be used. For years prior to 1982 the median values of predicted concentrations will be used. Table M-8 summarizes the uranium concentrations in South Plume groundwater that will be used for Task 6 dosimetry calculations.

Year Concentration Concentration · Year Concentration Year 1951-1962ª · 510 

Table M-8. Values of Uranium Concentration (pCi L<sup>-1</sup>) Used to Represent Annual Average Concentrations in Contaminated Wells of the South Plume Area

<sup>a</sup> The concentration listed is applied to each year in this range.

Insoluble chemical forms of uranium would be adsorbed readily on soils in the aquifer, while soluble forms would be adsorbed to lesser degree. It is thus reasonable that the uranium which has reached offsite wells in the South Plume would be in a soluble form. Thus, for the dosimetry calculations (in Task 6), all the uranium in the contaminated groundwater source is assumed in soluble chemical form.

#### REFERENCES

- Aas, C. A.; Jones, D. L.; Keys, R. W. Feed Materials Production Center environmental monitoring annual report for 1985. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; Rep. FMPC-2047; 1986.
- ASI-IT (Advanced Sciences, Inc. and International Technology Corp.). Engineering evaluation/cost analysis south plume, Feed Materials Production Center, Fernald, Ohio. Cincinnati, Ohio: Advanced Sciences, Inc. and International Technology Corp.; 1990; p. 2-6 and p. A-7.

Page M-23

- Byrne, J. M.; Dugan, T. A.; Oberjohn, J. S. Feed Materials Production Center annual environmental report for calendar year 1990. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; Rep. FMPC-2245; 1991.
- Courtney, L. Handwritten ledger sheets summarizing monthly loss reports. Cincinnati, Ohio: National Lead Company of Ohio; 1969.
- Cuthbert, F. L. Measured losses and removals of SS material from the production stream. Monthly reports to J. H. Noyes. Cincinnati, Ohio: National Lead Company of Ohio; January 1960 to September 1961.
- Dames and Moore. Department of Energy, Feed Materials Production Center, groundwater study, task C report. White Plains, New York: Dames and Moore; 1985.

DOE (U.S. Department of Energy). Engineering evaluation/cost analysis, south plume, Feed Materials Production Center, Fernald, Ohio. Oak Ridge Operations Office, U.S. Department of Energy; Rep. FMPC-0003-6; November 1990 (1990a).

DOE (U.S. Department of Energy). Groundwater report, Feed Materials Production Center, Fernald, Ohio, remedial investigation and feasibility study. Volume 1, Volume 2, and Volume 1 and Volume 2 Supplement (abbreviated appendices). Draft report. Oak Ridge Operations Office, DOE; December 1990 (1990b).

Decisioneering, Inc. Crystal Ball<sup>®</sup> version 3.0, user manual. Computer software manual. Denver, Colorado: Decisioneering, Inc.; 1993.

- Dugan, T. A.; Gels, G. L.; Oberjohn, J. S.; Rogers, L. K. Feed Materials Production Center annual environmental report for calendar year 1989. Cincinnati, Ohio: Westinghouse Materials Company of Ohio; FMPC-2200; 1990.
- Facemire, C. F.; Jones, D. L.; Keys, R. W. Feed Materials Production Center environmental monitoring annual report for 1984. Cincinnati, Ohio: NLO, Inc.; Rep. NLCO-2028; 1985.

FERMCO (Fernald Environmental Restoration Management Corporation). 1992 Fernald Environmental Management Project site environmental report. FERMCO; Rep. FEMP-2290; June 1993.

Fleming, D. A.; Ross, K. N. Feed Materials Production Center environmental monitoring annual report for 1982. Cincinnati, Ohio: NLO, Inc.; Rep. NLCO-1187; 1983.

Fleming, D. A.; Ross, K. N. Feed Materials Production Center environmental monitoring annual report for 1983. Cincinnati, Ohio: NLO, Inc.; Rep. NLCO-2018; 1984.

GeoTrans. Preliminary characterization of the groundwater flow system near the Feed Materials Production Center, Great Miami River valley-fill aquifer, Fernald, Ohio. Report prepared for Ohio Environmental Protection Agency. Columbus, Ohio: GeoTrans, Inc.; 1985; p. 57.

Gessiness, B. Reconciliation of SS quantities discarded in the NLO pits (VVB) — fiscal years 1952–1974. Letter to E. D. Marshall. Cincinnati, Ohio: National Lead Company of Ohio; 8 November 1974.

Harr, G.R. Unusual uranium losses to the pit. Memorandum to W. J. Strattman. Cincinnati, Ohio: National Lead Company of Ohio; 11 May 1960.

Ichimura, V. Preliminary groundwater travel time analysis for the FMPC area. Report prepared for Radiological Assessments Corporation. Barnwell, South Carolina: Chem-Nuclear Systems, Inc.; 12 February 1991 (1991a).

# Appendix M

<u>.</u>

.

8

#### Groundwater Contamination Outside the FMPC

- Ichimura, V. An analysis of uranium transport after deposition in soils around the Feed Materials Production Center. Report prepared for Radiological Assessments Corporation. Barnwell, South Carolina: Chem-Nuclear Systems, Inc.; 13 March 1991 (1991b).
- Jensen, M. E. Design and operation of farm irrigation system. American Society of Agricultural Engineers; Monograph No. 3; 1980; p. 203-204.
- Killough, G. G.; Case, M. J.; Meyer, K. R.; Moore, R. E.; Rogers, J. F.; Rope, S. K.; Schmidt, D. W.; Shleien, B.; Till, J. E.; Voillequé, P. G. The Fernald dosimetry reconstruction project, task 4: environmental pathways analysis — models and validation. Draft interim report for comment. Neeses, South Carolina: Radiological Assessments Corporation; Rep. CDC-3; February 1993.

Kraps, P. A. Letter to D. W. Schmidt, with attached tables of well water monitoring results. Cincinnati, Ohio: Fernald Environmental Management Project, Fernald Environmental Restoration Management Corporation; letter C:ESH:EP:93:171; 5 April 1993.

- Lerch, N. K.; Hale, W. F.; Lemaster, D. D. Soil survey of Hamilton County, Ohio. U.S. Department of Agriculture, Soil Conservation Service; 1982.
- NLCO (National Lead Company of Ohio). Accountability uranium losses to the scrap pit from the general sump. Daily control logbook of effluent pumped to the waste pits. Cincinnati, Ohio: NLCO; 1960.
- NLCO (National Lead Company of Ohio). General sump effluent uranium record. Daily control logbook of effluent pumped to the waste pits. Cincinnati, Ohio: NLCO; 1961.
- NLCO (National Lead Company of Ohio). General sump effluent uranium record. Daily control logbook of effluent pumped to the waste pits. Cincinnati, Ohio: NLCO; 1962.
- NLCO (National Lead Company of Ohio). Summary of operations and other reference information, prepared for U.S. AEC, Washington, D.C. Cincinnati, Ohio: NLCO; 15 November 1966.
- Noyes, J. H. Land burial of radioactive wastes. Letters to C. L. Karl. Cincinnati, Ohio: National Lead Company of Ohio; January, February, June, July, August 1961.
- Pennak, S. Liquid effluent review. Cincinnati, Ohio: National Lead Company of Ohio; 14 August 1973.
- Peterson, H. T. Terrestrial and aquatic food chain pathways. In: Till, J. E.; Meyer, H. R.; eds. Radiological assessment: a textbook on environmental dose analysis. Washington, DC: U.S. Nuclear Regulatory Commission; Rep. NUREG/CR-3332; 1983; p. 5-51.

Poff, T. A.; Pepper, C. E.; Gessiness, B. Elemental constituents in the FMPC pits and silos. Internal memorandum to W. J. Adams. Cincinnati, Ohio: National Lead of Ohio; 21 February 1985.

- Rich, B. L.; Hinnefeld, S. L.; Lagerquist, C. L.; Mansfield, W. G.; Munson, L. H.; Wagner, E. R. Manual of good practices at uranium facilities - draft. Draft report. Idaho Falls, Idaho: Idaho National Engineering Laboratory, EG&G Idaho, Inc.; Rep. EGG-2530; 1988.
- Schwarzman, G. E. Quarterly groundwater sampling locations and private wells. Cincinnati, Ohio: Westinghouse Environmental Management Company of Ohio; FMPC drawing index code 00X-5500-G-02006; 1992 (1992a).

Radiological Assessments Corporation "Setting the standard in environmental health"

Page M-25

. .

. . . . . . . .

11

÷ • • ,

Schwarzman, G. Contour area ≥ 20 ppb total uranium, 4th quarter 1991. Drawing, preliminary. Cincinnati, Ohio: Westinghouse Environmental Management Company of Ohio; 1992 (1992b).

raight a

SCS (U. S. Soil Conservation Service). Engineering field manual. Washington, DC: U.S. Soil Conservation Service, U.S. Department of Agriculture; 1969; Exhibit 2-8, p. 2-52.

Shleien, B.; Rope, S. K.; Case, M. J.; Killough, G. G.; Meyer, K. R.; Moore, R. E.; Schmidt, D. W.; Till, J. E.; Voillequé, P. G. The Fernald Dosimetry Reconstruction Project, task 5: review of historic data and assessments for the FMPC. Draft report for comment. Neeses, South Carolina: Radiological Assessments Corporation; Rep. CDC-4; May 1993.

Solow, A. J.; Phoenix, D. R. Characterization investigation study, volume 3: radiological characterization of surface soils in waste storage area. West Chester, Pennsylvania: Roy F. Weston, Inc.; Rep. FMPC/SUB 008, vol. 3; November 1987; p. 3-63 to 3-65.

Spieker, A. M. Ground-water hydrology and geology of the lower Great Miami River valley, Ohio. Washington, DC: U.S. Geological Survey; Professional Paper 605-A; 1968; p. A5.

Vath, J. E. Handwritten report on measured loss and product measurements. Initialed B. Gessiness. Cincinnati, Ohio: National Lead Company of Ohio; 2 June 1964 (1964a).

Vath, J. E. Report on the sampling of plant 8 trailer cake. Memorandum to B. Gessiness. Cincinnati, Ohio: National Lead Company of Ohio; 3 August 1964 (1964b).

Veihmeyer, F. J. Evapotranspiration. In: Chow, V. T., ed. Handbook of applied hydrology. McGraw-Hill Publishers; 1964; p.11-8.

Voillequé, P. G.; Meyer, K. R.; Schmidt, D. W.; Killough, G. G.; Moore, R. E.; Ichimura, V. I.; Rope, S. K.; Shleien, B.; Till, J. E. The Fernald Dosimetry Reconstruction Project, tasks 2 and 3: radionuclide source terms and uncertainties — 1960–1962. Draft interim report for comment. Neeses, South Carolina: Radiological Assessments Corporation; Rep. CDC-2; December 1991.

WEMCO (Westinghouse Environmental Management Company of Ohio). Fernald Environmental Management Project, annual site environmental report for calendar year 1991. WEMCO; Rep. FEMP-2275; December 1992.

Wischmeier, W. H.; Smith, D. D. Predicting rainfall erosion losses; a guide to conservation planning. Washington, DC: U.S. Department of Agriculture; Agriculture Handbook No. 537; 1978.

WMCO (Westinghouse Materials Company of Ohio). Feed Materials Production Center environmental monitoring annual report for 1986. Cincinnati, Ohio: WMCO; Rep. FMPC-2076; 1987.

WMCO (Westinghouse Materials Company of Ohio). Feed Materials Production Center environmental monitoring annual report for 1987. Cincinnati, Ohio: WMCO; Rep. FMPC-2135; 1988.

WMCO (Westinghouse Materials Company of Ohio). Feed Materials Production Center environmental monitoring annual report for 1988. Cincinnati, Ohio: WMCO; Rep. FMPC-2173; 1989.

WMCO (Westinghouse Materials Company of Ohio). Groundwater report, remedial investigation/feasibility study. Draft prepared for U.S. Department of Energy. Cincinnati, Ohio: Rep. FMPC-0004-02; December 1990.

# Appendix M Groundwater Contamination Outside the FMPC

٠. .

<u>.</u>....

# ANNEX 1 TO APPENDIX M

## DATA TABLES

# Table M1-1. Monthly FMPC Measurements of Uranium Concentrations (mg $L^{-1}$ ) in Wells 12, 15, and $17^{a}$

| Date     | Well 12 | Well 15          | Well 17 | Date   | Well 12 | Well 15   | Well 17 | Date   | Well 12 | Well 15 | Well 17 |
|----------|---------|------------------|---------|--------|---------|-----------|---------|--------|---------|---------|---------|
| Nov-81   | 0.190   |                  |         | Aug-85 | 0.189   | 0.224     | 0.053   | May-89 | 0.31    | 0.24    | 0.034   |
| Dec-81   | 0.160   | 0.320            | 0.054   | Sep-85 | 0.198   | 0.274     | 0.044   | Jun-89 | 0.25    | 0.23    | 0.030   |
| Jan-82   | . •     |                  |         | Oct-85 | 0.220   | 0.338     | 0.0322  | Jul-89 | 0.30    | 0.31    | 0.038   |
| Feb-82   | 0.240   | 0.520            | 0.050   | Nov-85 | · 0.243 | 0.352     | 0.0518  | Aug-89 | 0.22    | 0.28    | 0.038   |
| Mar-82   | 0.240   | 0.410            | 0.069   | Dec-85 | 0.214   | 0.352     | 0.0461  | Sep-89 | 0.25    | 0.30    | 0.036   |
| Apr-82   | 0.280   | 0.450            | 0.071   | Jan-86 | 0.155   | 0.232     | 0.039   | Oct-89 | 0.23    | 0.31    | 0.036   |
| May-82   | 0.310   | 0.450            | 0.075   | Feb-86 | 0.105   | 0.208     | 0.034   | Nov-89 | 0.21    | 0.26    | 0.039   |
| Jun-82   | 0.250   | 0.440            | 0.078   | Mar-86 | 0.201   | 0.378     | 0.053   | Dec-89 | 0.19    | 0.32    |         |
| Jul-82   | 0.270   | 0.440 -          | 0.099   | Apr-86 | 0.286   | 0.341     | 0.055   | Jan-90 | 0.21    | 0.27    |         |
| Aug-82   | 0.234   | 0.470            | 0.046   | May-86 | 0.226   | 0.337     | 0.061   | Feb-90 | 0.21    | 0.26    |         |
| Sep-82   | 0.238   | 0.480            | 0.061   | Jun-86 | 0.223   | 0.280 · . | 0.042   | Mar-90 | 0.21    | 0.28    | 0.038   |
| Oct-82   | 0.280   | 0.490            |         | Jul-86 | 0.222   | 0.286     | 0.040   | Apr-90 | 0.19    | 0.25    | 0.039   |
| Nov-82   | 0.220   | 0.502            | 0.054   | Aug-86 | 0.245   | 0.233     | 0.043   | May-90 | 0.19    | 0.24    | 0.040   |
| Dec-82   | 0.230   | 0.554            | 0.066   | Sep-86 | 0.222   | 0.278     | 0.045   | Jun-90 | 0.18    | 0.27    | 0.044   |
| Jan-83   | 0.255   | 0.539            | 0.065   | Oct-86 | 0.227   | 0.271     | 0.049   | Jul 90 |         | 0.27    | 0.040   |
| Feb-83   | 0.306   | 0.578            | 0.055   | Nov-86 | 0.332   | 0.301     | 1 N     | Aug-90 |         | 0.27    | 0.044   |
| Mar-83   | 0.239   | 0.483            | 0.045   | Dec-86 | 0.160   | 0.280     |         | Sep-90 | 0.19    | 0.30    | 0.056   |
| Apr-83   | 0.225   | 0.460 ·          | 0.060   | Jan-87 | 0.17    | 0.28      | 0.077   | Oct-90 | 0.18    | 0.33    | 0.041   |
| May-83   | 0.249   | 0.419            | 0.057   | Feb-87 | 0.13    | 0.25      | 0.115   | Nov-90 | 0.16    | 0.28    | 0.052   |
| Jun-83   | 0.287   | 0,416            | 0.066   | Mar-87 | 0.32    | 0.31      | 0.064   | Dec-90 |         | 0.26    |         |
| Jul-83   | 0.275   | 0.370            | 0.056   | Apr-87 | 0.41    | 0.32      | 0.047   | Jan-91 |         | 0.31    | 0.047   |
| · Aug-83 | 0.287   | 0.376            | 0.059   | May-87 | 0.33    | 0.30      | 0.056   | Feb-91 | 0.18    | 0.29    | 0.041   |
| Sep-83   | 0.274   | 0.379            | 0.068   | Jun-87 | 0.36    | 0.33      | 0.056   | Mar-91 | 0.18    | 0.25    | 0.045   |
| Oct-83   | 0.260   | 0.390            | 0.062   | Jul-87 | 0.36    | 0.27      | 0.049   | Apr-91 | 0.1546  | 0.2398  | 0.0536  |
| Nov-83   | 0.252   | 0.393            | 0.053   | Aug-87 | 0.30    | 0.33      | 0.049   | May-91 | 0.19    | 0.22    | 0.043   |
| Dec-83   | 0.230   | 0.363            | 0.041   | Sep-87 | 0.33    | 0.29      | 0.052   | Jun-91 | 0.16    | 0.23    | 0.028   |
| Jan-84   | 0.245   | 0.365            | 0.053   | Oct-87 | 0.30    | 0.28      | 0.043   | Jul-91 | 0.17    | 0.22    | 0.047   |
| Feb-84   | 0.235   | 0.358            | 0.045   | Nov-87 | 0.29    | 0.30      | 0.050   | Aug-91 | 0.13    | 0.20    | 0.031   |
| Mar-84   | 0.256   | 0.355            | 0.052   | Dec-87 | 0.27    | 0.30      |         | Sep-91 | 0.12    | 0.22    | 0.034   |
| Apr-84   | 0.270   | 0.348            | 0.050   | Jan-88 | 0.30    | 0.27      | 0.073   | Oct-91 | 0.12    | 0.25    | 0.036   |
| May-84   | 0.266   | 0.318            | 0.051   | Feb-88 | 0.24    | 0.26      | 0.069   | Nov-91 | 0.17    | 0.26    | 0.037   |
| Jun-84   | 0.270   | <b>0.311</b> : , | 0.059   | Mar-88 | 0.28    | 0.31      |         | Dec-91 | 0.13    | 0.25    |         |
| Jul-84   | 0.255   | 0.298            | 0.055   | Apr-88 | 0.24    | 0.25      | 0.047   | Jan-92 | 0.06    | 0.20    | 0.028   |
| Aug-84   | 0.236   | 0.286            | 0.048   | May-88 | 0.26    | 0.31      | 0.053   | Feb-92 | 0.185   | 0.2027  | 0.040   |
| Sep-84   | 0.257   | 0.292            | 0.054   | Jun-88 | 0.24    | 0.30      | 0.054   | Mar-92 | 0.19    | 0.24    | 0.031   |
| Oct-84   | 0.222   | 0.312            | 0.068   | Jul-88 | 0.23    | 0.27      | 0.047   | Apr-92 | 0.10    | 0.21    | 0.032   |
| Nov-84   | 0.240   | 0.355            | 0.058   | Aug-88 | 0.23    | 0.31      | 0.059   | May-92 | 0.18    | 0.23    | 0.041   |
| Dec-84   | 0.190   | 0.304            | 0.054   | Sep-88 | 0.23    | 0.30      | 0.048   | Jun-92 | 0.16    | 0.26    | 0.050   |
| Jan-85   | 0.189   | 0.360            | 0.048   | Oct-88 | 0.23    | 0.26      | •       | Jul-92 | .0.307  | 0.24    | 0.043   |
| Feb-85   | 0.240   | 0.290            | 0.041   | Nov-88 | 0.26    | 0.28      |         | Aug-92 | 0.18    | 0.24    | 0.031   |
| Mar-85   | 0.201   | 0.297            | 0.054   | Dec-88 | 0.21    | 0.28      | ]       | Sep-92 | 0.12    | 0.21    | 0.033   |
| Apr-85   |         |                  |         | Jan-89 | 0.23    | 0.29      | 0.054   | Oct-92 | 0.05    | 0.24    | •       |
| May-85   |         | 0.348            | 0.043   | Feb-89 |         | 0.27      | 0.051   | Nov-92 | 0.15    | 0.22    |         |
| Jun-85   | 0.169   | 0.236            | 0.055   | Mar-89 | 0.26    | 0.26      | 0.044   | Dec-92 | 0.13    | 0.25    |         |
| Jul-85   | 0.205   | 0.248            | 0.038   | Apr-89 | 0.35    | 0.26      | 0.039   |        | •       |         | •       |

<sup>a</sup> All results are from FMPC sampling. Results for November 1981 through 1983 were obtained from Dames and Moore (1985). Results for 1984 through 1992 were obtained from Kraps (1993). Blanks indicate no value was available, which apparently means no sample was taken for that month. For conversion of concentrations to units of pCi L<sup>-1</sup>, multiply by 675.

> Radiological Assessments Corporation "Setting the standard in environmental health"

والما موملة فتعاربني متوري لمو

and the house gen

N. 1

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

Table M1-2. Calculation of Estimated Concentrationsof Uranium in Storm Sewer Outfall Ditch Releases<sup>a</sup>

| Year                     | Release ()<br>quantity (kg) | Release<br>volume (gal)                                                                                          | Concentral<br>estimate (pC | ion<br>i L <sup>-1</sup> ) |
|--------------------------|-----------------------------|------------------------------------------------------------------------------------------------------------------|----------------------------|----------------------------|
| 1952                     | 520                         |                                                                                                                  | ·. ·.                      |                            |
| 1953                     | 520 ·                       | 9                                                                                                                |                            |                            |
| 1954                     | 520                         | and the second |                            | •                          |
| 1955                     | 300                         |                                                                                                                  | •                          | •                          |
| 1956                     | 270                         | ··· ·· ··                                                                                                        | • • •                      |                            |
| 1957                     | 340                         | * : .                                                                                                            |                            |                            |
| 1958                     | 630                         |                                                                                                                  | • •                        | •                          |
| <b>1959</b> ·            | 840                         | 26,000,000                                                                                                       | 5800                       |                            |
| <b>1960</b>              | <b>1300</b>                 | 28,000,000                                                                                                       | . 8300                     |                            |
| 1961                     | 1400                        | ,, 41,000,000                                                                                                    | 6100                       |                            |
| 1962                     | 1500                        | 60,000,000                                                                                                       | 4500                       |                            |
| 1963                     | 900                         | 70,000,000                                                                                                       | 2300                       | ÷.                         |
| 1964                     | 1700                        | <sup></sup>                                                                                                      | 3900                       |                            |
| 1965                     | 620                         | 66,000,000                                                                                                       | 1700                       | , <b>·</b> . · · ·         |
| 1966                     | 770                         | 87,000,000                                                                                                       | 1600 c                     | •. •                       |
|                          | <b>750</b>                  | 35,000,000                                                                                                       | 3800                       |                            |
| 1968                     | 360                         | 22,000,000                                                                                                       | 2900                       |                            |
| 1969                     | 290                         | 36,000,000                                                                                                       | 1400                       |                            |
| 1970                     | 350                         | 28,000,000                                                                                                       | 2200                       | -                          |
| 1971                     | <b>500</b> 6.67             | 24,000,000                                                                                                       | 3700                       | · ·                        |
| 1972                     | 320                         | 31,000,000                                                                                                       | 1900                       |                            |
| 1973                     | 230                         | 17,000,000                                                                                                       | 2400                       | <del>.</del> .:            |
| 1974                     | 255                         | 34,000,000                                                                                                       | 1300                       |                            |
| <b>1975</b> <sup>·</sup> | 245                         | 19,000,000                                                                                                       | 2300                       |                            |
| 1976                     | 270                         | 10,000,000                                                                                                       | 4800                       | • •                        |
| 1977                     | 200                         | 11,000,000                                                                                                       | 3300                       |                            |
| 1978                     | 68                          | 12,000,000                                                                                                       | 1000                       | ł                          |
| 1979                     | 84                          | 17,000,000                                                                                                       | 880                        | •                          |
| 1980                     | - 50                        | 5,000,000                                                                                                        | 1800                       |                            |
| 1981                     | 20                          | 2,000,000                                                                                                        | 1800                       | • .                        |
| 1982                     | 20                          | 11,000,000                                                                                                       | <b>320</b> .               |                            |
| 1983                     | . 54 .                      | 14,000,000                                                                                                       | 690                        |                            |
| 1984                     | 57                          | 15,000,000                                                                                                       | 680                        |                            |
| .1985 🗋                  | 39                          |                                                                                                                  | •                          | •                          |
| 1986                     | 17                          |                                                                                                                  |                            |                            |
| 1987                     | - <0.5 °                    | •                                                                                                                | 1 - A - A                  |                            |
| 1988                     | <0.5                        | $(\mathbf{r}, \mathbf{r})^{T} \in \mathbf{H}^{T}$ . (1)                                                          |                            |                            |
| Data for                 | release quantit             | ties to Paddy's R                                                                                                | un and releas              | <u></u> `<br>В             |

Data for release quantities to Paddy's Run and release volumes to SSOD are from Appendix L. We note that release quantities are total to Paddy's Run, which includes some material not released through the SSOD. This means the concentration estimates are biased somewhat high.

ť.

and **r o**i in a Think dr Syla

...

المحار المعادية والمحافظ فليتحا وترجي وتجلي المناجب والمعادي والمحادث والمعاد والمحاد المحاد المحاد

## ANNEX 2 TO APPENDIX M

#### INFORMATION REGARDING DISCARDS OF MATERIAL TO WASTE PITS

Two potential sources of offsite groundwater contamination originating on the FMPC site are (1) historical releases of uranium-contaminated water to Paddy's Run and to the Storm Sewer Outfall Ditch (SSOD), and (2) possible releases from the solid and liquid waste pits. Of these, the principal source of uranium contamination in the South Plume has been determined to be historical releases to Paddy's Run and the SSOD (DOE 1990a). The waste pits have not been significant direct contributors (by "direct" we mean through infiltration of contaminants through the bottoms of the pits) to the uranium contamination outside the site boundary. They are an indirect source, however, because runoff from contamination in and around the waste pits probably contributed to the historical releases to Paddy's Run. In our interim report (Voillequé et al. 1991), we evaluated the importance of the waste pits as a source of ground water contamination, and as a source of fugitive dust emissions (Appendix K). We studied the 1960 to 1962 period in some detail to improve our understanding of the general movement of materials around the site from the receipt of feed material, to transport and processing through the production areas, to waste disposal or shipment of product offsite. As part of this process, we compiled monthly quantities of uranium discarded to the pits for 1960-1962 in our consideration of the waste pits as a potential direct source of groundwater contamination. This annex is comprised of much of that data.

A series of waste disposal pits have been used for storage of low-level radioactive wastes during the course of the operations at the FMPC. These pits were located near the western boundary of the site, close to Paddy's Run. The waste pit area consists of waste pits numbered 1 through 6, the burn pit, and the clear well (Figure M2-1). The waste pits are typically referred to as "wet" if they received waste via pipes in slurry form or "dry" if they received solid waste from trucks. General characteristics of the waste disposal pits are summarized in Table K-35.

#### **FMPC ANNUAL ESTIMATES OF URANIUM DISCARDED TO THE WASTE PITS**

The total quantities of uranium discarded to the pits have been reported over the years in a number of records. In 1974, Gessiness reported a total of 195,000 kg of uranium to the wet pits and 2,500,000 kg to the dry pits from 1952 to 1974 (Table M2-1). In general, the quantity of uranium discarded to the dry waste pits is much higher than that in wet discards. Figure M2-2 shows that annual discards to the dry pits exceeded 100,000 kg U from 1955 to 1957 and from 1968 through 1974. In 1956, over 500,000 kg of uranium were discarded to the dry waste pit 1. For other years, from 5,000 to 50,000 kg of uranium were discarded to the dry pits. Uranium in slurries sent to the wet pits gradually increased from 43 kg in 1952 up to 22,000 kg in 1959, with levels varying from 2,000 to 10,000 kg from 1960 to 1974. The highest levels of uranium discarded to the wet pits were reported in 1963 and 1964 (about 30,000 kg), due in part to a Nuclear Materials Accounting adjustment made retrospectively for FY 1963 and 1964 (Table M2-1).

1.1.1.1

No. of the second s

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty



Figure M2-1. Time line of FMPC waste pits activity. The dry pits received material by truck while the wet pits usually received material by pipe in slurry form.

Thus, by mid-1974, approximately 2.7 million kg of uranium had been discarded to the waste pits (Gessiness 1974). In 1985, it was estimated that 5.3 million kg of uranium had been discarded to the waste pits from facility startup through December 1984 (Poff et al. 1985). By 1974, Pits 1 and 2 were filled, while Pits 3, 4, and 5 were still receiving waste materials (See Appendix K). By 1985, pit 1 to 5 had been "retired", while Pit 6 was 75% full (Figure M2-1).

15555

.

| Appendix M      | .:         |            |        |   |
|-----------------|------------|------------|--------|---|
| Groundwater Con | tamination | Outside th | e FMPC | ; |

| (kg) Discarded to the Waste Pits From 1952 to 1974 <sup>a</sup> |             |           |  |  |
|-----------------------------------------------------------------|-------------|-----------|--|--|
| Fiscal year                                                     | Wet Pits    | Dry Pits  |  |  |
| 1952                                                            | 43          | 0         |  |  |
| 1953                                                            | 409         | 0         |  |  |
| 1954                                                            | 863         | 325       |  |  |
| 1955                                                            | 2107        | 170076    |  |  |
| 1956                                                            | 4809        | 506235    |  |  |
| 1957                                                            | 8743        | 361769    |  |  |
| 1958                                                            | 12575       | 5789      |  |  |
| 1959                                                            | 22315       | 8882      |  |  |
| 1960.                                                           | 11089       | 11971     |  |  |
| 1961                                                            | 13782       | 49229     |  |  |
| 1962                                                            | 7182        | 8887      |  |  |
| 1963                                                            | 28147       | 45872     |  |  |
| 1964                                                            | 30960       | 48112     |  |  |
| 1965                                                            | 6857        | . 3649    |  |  |
| 1966                                                            | 6200        | 1226      |  |  |
| 1967                                                            | 4555        | 34520     |  |  |
| 1968                                                            | 10129       | 195309    |  |  |
| 1969                                                            | 7181        | 160972    |  |  |
| 1970                                                            | 7552        | 163471    |  |  |
| 1971                                                            | 1557        | 170394    |  |  |
| 1972                                                            | 2958        | 126311    |  |  |
| 1973                                                            | 2041        | 283822    |  |  |
| 1974                                                            | <b>2646</b> | 129322    |  |  |
| Total                                                           | 194,700     | 2,486,143 |  |  |

<sup>a</sup> From Gessiness 1974.

#### DISCARDS TO THE WASTE PITS FROM 1960 TO 1962

As part of our investigation of the waste pits as a source of ground water contamination, we compiled information for the early sixties on various types of discards to the waste pits. Much of these data were included in our interim source term report for the 1960 to 1962 period (Voillequé 1991). These data provide an understanding of the types, quantities and methods for quantifying these discards. In the early sixties, liquid and solid wastes were discarded to waste pits 3 and 4, respectively. Monthly totals of volume (or net weight) and quantity of uranium were reported in routine monthly loss reports (Cuthbert 1960–1961), in monthly ledger sheets (Courtney 1969), in monthly land burial reports (Noyes 1961), and in General Sump Effluent Control Logbooks for 1960, 1961 and 1962 which listed daily discards from the plants to the General Sump and from the General Sump to the waste pits (NLCO 1960; NLCO 1961; NLCO 1962).

> Radiological Assessments Corporation "Setting the standard in environmental health"

) جي ا

.



S. 1998

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty



Figure M2-2. Reported quantities of uranium discarded to the wet and dry waste pits from 1952 to 1974 (Gessiness 1974). Approximately 2.7 million kg of uranium had been discarded by 1974.

· .1

Figure M2-3 shows the monthly quantities of uranium in liquid and dry wastes deposited in the waste pits from January 1960 to December 1962. For this time period, total uranium discards to the pit were nearly 1,000 kg or greater for all months except for January 1960, and July-December 1962. From May 1960 to June 1961, the totals exceeded 2,000 kg per month, with the highest quantity discarded in April 1961 (3,600 kg). The total uranium discarded to the pit in 1960 and 1961 was approximately 26,000 kg, and in 1962 approximately 12,000 kg. Uranium data for dry and wet discards are given in Table M2-2.



Figure M2-3. Reported quantities of uranium in materials discarded to the waste pits.
Page M-33

| able M2-2. M | able M2-2. Monthly Quantities of U to the Waste Pits |          |            |  |  |  |  |  |  |  |  |  |
|--------------|------------------------------------------------------|----------|------------|--|--|--|--|--|--|--|--|--|
| Date         | Dry (kg)ª                                            | Wet (kg) | Total (kg) |  |  |  |  |  |  |  |  |  |
| Jan-60       | ż30                                                  | 630      | 860        |  |  |  |  |  |  |  |  |  |
| Feb-60       | 709                                                  | 685      | 1394       |  |  |  |  |  |  |  |  |  |
| Mar-60       | 980                                                  | 815      | 1795       |  |  |  |  |  |  |  |  |  |
| Apr-60       | 1060                                                 | 730      | 1790       |  |  |  |  |  |  |  |  |  |
| May-60       | 1415                                                 | 910      | 2325       |  |  |  |  |  |  |  |  |  |
| Jun-60       | . 1470                                               | 870      | 2340       |  |  |  |  |  |  |  |  |  |
| Jul-60       | 1425                                                 | 936      | 2361       |  |  |  |  |  |  |  |  |  |
| Aug-60       | 1675                                                 | 1420     | 3095       |  |  |  |  |  |  |  |  |  |
| Sep-60       | 1540                                                 | 1070     | 2610       |  |  |  |  |  |  |  |  |  |
| Oct-60       | 1618                                                 | 1418     | 3036       |  |  |  |  |  |  |  |  |  |
| Nov-60       | 1355                                                 | 780      | 2135       |  |  |  |  |  |  |  |  |  |
| Dec-60       | 1400                                                 | 1200     | 2600       |  |  |  |  |  |  |  |  |  |
| Jan-61       | 1230                                                 | 1590     | 2820       |  |  |  |  |  |  |  |  |  |
| Feb-61       | 1140                                                 | 1295     | 2435       |  |  |  |  |  |  |  |  |  |
| Mar-61       | 1490                                                 | 1070     | 2560       |  |  |  |  |  |  |  |  |  |
| Apr-61       | 1680                                                 | 1945     | 3625       |  |  |  |  |  |  |  |  |  |
| May-61       | 1050                                                 | 1555     | 2605       |  |  |  |  |  |  |  |  |  |
| Jun-61       | 740                                                  | 1390     | 2130       |  |  |  |  |  |  |  |  |  |
| Jul-61       | 520                                                  | 1040     | 1560       |  |  |  |  |  |  |  |  |  |
| Aug-61       | 1075                                                 | 770      | 1845       |  |  |  |  |  |  |  |  |  |
| Sep-61       | 440                                                  | 675      | 1115       |  |  |  |  |  |  |  |  |  |
| Oct-61       | 480                                                  | 560      | 1040       |  |  |  |  |  |  |  |  |  |
| Nov-61       | 950                                                  | 665      | - 1615     |  |  |  |  |  |  |  |  |  |
| Dec-61       | 790                                                  | 625      | 1415       |  |  |  |  |  |  |  |  |  |
| Jan-62       | 660                                                  | 660      | 1320       |  |  |  |  |  |  |  |  |  |
| Feb-62       | 1050                                                 | 495      | 1545       |  |  |  |  |  |  |  |  |  |
| Mar-62       | 435                                                  | 515      | 950        |  |  |  |  |  |  |  |  |  |
| Apr-62       | 550                                                  | 470      | 1020       |  |  |  |  |  |  |  |  |  |
| May 62       | 470                                                  | 715      | 1185       |  |  |  |  |  |  |  |  |  |
| Jun-62       | 945                                                  | 800      | 1745       |  |  |  |  |  |  |  |  |  |
| Jul-62       | 420                                                  | 230      | 650        |  |  |  |  |  |  |  |  |  |
| Aug-62       | 780                                                  | 150      | 930        |  |  |  |  |  |  |  |  |  |
| Sen-62       | 840                                                  | 135      | 975        |  |  |  |  |  |  |  |  |  |
| Oct.62       | 450                                                  | 150      | 600        |  |  |  |  |  |  |  |  |  |
| Nov-62       | 125                                                  | 160      | 285        |  |  |  |  |  |  |  |  |  |
| Dec-62       | 315                                                  | 375      | 690        |  |  |  |  |  |  |  |  |  |
| Total 1960   | 14880                                                | 11470    | 26350      |  |  |  |  |  |  |  |  |  |
| Total 1961   | 11590                                                | 14385    | 25975      |  |  |  |  |  |  |  |  |  |
| Total 1962   | 7040                                                 | 5350     | 12390      |  |  |  |  |  |  |  |  |  |

<sup>a</sup> Discards include trailer cake from Plant 8, and ceramics and graphite from Plant 5.

#### Dry Discards

\$

Routine monthly reports and ledger sheets tabulated solid or dry waste deposited in the waste pits that originated from Plant 8 (trailer cake) and Plant 5 (graphite or ceramic material) (Courtney 1969; Cuthbert 1960–1961). Table M2-3 contains the data on uranium discarded to the pit from Plant 8 and Plant 5 in dry material as an example of one source of material to the dry pits. The data show that monthly discards to the waste pits were

167.22

dominated by the Plant 8 trailer cake residues, with Plant 5 contributing a small fraction during this time period. Discards of uranium in trailer cake from Plant 8 approached or exceeded 1,000 kg per month during much of 1960 and 1961 (Figure M2-4).

|          | Pla    | nt 8                                   | Plant 5 |        | Pla             | nt 8 1'. | Plant 5    |        | ., Pla | nt 8     | Plant 5 |
|----------|--------|----------------------------------------|---------|--------|-----------------|----------|------------|--------|--------|----------|---------|
| Date     | Normal | Enriched                               | Total   | Date   | Normal          | Enriched | Total      | Date   | Normal | Enriched | Total   |
| Jan-59   | 805    |                                        | 9       | Jan-62 | 590             | r        | 65         | Jan-65 | 169    |          | 39      |
| Feb-59   | 777    |                                        | 10 🕻    | Feb-62 | 987             | •        | 66         | Feb-65 | 25     | 280      | 24      |
| Mar-59   | 657    | · •                                    | 8       | Mar-62 | 368             | •        | 66         | Mar-65 |        | : 243    | 50      |
| · Apr-59 | 1089   |                                        | 4       | Apr-62 | 490             | 1        | 65         | Apr-65 |        | 13       | 26      |
| May-59   | 982    |                                        |         | May-62 | 409             |          | 62         | May-65 |        | . 30     | · 8     |
| Jun-59   | 858    |                                        |         | Jun-62 | 889             | •        | 58         | Jun-65 | •      | 92       | 45      |
| Jul-59   | 949    |                                        |         | Jul-62 | 397             | 1.1%     | 26         | Jul-65 | • •    | . 52     |         |
| Aug-59   | 868    |                                        | · · ·   | Aug-62 | 754             | •        | 27         | Aug-65 |        | 52       | 46      |
| Sep-59   | 899    |                                        |         | Sep-62 | ÷ 804           |          | 42         | Sep-65 |        | 60       | 115     |
| Oct-59   | 991    |                                        |         | Oct-62 | 400             |          | 54         | Oct-65 |        | 20       | 51      |
| Nov-59   | 1100   |                                        |         | Nov-62 | ę               | 70       | <b>5</b> 5 | Nov-65 |        | · 51     | · 31    |
| Dec-59   | 545    |                                        |         | Dec-62 |                 | 265      | 50         | Dec-65 | 8      | 66       | 2       |
| Totals   | 10520  | 0                                      | 31      | Totals | 6088            | 335      | 636        | Totals | 194    | 959      | 437     |
| Jan-60   | 215    | 1.1                                    | 17      | Jan-63 |                 | 480      | 40         | Jan-66 | ÷      | - 41     | 4       |
| Feb-60   | - 710  |                                        | 0       | Feb-63 | · * ·<br>· · ·  | · 80     | 53         | Feb-66 |        | 94       | 5       |
| Mar-60   | 954    |                                        | 29      | Mar-63 | 399             |          | 61         | Mar-66 |        | 89       | 10      |
| Apr-60   | 1051   |                                        | 13      | Apr-63 | 1428            | -        | 73         | Apr-66 |        | 54       | 4       |
| May-60   | 1397   |                                        | 20      | May-63 | 1440            | :        | 73         | May-66 |        | 32       |         |
| Jun-60   | 1466   | •                                      | -9      | Jun-63 | 1621            | •        | 95         | Jun-66 | 51     |          | 13      |
| Jul-60   | 1418   |                                        | 12      | Jul-63 | 883             |          | 41         | Jul-66 | 17     |          |         |
| Aug-60   | 1674   | •                                      | 6       | Aug-63 | 1023            |          | 100        | Aug-66 | 36     |          | . 32    |
| Sep-60   | 1502   |                                        | 38      | Sep-63 | 317             | 473      | 103        | Sep-66 | 11.    | •        | 32      |
| . Oct-60 | 1557   |                                        | 64      | Oct-63 |                 | 1535     | 69         | Oct-66 | 6      |          |         |
| Nov-60   | 1315   | •                                      | 45      | Nov-63 | · ·             | 1545     | 180        | Nov-66 | 31     | •        |         |
| Dec-60   | 1375   |                                        | 28      | Dec-63 |                 | 425      | 50         | Dec-66 | 23     | •        | 6       |
| Totals   | 14634  | 0                                      | 281     | Totals | 7111            | 4538     | 938        | Totals | . 175  | . 310    | 106     |
| Jan-61   | 1218   | ······································ | 14      | Jan-64 |                 | .809     | 354        | Jan-67 | 38     | •        | 8       |
| Feb-61   | 1130   | · ·                                    | 12      | Feb-64 | •               | 556      | 33         | Feb-67 | 45     | •        |         |
| Mar-61   | 1488   | •                                      | 5       | Mar-64 | 834             | 87       | 48 ·       | Mar-67 | 54     | es te    | 14      |
| Apr-61   | 1675   |                                        | 8       | Apr-64 | 570             |          | 21         | Apr-67 | 62     |          |         |
| May-61   | 1038   |                                        | 19      | May-64 | <b>'</b> '341 ' |          | 45         | May-67 | 85     |          | 5       |
| Jun-61   | 730    | • •                                    | 12      | Jun-64 | 476             | · · · .  | ;          | Jun-67 | 53     | •        | 5       |
| Jul-61   | 101    | 392                                    | 29.     | Jul-64 | 141             |          | 22         | Jul-67 | . 72   |          |         |
| Aug-61   | 1062   | ;                                      | . 16    | Aug-64 | 628             |          | 51         | Aug-67 | 42     |          | 5       |
| Sep-61   | 372    | 44                                     | · 21 ′  | Sep-64 | 359             |          | 42         | Sep-67 | 48     | · ·      |         |
| Oct-61   |        | 474                                    | 10 .    | Oct-64 | 221             | 1 12     | 26         | Oct-67 | . 46   | ·•       |         |
| Nov-61   | 896    | •••                                    | 55      | Nov-64 | 225             |          | 58         | Nov-67 | 16     |          |         |
| Dec-61   | 743    | • • •                                  | 53      | Dec-64 | 125             | er e 19  | 32         | Dec-67 |        | 19       | 4       |
| Totals   | 10453  | <sup>:</sup> 910                       | 254     | Totals | 3920            | 1452     | 732        | Totals | 561    | 19       | 41      |

Table M2-3. Quantities of Uranium Transferred to the Waste Pits: from Plant 8, Normal and Enriched U in Trailer Cake, and from Plant 5, Total U in Graphite or Ceramics (kg) <sup>a</sup>

<sup>a</sup>. From Courtney 1969.

(時代)もい くれた たいとう

There was concern about Plant 8 trailer cake discard measurements. In 1964, Nuclear Materials Control personnel pipe-sampled seven lots of trailer cake as it was being discarded into the chemical waste pit (Vath 1964b). Percent loss at 110°C, as moisture, and percent

uranium were requested for these samples and the original Plant 8 samples. On a dry weight basis, the Plant 8 samples had  $0.306 \pm 0.247\%$  uranium while the pit samples had  $0.406 \pm 0.181\%$  uranium. The report concluded that the comparison indicated a significant bias of 0.10% uranium or 33% of the original plant sample value (Vath 1964b). These limited data indicate that more uranium may have been discarded from the Plant 8 process than was detected by their sampling program. A limit of error estimate of 50% was assumed for trailer cake losses to the pit (NLCO 1966).



Figure M2-4. Monthly quantities of normal and enriched uranium in trailer cake from Plant 8 Discarded to the Waste Pits from July 1958 through June 1968.

#### Wet Discards

.

In the early sixties, liquid discharges were pumped to Waste Pit 3 directly from Plant 6, Plant 8, Plant 2/3 Refinery, and from the General Sump which processed waste from Plants 2/3, 4, 5, 6, 9, the analytical laboratory, and the decontamination area (Appendix L). Table M2-4 lists quantities of uranium in liquid effluents pumped to the waste pits from these sources, for 1960-1962. Figure M2-5 shows that the greatest contributors of uranium in liquid effluent to the waste pits were the Plant 2/3 Refinery, and the General Sump. Uranium discharges to the wet pits exceeded 500 kg per month except for June to October 1962. Discards during this three year period were highest from July 1960 to July 1961 when uranium discharged to the pits generally exceed 1,000 kg per month.

General sump logbooks recorded daily volume and uranium concentration measurements of liquid discards to the pit, and these data are tabulated for 1960, 1961, and 1962 in Tables M2-5, M2-6, and M2-7, at the end of this Annex (NLCO 1960; NLCO 1961; NLCO 1962). Figure M2-6 compares the volume and uranium quantities on a monthly basis for transfer of material from the General Sump to Waste Pit 3. This figure shows that effluent volume to the pits averaged approximately 250,000 gallons per day until June 1962

> Radiological Assessments Corporation "Setting the standard in environmental health"

Page M-35

New York

### The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

when it dropped three-fold to about 80,000 gallons per day. The uranium quantities were highest from July 1960 to July 1961 with a gradual decrease in quantities in 1962. The tables illustrate the detailed records that were maintained on the transfer of materials sent to the waste pits from the production buildings by way of the General Sump. Similar records were maintained for other years.

| Month      | General Sump Plant 2/3 | Plant 8   | Plant 6          |
|------------|------------------------|-----------|------------------|
| Jan-60     | 298 298                | 34        | · 1              |
| Feb-60     | 320 295                | 68        | 1                |
| Mar-60     | .240 511               | 62        | 2                |
| Apr-60     | 270 - 394              | 67        | 6                |
| May-60     | 240 602                | 74        | Ь                |
| Jun-60     | 270 512                | 90        | 5                |
| Jul-60     | 220 662                | 51        | 4                |
| Aug-60     | 370 955                | 100       | c                |
| Sep-60     | 240 738                | 92 .      | - 1              |
| Oct-60     | 210 1111               | 96        | <b>b</b>         |
| Nov-60     | 330 351                | 99        | 2                |
| Dec-60     | 590 517                | 89        | 3,               |
| Jan-61     | 510 979                | 101       | 2                |
| Feb-61     | 440 765                | 93        | 1                |
| Mar-61     | 210 658                | 102       | 3                |
| Apr-61     | 710 1137               | 95        | 5                |
| May-61     | 300 1160               | 90        | · 5              |
| Jun-61     | 400 893                | 93        | 7                |
| Jul-61     | 240 667                | 113       | 16               |
| Aug-61     | 315 322                | 95        | 40               |
| Sep-61     | 270 312                | 68        | 23               |
| Oct-61     | 190 256                | 104       | 6                |
| Nov-61     | 270 305                | 86        | · <sup>2</sup> 3 |
| Dec-61     | 250 249                | 100       | 22               |
| Jan-62     | 230 316                | 91        | 19               |
| Feb-62     | 180 207                | 100       | • 11             |
| Mar-62     | 220 204                | <b>84</b> |                  |
| Apr-62     | 170 191                | 68        | 40               |
| May-62     | 250 362                | 94        | 12               |
| Jun-62     | 140 567                | 88        | 10               |
| Jul-62     | 86 93                  | 52        | 2                |
| Aug-62     | 66 🗘 🤤 🐉               | 77        | 6                |
| Sep-62     | .56 b                  | 82        | 6                |
| Oct-62     | 68 . <sup>b</sup>      | 95        | c                |
| Nov-62     | 250 b                  | 93        | <0.5             |
| Dec-62     | 550 12 Yan 16          | 125       | 1                |
| Total 1960 | <b>3600</b>            | .920      | • 19             |
| Total 1961 | 4800 8200              | 1200      | 140              |
| Total 1962 | 2300 1900              | 1100      | 110              |

# Table M2-4. Monthly Quantities of Uranium (kg) in Liquid Effluent Pumped to the Waste Pits From 1960 to 1962 <sup>a</sup>

ords indicate none pumped......

No records located.



Figure M2-5. Monthly quantities of uranium in liquid effluents pumped to Waste Pit during 1960, 1961 and 1962.



Figure M2-6. Monthly summary of effluent volume and uranium quantities discharged from the General Sump to Waste Pit 3 in 1960, 1961 and 1962. The daily discharge quantities are tabulated in Tables M2-5, M2-6, and M2-7.

Frequently, higher than usual quantities of uranium were discarded to the wet pit (Pit 3) without detection by the General Sump safeguards. This was attributed to wet weather, and to the fact that while the uranium was insoluble, the spot checks only detected dissolved uranium (Harr 1960). Plant 8 pumped its liquid waste (UAP effluent) directly to

Radiological Assessments Corporation "Setting the standard in environmental health"

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

the waste pit, but its contribution was small. There was concern, however, that the Plant 8 sump effluent were not being measured accurately. A 10-day test from May 12 to 22, 1964, in which Plant 8 pumped to the General Sump rather than directly to the pit, revealed that the volume pumped as shown in Plant 8 records (144,000 gallons) was only one-fourth of the actual volume (593,000 gallons) measured by General Sump personnel (Vath 1964a). The SS uranium discarded was 11 times greater (1,044 lb.) than originally reported by Plant 8 records (94 lb.) for this 10-day period.

#### CONCLUSIONS

Server a

10000

- . ÷

For 1960, 1961, and 1962, the reported annual totals were about 23,000 kg, 63,000 kg, and 16,000 kg, respectively. There is general agreement between the discard totals taken from the annual (Gessiness 1974) and monthly (Courtney 1969) reports for 1960 and 1962 for both wet and dry discards to the pits. For 1961, however, the reported annual total (63,000 kg) is significantly higher than the total tabulated from monthly reports. This is due to differences in quantities of dry materials. However, it should be noted that the monthly reports only list dry discards from Plant 5 and Plant 8. Contaminated residues, General Sump sludge, turnings and solid metal scrap were put into the pit at various times, but the exact quantities were not always documented.

| Appendix M                | • :     |     |      |
|---------------------------|---------|-----|------|
| Groundwater Contamination | Outside | the | FMPC |

.....

3

| Page | M-39 |
|------|------|
|------|------|

| 1960  | Janua    | ary   | Febru          | ary   | Mar      | ch    | Apr      | <b>il</b> 1 | May      | 1     | Jun      | e     |
|-------|----------|-------|----------------|-------|----------|-------|----------|-------------|----------|-------|----------|-------|
| Date  | Vol(gal) | U(kg) | Vol(gal)       | Ú(kg) | Vol(gal) | U(kg) | Vol(gal) | U(kg)       | Vol(gal) | U(kg) | Vol(gal) | U(kg) |
| 1     |          |       | 372932         | 17    | 441420   | 25    | 255304   | 28          | 140756   | 11    | 308168   | 44    |
| 2     |          |       | 39345 <b>6</b> | 58    | 473760   | 34    | . •      |             | 332024   | 27    | 285040   | 9     |
| 3     | 512796   | 8     | 397432         | - 40  | 395276   | 17    | 329084   | 12          | 310520   | 202   | 305424   | 46    |
| 4     | 420500   | . 42  | 373324         | 25    | 404488   | 33    | 327898   | 5           | 307916   | 95    |          |       |
| 5     | 419328   | 27    | 490828         | 57    |          |       | 329476   | 7           | 355096   | 55    | 109940   | 29    |
| 6     | 394492   | 32    |                | •     | 232568   | 12    | 305620   | 25          | 302820   | 34    | 237272   | 5     |
| 7     | 419524   | 14    | 430892         | · 20  | 390572   | 41    | 305424   | 24          |          |       | 305956   | 52    |
| 8     | 389928   | 27    | 418348         | 17    | 373520   | 37    | 276180   | 13          | 143708   | 2     | 308952   | 88    |
| 9     |          |       | 439516         | 30    | 349468   | 33    |          |             | 352744   | 48    | 284844   | 9     |
| 10    | 419916   | 5     | 438928         | 21    | 372736   | 10    | 284648   | 8           | 305394   | 49    | 306992   | 23    |
| 11    | 373912   | 6     | 373716         | 9     | 373716   | 4     | 381378   | 8           | 312480   | 37    |          |       |
| 12    | 442456   | 37    | 353584         | 26    |          | • •   | 311248   | 32          | 302092   | 21    | 189896   | 7     |
| 13    | 400528   | 35    |                |       | 345448   | 26    | 304052   | . 34        | 306012   | . 22  | 331632   | 11    |
| 14    | 449044   | 37    | 279160         | 3     | 326928   | 3     | 285628   | 12          |          |       | 284844   | 3     |
| 15    | 394436   | 25    | 394808         | 19    | 397432   | 33    | 124252   | 72          | 141540   | 2     | 278236   | 71    |
| 16    |          |       | 395864         | 22    | 491792   | 42    |          |             | 285040   | . 6   | 267064   | 50    |
| 17    | 327516   | 5     | 392336         | 22    | 325948   | 6     | 140560   | 3           | 319340   | 31    | 361620   | . 41  |
| 18    | 326536   | . 7   | 398355         | 44    | 396452   | 44    | 237860   | 15          | 310520   | 26    |          |       |
| 19    | 379680   | 32    | 327124         | 32    | •        |       | 309484   | 46          | 306992   | 19    | 142716   | 3     |
| 20    | 395668   | 30    |                |       | 325752   | 3.    | 261128   | - 37        | 354564   | 22    | 237468   | 7     |
| 21    | 373128   | 6     | 322224         | · 5   | 440832   | 45    | 259204   | 54          |          | •     | 309484   | 50    |
| 22    | 399632   | 31    | 326928         | 9     | 395472   | 50    | 237272   | 11          | 142520   | 6     | 262360   | 45    |
| 23    |          |       | 401156         | 30    | 394100   | 44    |          |             | 259224   |       | 331828   | 9     |
| 24    | 324576   | 3     | 401352         | 30    | 348784   | 35    | 189504   | 4           | 284648   | 18    | 306012   | 47    |
| 25    | 403861   | 50    | 399000         | 34    | 457940   | 60    | 259812   | 49          | 303212   | 5     |          |       |
| 26    | 394688   | 27    | 451416         | 32    |          |       | 355740   | 79          | 303660   | 26    | 237468   | 13    |
| 27    | 350644   | 30    |                |       | 186760   | 9     | 313068   | 29          | 349664   | 40    | 237860   | 12    |
| 28    | 351524   | 39    | 511728         | 6     | 235900   | 12    | 305032   | 18          |          | 32    | 306193   | 35    |
| 29    | 402724   | 37    | 420700         | 6     | 351036   | 36    | 311108   | 29          | 188524   |       | 331828   | 29    |
| 30    |          |       |                | -     | 348096   | 35    |          |             |          | 6     | 304640   | 42    |
| 31    | 375872   | 7     |                | •     | 396060   | 40    |          |             | 237272   | 7     |          |       |
| otals |          |       |                |       |          |       |          |             |          |       |          |       |
| 'ol   | 8909613  |       | 9905107        |       | 9972256  |       | 6999964  |             | 7258282  |       | 7173737  |       |
| (kg)  |          | 600   |                | 610   |          | 770   |          | 650         |          | 850   |          | 780   |

<sup>a</sup> From NLCO 1960. Values include quantities of neutralized evaporative product (NEP) from Plant 2/3 and effluent from General Sump pumped to pit (see Table M2-4). Gaps in data indicate either that no pumping occurred on that day, or that the day's pumping is accounted for in an adjacent day's measurement; all material pumped is accounted for.

09440

1.1.1.1.1

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

۰Y

Table M2-5. Daily Record of General Sump Effluent Pumped to Pit in 1960 (cont'd.) "

12 BAD 1 - JP

|             | 1960           | July     | ,      | Augu     | st     | Septer           | nber           | Octo     | ber .  | Noven    | iber   | Десеп    | iber  |
|-------------|----------------|----------|--------|----------|--------|------------------|----------------|----------|--------|----------|--------|----------|-------|
|             | Date           | Vol(gal) | U(kg)  | Vol(gal) | U(kg)  | Vol(gal)         | U(kg)          | Vol(gal) | U(kg)  | Vol(gal) | U(kg)  | Vol(gal) | U(kg) |
|             | 1              | 310128   | 55     | 260884   | 86     | 264264           | 93             | ÷ .      |        | 334180   | 10     | 405076   | 67    |
|             | 2              | • •      |        | 190092   | 10 ·   | 301448           | · 40 ·         | 189896   | • 4    | 307776   | 53     | 300328   | 55    |
|             | - 3            | · .      |        | 236488   | 13 .   | esete-           | ÷ :            | 237468   | . 9    | 329222   | 71     |          |       |
|             | 4              | 284648   | 17     | 316890   | 134    | 5764             |                | 275065   | 28     | 257872   | 34     | 233940   | 10    |
|             | ຸ 5            | 250388   | 50     | 260932   | 102    | 236292           | 5 🗇            | 262108   | 29     | 5 - F    |        | 332612   | 21    |
|             | 6              | 320544   | 41     |          |        | 237272 ;         | · 5 ·          | 316792   | 668    | 240736   | 7      | 353724   | 62    |
|             | 7              | 378666   | 33     | 141932   | 10     | 259756           | 54             | 306064   | 51     | 237272   | 6      | . 332808 | 17    |
|             | 8              | 222350   | 18     | 284452   | 6;     | 189896           | 13             |          |        | 379204   | 10     | 401688   | 73    |
| <b>۰</b> ۰. | <sup>-</sup> 9 |          |        | 306404   | 71     | 264124           | 91             | 142520   | 5      | 332808   | 11     | 349368   | 26    |
| •           | 10             | 189112   | 17     | 309876   | 89     | 11.1             |                | 237076   | 9      | 380380   | - 5    | •        |       |
|             | · 11           | 337720   | 40     | 285236   | 7      | 190278           | . <b>10</b> .1 | 284648   | 14     | 313992   | - 55   | 279748   | 15    |
| •           | 12             | 337305   | 55 ,   | 353188   | 160    | 189896           | 12             | 285040   | 10 -   |          |        | 322024   | 11    |
| ••          | 13             | 317464   | 44     |          |        | 237076           | . <b>8</b> ·   | 310660   | 83     | 187644   | . 9    | 332024   | 12    |
|             | 14 ·           | 342760   | 45     | 237664   | 7      | 261772           | . 112 ;        | 262360   | 55     | 284648   | 11     | 332024   | 17    |
| ۰.          | 15             | 327584   | 54     | 285040   | . 8    | 302848           | . 88 ;-        |          |        | 300328   | .60    | 381164   | 14    |
| • •         | 16             |          |        | 285236   | 17 .   | 284452           | 9 :            | 190092   | 5      | 332024   | 12     | 375340   | 98    |
| •           | 17             | 142912   | 5      | 306796   | 81     |                  | •              | 189700   | 6      | 332908   | 8      |          |       |
|             | 18             | 252134   | . 21   | 304238   | 64     | 142324           | 4 :            | 284452   | 12     | 306600   | 77     | 283472   | 20    |
|             | 19             | 260870   | 48     | 305002   | 44     | 284256           | 14             | 358624   | 80 .   | · .      | 0      | 331632   | 30    |
|             | 20             | 278640   | 64     | •        |        | 350448           | 54             | 306936   | 38     | 187740   | 8      | 359464   | 126   |
|             | 21             | 240708   | 45     | 238056   | 7      | 361544           | 52             | 284648   | 5      | 380576   | 40     | 379546   | 41    |
|             | . 22           | 343772   | 47     | 237272   | 40     | 433440           | 108            |          |        | 332612   | 18     | 379008   | 31    |
|             | 23             |          | :      | 283276   | • 15 • | 356416 :         | * 48           | 189700   | - 9    | 353192   | 117    | 378224   | 17    |
| · .         | 24             | 110544   | 2      | 344764   | 40     | 1 1              | ;              | 284648   | 6      | × ,      |        | · ·      |       |
|             | 25             | 280268   | 44     | 304620   | 39     | 236684           | 5 <b>3</b> 7   | 284452   | . 9 .  | 236292   | - 8    |          |       |
|             | 26             | 292368   | • 41 : | 265104   | 83     | 332612           | 11             | 315420   | 77     | · ·      |        | 237076   | 16    |
| •           | 27             | 289872   | 43     |          |        | 272856           | 25             | 312932   | 70     | 235116   | . 13   | 365344   | 159   |
|             | 28             | 353032   | 28     | 237860   | 46     | 310520           | 34             | 303072   | 33 - 1 | 285040   | 9      | 282688   | 78    |
| . ·         | 29             | 285236   | 6      | · 282100 | . 47   | 336924           | 53             |          | -      | 380380   | ີ 17 ຸ | 331828   | 54    |
|             | 30             |          | •      | 353584   | 48     | 324772           | 31             | 141148   | 4      | 332220   | 10 -   | 330848   | 30    |
|             | 81             | 190092   | 4      | 357300   | 47     |                  |                | 237272   | 5      |          |        | 330848   | 10    |
|             |                |          | •      |          | ••     |                  |                |          | - ,    | •<br>•   |        |          |       |
|             | Totals         |          |        |          | •      |                  |                |          | •      |          | ••     |          |       |
|             | Vol            | 6939117  |        | 7574286  |        | 6962170          |                | 6792793  |        | 7580662  | ,      | 8721846  | •     |
| . •         | U (kg)         | •···•    | · 870  |          | 1300   | 3. <b>2</b> 0. 1 | 980            |          | 1300   |          | 680    | · ·      | 1110  |

<sup>a</sup> From NLCO 1960. Values include quantities of neutralized evaporative product (NEP) from Plant 2/3 and effluent from General Sump pumped to pit (see Table M2-4). Gaps in data indicate either that no pumping occurred on that day, or that the day's pumping is accounted for in an adjacent day's measurement; all material pumped is accounted for.

Appendix M 👾

ста С. Ч.

-

٠.

· ·.

51.

Groundwater Contamination Outside the FMPC

| 1961  | Janua    | агу   | Febru    | агу   | Marc     | :h    | Apr      | i <b>l</b> . | Ma                 | 7     | Jun            | e    |
|-------|----------|-------|----------|-------|----------|-------|----------|--------------|--------------------|-------|----------------|------|
| Date  | Vol(gal) | U(kg) | Vol(gal) | Ú(kg) | Vol(gal) | U(kg) | Vol(gal) | U(kg)        | Vol(gal)           | U(kg) | Vol(gal)       | Uſkg |
| 1     |          | ,     | 7574286  | 105   | 388394   | 52    | ÷ •      |              | 252560             | 11    | 347416         | 61   |
| 2     |          | :     | 310128   | 152   | 382876   | 56    | 144170   | 4            | 390216             | 127   | 401117         | 68   |
| 3     | 332220   | 20    | 353780   | 88    | 322272   | 49    | 282884   | 58           | 389844             | 79    |                |      |
| 4     | 333396   | 35    |          | 0     |          |       | 350644   | 12           | 352604             | 11    | 299054         | 9    |
| 5     | 407624   | 153   | 280924   | 78    | 341774   | 22    | 292440   | 82           | 352800             | 14    | 329290         | 59   |
| 6     | 414448   | 220   | 284452   | 23    | 333360   | 18    | 326396   | 54           | •                  |       | 354564         | 13   |
| 7     | •        |       | 353388   | 104   | 424286   | 67    | 346138   | 58           | 352747             | 14    | 352619         | 62   |
| 8     | 189504   | 21    | 332416   | 27    | 339082   | · 6   |          |              | 363680             | 19    | 395630         | 54   |
| 9     | 284452   | - 20  | 312676   | 94    | 457996   | 95    | 196756   | 11           | 436404             | 71    | 246538         | 54   |
| 10    | 310324   | 129   | 245700   | 10    | 251852   | 11    | 251876   | 14           | 330900             | . 37  |                |      |
| 11    | 366660   | 118   | ·        | 0     | •        |       | 282548   | 96           | 313068             | 9     | 200866         | 8    |
| 12    | 284648   | 17    | 179896   | 13    | 338688   | 11    | 139892   | 30           | 332056             | 70    | 235698         | 15   |
| 13    | 310912   | 88    | 283276   | 15    | 335064   | 37    | 333860   | 133          | •                  |       | 348467         | 41   |
| 14    |          |       | 378310   | 60    | 418796   | 46    | 344568   | 162          | 147560             | 6     | 329052         | 25.  |
| 15    | 332416   | ´ 10  | 259148   | 67    | 330800   | 63    | · •      |              | 351622             | 6     | 4035 <b>94</b> | 132  |
| 16    | 284648   | 34    | 291560   | 9     | 351232   | 10    | 251972   | 10           | 303660             | 7 -   | 350114         | 96   |
| 17    | 351036   | 93    | 311048   | 93    | 291856   | 63    | 382592   | 110          | 332256             | 136   |                |      |
| 18    | 284648   | 14    |          |       |          |       | 383180   | 94           | 389608             | 49    | 249026         | 23   |
| 19    | 297780   | 81    | 230802   | 18    | 248538   | 15    | 308880   | <b>61</b>    | 283136             | 45    | 250982         | 10   |
| 20    | 372596   | 161   | 286594   | 10    | 298764   | 18    | 405504   | 100          | •                  |       | 393200         | 83   |
| 21    |          | •     | 356720   | 38    | 379252   | 45    | 321000   | 15           | 236168             | 117   | 251580         | 11   |
| 22    | 234332   | 10    | 139046   | 3     | 379036   | 64    | · ·.     |              | 389846             | 67    | 328354         | 107  |
| 23    | 238252   | 14    | 336346   | × 24  | 384408   | 71    | · 105924 | 55.          | 295580             | 92    | 200872         | 8    |
| 24    | 362740   | 50    | 374402   | ʻ 33  | 270392   | 32    | 202072   | 16           | 348136             | 85    |                |      |
| 25    | 308168   | 47    | •        | •     |          |       | 455784   | 23           | 290844             | 144   | 99652          | 4    |
| 26    | 332220   | 12    | 368102   | 15    | 197593   | 7     | 328652   | 14           | 343452             | 67    | 253344         | - 11 |
| 27    | 307720   | 51    | 388922   | 60    | 252560   | 10    | 389608   | 58           |                    |       | 354956         | ʻ 10 |
| 28    |          |       | 439161   | 59    | 302295   | 10    | 422700   | 80           | 282408             | 129   | 252364         | 9    |
| 29    | 281512   | 19    |          |       | 341648   | 50    | • `      | •            |                    |       | 287656         | 213  |
| 30    | 293956   | 51    |          | . •   | 344276   | 41    | 195493   | 7            | 183872             | 39    | 303856         | 11   |
| 31    | 331828   | 23    |          |       | 50512    | 2     |          |              | 247 <del>944</del> | 5     |                |      |
| otals |          |       | •        |       |          |       |          |              |                    |       |                |      |
| ol    | 7848040  |       | 7398413  |       | 8757602  |       | 7445533  |              | 8292971            |       | 7819861        |      |
| (lea) |          | 1500  |          | 1200  |          | 970   | • •      | 1400         |                    | 1500  |                | 1200 |

<sup>a</sup> From NLCO 1961. Values include quantities of neutralized evaporative product (NEP) from Plant 2/3 and effluent from General Sump pumped to pit (see Table M2-4). Gaps in data indicate either that no pumping occurred on that day, or that the day's pumping is accounted for in an adjacent day's measurement; all material pumped is accounted for.

# Radiological Assessments Corporation

"Setting the standard in environmental health"

Page M-41

# The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

۰.

21-

.

e,

10. Cal. 5

è.

Sec. A

12.151.21

**1 - 1 - 1** - 1 - 1 - 1

| Table MZ-6. Daily Record of General Sump Effluent Pumped to Pit in 1961 (contro | Pumped to Pit in 1961 (cont'd.) a | np Ef | General Su | Record of | Daily | Table M2-6. |
|---------------------------------------------------------------------------------|-----------------------------------|-------|------------|-----------|-------|-------------|
|---------------------------------------------------------------------------------|-----------------------------------|-------|------------|-----------|-------|-------------|

| 1961    | Jul      | y     | Augu     | ISL   | September       | Octo     | ber   | Novem     | ber   | December         |       |  |
|---------|----------|-------|----------|-------|-----------------|----------|-------|-----------|-------|------------------|-------|--|
| Date    | Vol(gal) | U(kg) | Vol(gal) | U(kg) | Vol(gal); U(kg) | Vol(gal) | U(kg) | Vol(gal). | U(kg) | Vol(gal)         | U(kg) |  |
| 1       |          | • •   | 298998   | 33    | 380270 28       | 48904    | -1    | 302680    | 14    | 303992           | 23    |  |
| 2       | 101416   | 4     | 238308   | . 8   | : 1-1-          | 50216    | 2     | 343554    | 32    | -                |       |  |
| 3       |          | 1812  | 290388   | 20    | 2 control 2     | 50708    | 1     | 252168    | 13    | 242436           | 11    |  |
| 4       | 200872   | 10    | 292388   | 15    | 389460 19       |          |       |           |       | 289815           | 13    |  |
| 5       | 302876   | 9     | · .      | ,     | 200872 : 14     | 201656   | : 5   | 266676    | 10    | 289304           | 26    |  |
| 6       | 300840   | -168  | 150752   | 3     | 287977 8        | 290312   | 25    | 252168    | 11 .  | 267550           | 17    |  |
| 7       | 303060   | 148   | 350252   | · 8   | 441704 39       |          |       | 295092    | 201   | 349048           | 23    |  |
| 8 ິ     |          |       | 291760   | 30    | 303856 2214     | 100044   | 3     | 251902    | 10    | 302284           | 18    |  |
| . 9     | 105336   | 4     | 252168   | 9     | 4               | 245364   | - 5   | 268168    | 15    |                  |       |  |
| 10      | 252756   | . 1   | 301596   | 15    | 241816          | 201656   | 3     | 293364    | 15    | 157536           | 9     |  |
| 11 -    | 252168   | 8     | 352700   | 13    | 200053 8        | 245896   | 21    |           |       | 251188           | 34    |  |
| 12      | 251580   | 11    |          | •     | 396939          | 292152   | 22    | 200872    | 9     | 258168           | 9     |  |
| 13      | 251776   | 8     | 213200   | . 8   | 291564 34       | 339525   | 30    | 256844    | 10    | 373422           | 14    |  |
| 14      | 338136   | 170   | 204600   | 33    | 301896 6        | · .      |       | 293080    | 12    | 303268           | 9     |  |
| . 15    |          |       | 202046   | ັ 19  | 173480 22       | 100828   | 3     | 339922    | 32    | 355664           | 15    |  |
| 16      | 148968   | . 7   | 294105   | 16    | p               | 202048   | 17    | 332000    | 12    | • •              |       |  |
| 17      | 252364   | 24    | 304000   | 10    | 303056 13       | 242564   | 20    | 303464    | 8     | 201264           | 4     |  |
| 18      | 302680   | 14    | 202057   | 35    | 201460 12       | 252148   | 10    |           |       | 202244           | 11    |  |
| 19      | 285459   | .72   |          |       | 251186 9        | 296494   | 15    | 199500    | . 5   | 343784           | 43 ·  |  |
| 20      | 302288   | 9     | 201068   | 10    | 238276 7        | 315856   | 11    | 252560    | 10    | 329194           | 39    |  |
| 21      | 303660   | . 9   | 201852   | · 27· | 364250          |          |       | 341122    | 45    | 348930           | 22    |  |
| 22      |          | -     | 293308   | 53    | 324604 . 46     | 152124   | 4     | 308444    | . 13  | 292488           | 20    |  |
| 23      | 144284   | . 7   | 343992   | -20   |                 | 247197   | 18    | 167340    | .1:4  |                  |       |  |
| 24 .    | 252365   | 6     | 344423   | 36    | 151152 13       | 242600   | 50    | 107240    | 2     | 201068           | 7     |  |
| 25      | 341488   |       | 303072   | 15    | 290983 40       | 290976   | 36    |           | . · • | 100632           | 4     |  |
| 26      | 296564   | 39    |          |       | 301879 14       | 293524   | 62    | 165336    | 2     | 151732           | 4     |  |
| . 27    | 290780   | 32    | 285196   | 69    | 338958 24       | 247226   | 9     | 344640    | 7     | 326780           | 31    |  |
| • 28    | 240876   | 45    | 202048   | 6     | 275230 43       |          | ,     | 266364    | 7     | 323456           | 37    |  |
| 29      |          |       | 303072   | 150   | 239442          | 301896   | ิ่ย   | 286914    | 35    | 352996           | 57    |  |
| . 30    | 250594   | . 8   | 392000   | - 14  |                 | 302680   | 5     | 308204    | 44    |                  | •••   |  |
| 31      | 201164   | . 9   | 290976   | 17    | 96672 5         | 291297   | 28    |           |       | 202440           | 5     |  |
| Totals  |          |       |          |       |                 |          |       | ·         |       | ۰ <b>۲</b> ۰۰۰ - |       |  |
| Vol ··· | 6274370  |       | 7400325  | . :   | 6987035         | 5845891  |       | 6999618   |       | 7120683          |       |  |
| U (kg)  | ر:       | 910   |          | 690   | 560             | ·        | 410   |           | 580   | ·                | 500   |  |

<sup>a</sup> From NLCO 1961. Values include quantities of neutralized evaporative product (NEP) from Plant 2/3 and effluent from General Sump pumped to pit (see Table M2-4). Gaps in data indicate either that no pumping occurred on that day, or that the day's pumping is accounted for in an adjacent day's measurement; all material pumped is accounted for.

| 1962           | Janua    | iry   | Febru    | ary   | Mart     | ch ·  | Apri     | il         | May      |       | June.    |       |
|----------------|----------|-------|----------|-------|----------|-------|----------|------------|----------|-------|----------|-------|
| Date           | Vol(gal) | U(kg) | Vol(gal) | U(kg) | Vol(gal) | U(kg) | Vol(gal) | U(kg)      | Vol(gal) | U(kg) | Vol(gal) | U(kg) |
| 1              | 50120    |       | 252364   | 13    | 344176   | 20    | ,        |            | 346344   | 29    | 287056   | 88    |
| 2              | 260045   | 30    | 302876   | 8     | 258972   | 10    | 193720   | 37         | 352388   | 10    | 151732   | 5     |
| 3              | 217460   | 2     | 99064    | 3     | 100632   | 1     | 308464   | 13         | 291116   | 46    |          |       |
| 4              | 378332   | 74    |          |       |          | •     | 265756   | 8          | 353584   | 8     | 280784   | 60    |
| <sup>.</sup> 5 | 366613   | 35    | 253424   | 5     | 251574   | 18    | 313072   | 10         | 98666    | 1     | 286860   | 16    |
| 6              | 252554   | 8     | 251972   | 9     | 247632   | 22    | 179508   | 28         |          |       | 347704   | 10    |
| 7              |          |       | 397432   | . 39  | 239775   | 38    | 99842    | <b>2</b> · | 343993   | 34    | 285824   | 17    |
| <b>8</b> ·     | 246876   | 49    | 397236   | 28    | 298684   | 39    |          | •          | 303464   | 6     | 247716   | 7     |
| 9              | 303740   | 53    | 303464   | 7     | 262250   | 38    | 245112   | · 37       | 344176   | 56    | 201852   | 2     |
| 10             | · 152121 | 4     | 152904   | 3     | 155008   | • 5   | 254128   | 8          | 304052   | 13    |          |       |
| 11             | 202432   | 3     |          |       |          |       | 252952   | 5          | 347162   | 49    | 313750   | . 24  |
| 12             | 338884   | `20   | 208568   | 4     | 259916   | 17    | 252952   | 6          | 101024   | 3     | 350036   | 39    |
| 13             | 202038   | 5     | 346724   | 15    | 302876   | 14    | 303856   | 6          |          | •     | 340928   | 40    |
| 14             |          | · · * | 288784   | 22    | 306312   | 13    | 151928   | 2          | 283276   | 5     | 302720   | 27    |
| 15             | 253148   | 14    | 201656   | 6     | 262364   | 12    |          | •          | 286272   | 43    | 348684   | 13    |
| 16             | 253148   | · 8   | 252560   | 55    | 262560   | 15    | 297851   | 12         | 353388   | 11    | 201656   | 1     |
| 17             | 252364   | 8     | 151536   | 3     | 99446    | 5     | 252952   | - 4        | 282940   | 36    |          |       |
| 18             | 303660   | . 13  |          |       |          |       | 308282   | 37         | 303464   | 7     | 317500   | 9     |
| 19             | 305684   | 60    | 250012   | 46    | 252756   | 7     | 252560   | 9          | 202440   | 5     | 299355   | 26    |
| 20             | 251590   | 6     | 313072   | 7     | 279125   | 37    | 101024   | 3          |          |       | 302680   | 38    |
| 21             |          |       | 197932   | 24    | 278432   | 37    | 150752   | 1          | 244132   | 66    | 346584   | 20    |
| 22             | 317052   | 8     | 92952    | 3     | 232648   | · 27  |          |            | 252364   | 4     | 353780   | 19    |
| 23             | 369172   | 13    | 92005    | 16    | 257952   | 5     | 237468   | . 36       | 340332   | 38    | 104613   | 6     |
| 24             | 373780   | 20    | 100828   | 1     | 100436   | 4     | 252365   | 10         | 257756   | 4     |          |       |
| 25             | 202648   | 6     |          |       |          | •     | 252756   | 11         | 298348   | 38    | 353388   | 12    |
| 26             | 251972   | 8     | 253932   | 6     | 202832   | 6     | 304052   | 5          | 248952   | 9     | 352604   | 37    |
| 27             | 99676    | 3     | 360820   | 32    | 300708   | 19    | 300328   | 46         |          |       | 402724   | 103   |
| 28             |          |       | 300132   |       | 226002   | 7     | 140025   | A          | 202660   | 10    | 202484   | 64    |

<sup>a</sup> From NLCO 1962. Values include quantities of neutralized evaporative product (NEP) from Plant 2/3 and effluent from General Sump pumped to pit (see Table M2-4). Gaps in data indicate either that no pumping occurred on that day, or that the day's pumping is accounted for in an adjacent day's measurement; all material pumped is accounted for.

Radiological Assessments Corporation "Setting the standard in environmental health"

1.0.0

Page M-43

۰.

*Totals* Vol

U(kg)

•... · ·

10102

......

(A) (A)

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

ويعجم ويتدعون والمراجع المترجع

Table M2-7. Daily Record of General Sump Effluent Pumped to Pit in 1962 (cont'd) a

| 1962        | July     |       | Aum      |            | Santar             |               | Octob    |                | Novor    | har        | Decem    | har   |
|-------------|----------|-------|----------|------------|--------------------|---------------|----------|----------------|----------|------------|----------|-------|
| Date        | Vol(gal) | U(kg) | Vol(gal) | U(kg)      | · Vol(gal)         | U(kg)         | Vol(gal) | U(kg)          | Vol(gal) | U(kg)      | Vol(gal) | U(kg) |
| 1           | 252756   | 7     | 148008   | 5          | a. 99              | ۰.            | 50316    | 1              | 99848    | 4          |          |       |
| 2           |          |       | 101217   | 5          |                    |               | 150556   | 6              | 99652    | 5          |          |       |
| 3           | •        |       | 241584   | 9          |                    | •             | 47964    | 3              |          |            |          |       |
| 4           |          |       |          |            | 1899892            | 4             | 49924    | 2              |          | · • • .    | 150752   | 4     |
| 5           | 252952   | 37    |          |            | 50944              | 1             | 92792    | <sup>.</sup> 3 | 49728    | 1          | 97104    | 2     |
| 6           |          |       | 50120    | 1          | 49336              | 1             | •        |                | 99848    | 5          | 99652    | 5     |
| · 7         |          | ÷     | 147616   | 4          | 99456              | - 4           | · · .    |                | 49140    | 3          | 49140    | 2     |
| 8           |          | •     | 96908    | 1          |                    |               | 47964    | 1              | 101220   | 3          |          |       |
| 9           |          |       | 96516    | 2          |                    | •             | 96320    | 5              | 99848    | 1          | ·` :     |       |
| · •10       | 254116   | 10    | 95340    | 2          | 98476              | 4 -           | 47180    | 3              | · · ·    |            | 49456    | 3     |
| 11          |          |       | •        |            | 50120              | 72 - 1 - 2    | 47964    | 2              |          |            | 48552    | 2     |
| 12          |          | •     |          |            | 99848              | 1             | 100808   | 2              | 50120    | 4          | 148988   | 7     |
| 13          |          | . ,   | 100240   | 2          | 100236             | 4             | • '      | •              | 99652    | <b>4</b>   | 148008   | 14    |
| 14          | 49336    | 22    | 100044   | 1          | 100440             | 2             | · · .    |                | . 148988 | 10         | 145656   | 11    |
| · 15        |          |       | · 101808 | · 1        | e • 1 • 1 5        | 1             | 49728    | 3              | 49728    | 1          |          |       |
| 16          |          |       | 93380    | 2          | and and the        | • •           | 48748    | <b>1</b>       | 100820   | 7          | •        |       |
| 17          | 144068   | 20    | 99652    | 2          | 49727              | <b>C</b> - 1. | 46592    | 1              |          | •          | 49728    | 1     |
| 18          | 143304   | 22    | •        |            | 50316              | 1             | 96908    | 4              |          |            | 49728    | 3.    |
| 19          | 197932   | 16    |          |            | 150164             | 2             | 50708    |                | 49140    | 1          | 99652    | 3     |
| 20          | 98672    | · 6   | 99456    | 2          | 48944              | •             |          |                | 99652    | - 4        | 99652    | 31    |
| 21          | 95732    | 3     | 99260    | 3          | 94948              | 4             | 4        |                | . 149380 | 5          | 50120    | 6     |
| 22          | •.       |       | 50905    | 3          |                    | •             | 100436   | 2              |          | •,         |          |       |
| <b>23</b>   | 100828   | 3     | 96712    | 5          | ч.                 |               |          |                | 49924    |            |          |       |
| 24          | 50904    | 3     | 149962   | 4          | 95536              | 5 `           | 100044   | 5              |          |            | 150556   | 13    |
| 25          | 149772   | 13    |          | -          | 99260              | . 3           | 94164    | 3              | •        | : <b>.</b> | ΄.       |       |
| <b>26</b> · | . 99848  | . 3   |          | •          | 100632             | - 4           | 101132   | 3              | 96516    | 2          |          |       |
| 27          | 200284   | 8     | 93968    | 2          | 46590              | 4             |          |                | 100828   | 2          | 50120    | 1     |
| 28          | • .      |       | 50904    | 2          | 100436             | 6             | ; .      |                | 99652    | •3         | 150556   | 9     |
| 29          | 101808   | - 5   | 98868    | 2          | · ·                | 1             | 41888    | 2              | . 99652  | 3          | •        |       |
| 30          |          |       | 98944    | 1          |                    |               | 98868    | 8              | 99848    | 4          |          |       |
| 31          | 101612   | 5     | 148008   | 4          | •                  |               | 49336    | 2              |          |            | 99456    | 5     |
|             | •        | •     |          | , ···      | -12 - 1 <b>-</b> 1 | •             |          |                | • •      |            |          |       |
| Totals      |          |       |          |            | · · · · ·          | •             | ;        |                |          |            |          |       |
| Vol         | 2293924  | •     | 2459420  | •••        | 3385301            |               | 1610340  |                | 1893184  |            | 1736876  |       |
| U (kg)      | • •      | 180   | ·.       | <b>6</b> 6 | · · ·              | 50            |          | 63             | · ·.     | 72         |          | 120   |

<sup>a</sup> From NLCO 1962. Values include quantities of neutralized evaporative product (NEP) from Plant 2/3 and effluent from General Sump pumped to pit (see Table M2-4). Gaps in data indicate either that no pumping occurred on that day, or that the day's pumping is accounted for in an adjacent day's measurement; all material pumped is accounted for.

1. S. 1. 1. S. 1.

and the second

••

· · ·

5 a .

n de seite Service de sette Constant const Stanting de Sa

#### Page M-45

#### ANNEX 3 TO APPENDIX M

#### FATE OF URANIUM DEPOSITED ON THE GROUND SURFACE

#### INTRODUCTION

A source of ground contamination outside the facility boundaries was the deposition of uranium that had been discharged to the atmosphere from the variety of atmospheric sources at FMPC described in Appendices E, H, and I. The behavior of uranium deposited on the soil surface is of interest for determining contributions to alternate human exposure pathways. The physical size and relatively high density of uranium particles released to the atmosphere led to deposition of these particles on surfaces at ground level. Unless the vegetation cover is very dense most of the deposition would be from air to soil. Deposition on vegetation is gradually lost by weathering and is ultimately a source of contamination of the top layer of the soil.

Uptake of uranium from soil by vegetation is not an important transport mechanism. The maximum value reported (Peterson 1983) for the plant/soil concentration factor was that for grasses,  $5 \times 10^{-3}$  (dry weight basis). For a uniform concentration of 30 pCi g<sup>-1</sup> in the soil, the grasses growing in that soil would be expected to reach 0.15 pCi g<sup>-1</sup> at equilibrium. To estimate the maximum removal from soil by plant uptake, one can consider the removal by a very dense crop of vegetation. If the dry matter yield is assumed to be 0.4 kg m<sup>-2</sup>, which is quite high, and it is assumed that multiple cuttings of the vegetation occur over an extended growing season, the removal rate of uranium from the soil is less than 0.1 pCi cm<sup>-2</sup> y<sup>-1</sup>.

A special study that was conducted to determine the primary transport pathway for uranium deposited on soil around the FMPC is summarized below. Calculations addressed in this study compare uranium migration due to infiltration, surface soil erosion, and surface water runoff (Ichimura 1991b).

#### GENERAL METHOD

There are numerous transport models available in the literature; however, to simplify this evaluation, the calculations were based on simple algebraic and "handbook" models. The goal of this study was to estimate the annual quantities and average concentrations of uranium that would be transported through each of the above pathways from a unit area of soil having homogeneous uranium concentration in soil.

Uranium migration estimates within this report only apply to the flat lying, poorly drained soils around the FMPC which are covered with pasture grass. These soils include the Fincastle silt loam and the Henshaw silt loam (Lerch et al. 1982). For these calculations it was assumed that the land slope is less than 2% and the typical drainage length before encountering ravines is 660 ft. Also, these soils are poorly drained and require artificial drainage to help maintain crop productivity. Where artificial drainage is not installed, the

> Radiological Assessments Corporation "Setting the standard in environmental health"

.;: ·

.

• .

1.100

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

water content in these soils is high during extended periods in the winter and spring. For this reason, the infiltration calculation assumes saturated groundwater flow in the vertical direction.

#### WATER BALANCE

The fate of adsorbed uranium in soil can be estimated if the rates of soil and water movement are well known. Therefore, the hydrologic water balance must be estimated to quantify water movement. Water balance considers the rates of rainfall, runoff, infiltration, and evapotranspiration. The infiltration component of the water balance moves uranium through the soil column. The runoff waters carry uranium by desorption and ion exchange from contaminated soil and transport surface soil in the form of suspended sediments away from contaminated areas. To compare these transport mechanisms, all models assume that the source of uranium is the soil, and that the soil is infinitely replenished with uranium. For comparison purposes, the concentration of uranium in the soil is assumed to be:

$$C_{s} = 30 \text{ pCi g}^{-1}$$

This concentration is typical of  $^{238}$ U concentration found in soils on the FMPC site (Solow and Phoenix 1987). Note, however, that the magnitude of soil uranium concentration used for these comparisons is not critical, as we are most interested in the relative transport rates for the different mechanisms. Furthermore, if the soil concentration is  $C_s$ , then the associated soil-water concentration, C, can be obtained from the distribution coefficient ( $K_d$ ) relationship:

$$K_{d} = \frac{C_{s}}{C} \qquad \left(\frac{pCi g^{-1}}{pCi mL^{-1}}\right)$$

A distribution coefficient of 9 mL g<sup>-1</sup> has been estimated for the sand-clay aquifer which underlies the FMPC (ASI-IT 1990). At present, the distribution coefficient of the surface soils is not known.

Movement of uranium is dependent upon the various components of the water balance. This section describes the models, data, and results of the water balance calculations which require estimating annual surface runoff, annual evapotranspiration, and annual water infiltration. In summary, the water balance for a watershed can be described as follows:

#### Annual Precipitation = Annual Runoff

+Annual Evapotranspiration

#### entre enternal Infiltration

First, the annual runoff from the area was determined. The U.S. Soil Conservation Service (SCS) has developed a number of models for estimating runoff from ungauged watersheds. The model used is described in the reference (SCS 1969). It requires estimates of watershed size, annual precipitation, annual temperature, and land condition. For this calculation, the size of the watershed was assumed to be about 40,000 m<sup>2</sup> (10 acres). The

average annual precipitation in the vicinity of the FMPC is 97 cm  $y^{-1}$  (38 in  $y^{-1}$ ) (ASI-IT 1990). The average annual temperature is 12°C (54°F) (Spieker 1968). The land condition was assumed to be a "Good Pasture." Applying the above parameters yields an estimated runoff of 5.1 cm  $y^{-1}$  (2.0 in  $y^{-1}$ ).

Next, the evapotranspiration was estimated using pan evaporation data. For the FMPC area, the average annual pan evaporation is 111 cm  $y^{-1}$  (44 in  $y^{-1}$ ) (Veihmeyer 1964). By applying the method described by Jensen (1980), the estimated annual evapotranspiration was 79 cm  $y^{-1}$  (31 in  $y^{-1}$ ).

Using these values calculated above, the annual infiltration rate is estimated to be 13 cm  $y^{-1}$  (5 in  $y^{-1}$ ). This annual infiltration rate compares well with the estimated groundwater recharge rate of 15 cm  $y^{-1}$  (6 in  $y^{-1}$ ) in the glacial till which surrounds the FMPC (GeoTrans 1985). Figure M3-1 summarizes the results of the water balance calculations for flat lying areas underlain by low permeability soils around the FMPC.



Figure M3-1. Summary of annual water balance summary for flat lying, low-permeability pasture land around the FMPC.

#### ANNUAL SHEET SOIL EROSION

5

....

In this section, the annual sheet erosion rate around the FMPC is described using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). The USLE is designed to estimate average soil loss due to sheet and rill erosion. The USLE uses rainfall pattern, soil type, slope, cover, and land management practice to estimate the annual erosion rate. Since deposited uranium is attached to soil particles, the amount of uranium in motion is partially dependent on soil particle transport. Soil particle transport is estimated by using the soil erosion rates.

Due to the low slope angle, lack of ravines, and ground cover management practices around the FMPC, the estimated annual erosion rate is  $45 \text{ g m}^{-2} \text{ y}^{-1}$  (0.2 tons acre<sup>-1</sup> y<sup>-1</sup>). For an assumed soil density of 1.6 g cm<sup>-3</sup> (100 lb ft<sup>-3</sup>), the associated soil loss thickness is  $3 \times 10^{-3}$  cm y<sup>-1</sup> ( $1 \times 10^{-4}$  ft y<sup>-1</sup>). Soil loss estimates for other erosion rates are shown in Table M3-1. It can be seen from the table that, even at the high erosion rate of 4500 g m<sup>-2</sup> y<sup>-1</sup> (20 tons acre<sup>-1</sup> y<sup>-1</sup>), the thickness of soil lost due to erosion is negligible.

| for various prosion naves                                    |  |  |  |  |  |  |  |
|--------------------------------------------------------------|--|--|--|--|--|--|--|
| Thickness of soil lost<br>(cm y <sup>-1</sup> ) <sup>a</sup> |  |  |  |  |  |  |  |
| 0.002                                                        |  |  |  |  |  |  |  |
| 0.003                                                        |  |  |  |  |  |  |  |
| 0.06                                                         |  |  |  |  |  |  |  |
| 0.2                                                          |  |  |  |  |  |  |  |
| 0.3                                                          |  |  |  |  |  |  |  |
|                                                              |  |  |  |  |  |  |  |

Table M3–1. Estimates of Soil Loss for Various Erosion Rates

Assumed soil unit weight =  $1.6 \text{ g cm}^{-3}$ .

# ANNUAL URANIUM TRANSPORT BY SOIL LOSS

The model of uranium transport due to erosion is shown in Figure M3-2. As shown in this figure, the quantity of uranium leaving a unit area is the sum of all uranium in the soil removed from the surface in a given year.



Figure M3-2. Uranium transport by soil erosion.

The amount of uranium leaving a square centimeter of area is calculated from the soil erosion losses each year. If the annual soil loss is  $3 \times 10^{-3}$  cm y<sup>-1</sup> for each square centimeter, erosion will move about  $5 \times 10^{-3}$  g y<sup>-1</sup> of soil. Assuming a uranium concentration in soil of 30 pCi g<sup>-1</sup>, the quantity of uranium leaving each square centimeter by sheet erosion is estimated to be 0.14 pCi y<sup>-1</sup>.

State of the second state of the second

1.12

#### ANNUAL URANIUM TRANSPORT BY INFILTRATION

Figure M3-3 shows the uranium transport model for infiltration that is described below. Annual movement of uranium through the soil column assumes a continuous supply of uranium is being added to the soil column. This assumption is consistent with continuous airborne deposition of uranium during early FMPC operations. The calculations have assumed that the deposition resulted in a homogeneous uranium concentration in soil of 30 pCi g<sup>-1</sup>. In the model, flow through porous media is assumed to be steady and saturated, and dispersion and diffusion are considered negligible. The ratio of uranium in water and soil is related by the distribution coefficient ( $K_d$ ).



Figure M3-3. Annual uranium transport by infiltrating water.

According to this model, the quantity of 15 cm (6 in) of infiltrating groundwater will move 50 pCi of uranium in the soil column each year. The concentration of uranium in the water is 3.3 pCi mL<sup>-1</sup> and the distribution coefficient is 9 mL g<sup>-1</sup>. However, due to uranium adsorption, the uranium will only move 1.0 cm into the soil column each year while the water will move a distance of 61 cm (2 ft). This calculation assumes that the soil effective porosity is 0.25.

#### ANNUAL URANIUM TRANSPORT BY SURFACE WATER RUNOFF

The model of uranium migration by surface water runoff is illustrated in Figure M3-4. Movement of uranium by surface water assumes that a continuous supply of uranium is available from the soil and the concentration of uranium in the soil is constant. Uranium from contaminated soil exchanges with the runoff component of precipitation, and the exchange ratio is dependent upon the distribution coefficient ( $K_{a}$ ).

The Fernald Dosimetry Reconstruction Project Tasks 2 and 3, Source Terms and Uncertainty

ĥ



# Figure M3-4. Uranium transport by runoff water.

For comparison purposes, the soil concentration is assumed to be 30 pCi  $g^{-1}$  and the distribution coefficient is 9 mL  $g^{-1}$ . According to the hydrologic water balance calculations, runoff is 5.1 cm  $y^{-1}$  (2.0 in  $y^{-1}$ ). Therefore, the quantity of uranium moved by surface water runoff is 17 pCi  $y^{-1}$ , and the concentration of uranium in the water is 3.3 pCi mL<sup>-1</sup>.

#### URANIUM TRANSPORT SUMMARY.

Table M3-2 shows the rate of uranium migration from a square centimeter of soil having a concentration of 30 pCi  $g^{-1}$  and a distribution coefficient of 9 mL  $g^{-1}$ . The results show that uranium deposited on pastured soils is primarily transported by infiltration and that soil erosion transports the least amount of uranium.

| Transport<br>mechanism | Medium        | Transport rate<br>(pCi y <sup>-1</sup> ) | Uranium<br>concentration<br>in medium              |
|------------------------|---------------|------------------------------------------|----------------------------------------------------|
| Soil sheet erosion     | Soil          | 0.14                                     | 30 pCi g <sup>-1</sup>                             |
| Infiltration           | Soil<br>Water | na<br>50                                 | 30 pCi g <sup>-1</sup><br>3.3 pCi mL <sup>-1</sup> |
| Surface runoff         | Water         | 17                                       | 3.3 pCi mL <sup>-1</sup>                           |

|  | Ta | bl | le | M3-2 | 2. ( | Com | pariso | ı of | Uraniu | un Tra | nsport | Mec | hanisms <sup>a</sup> | 6 |
|--|----|----|----|------|------|-----|--------|------|--------|--------|--------|-----|----------------------|---|
|--|----|----|----|------|------|-----|--------|------|--------|--------|--------|-----|----------------------|---|

<sup>a</sup> Per cm<sup>2</sup> soil having a uranium concentration of 30 pCi g<sup>-1</sup>.

It should be noted that the distribution coefficient of the surface soil is unknown. The distribution coefficient of 9 mL g<sup>-1</sup> used in this study was obtained from a provisional calibration of the ASI-IT (1990) South Plume model. Therefore, this distribution coefficient may not be applicable because the groundwater model does not predict uranium transport at

the surface. Because of the uncertainty in the estimated value of the distribution coefficient for the surface soil, an analysis of uranium transport for different values of  $K_d$  was performed. Table M3-3 shows the relationship of the distribution coefficient to uranium mobility. Lower distribution coefficients result in higher rates of uranium migration. However, in all three cases, the infiltration of uranium down the soil column towards the groundwater is the dominant migration route.

| Distribution<br>coefficient (mL g <sup>-1</sup> ) | Transport<br>mechanism | Transport rate<br>(pCi cm <sup>-2</sup> y <sup>-1</sup> ) | Uranium<br>concentration in<br>water (pCi mL <sup>-1</sup> ) |
|---------------------------------------------------|------------------------|-----------------------------------------------------------|--------------------------------------------------------------|
| 5                                                 | Infiltration           | 91                                                        | 6.0                                                          |
|                                                   | Surface runoff         | 31                                                        | 6.0                                                          |
| 9                                                 | Infiltration           | 50                                                        | 3.3                                                          |
|                                                   | Surface runoff         | 17                                                        | 3.3                                                          |
| 20                                                | Infiltration           | 23                                                        | 1.5                                                          |
|                                                   | Surface runoff         | 7.6                                                       | 1.5                                                          |

# Table M3-3. Sensitivity of Uranium Transport Calculations to<br/>the Value of the Distribution Coefficient

Radiological Assessments Corporation "Setting the standard in environmental health"

The second s

.....

5. N

· · · · · · · · ·