DOE/RW-0006, Rev. 7

Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics

October 1991

Prepared by:

Oak Ridge National Laboratory
Managed by Martin Marietta Energy Systems, Inc., for the
U.S. Department of Energy under contract DE-AC05-84OR21400

Prepared for:

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Environmental Restoration and Waste Management
Washington, D.C. 20585

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DOE/RW-0006, Rev. 7

Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics

October 1991

Prepared by:

Oak Ridge National Laboratory
Managed by Martin Marietta Energy Systems, Inc., for the
U.S. Department of Energy under contract DE-AC05-84OR21400

Prepared for:

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Environmental Restoration and Waste Management
Washington, D.C. 20585

PREFACE

The information in this report summarizes the U.S. Department of Energy (DOE) data base for inventories, projections, and characteristics of domestic spent nuclear fuel and radioactive waste. This report is updated annually to keep abreast of continual waste inventory and projection changes in both government and commercial sectors. Baseline information is provided for planning purposes and to support program decisions. Although the primary purpose of this document is to provide background information for program planning within the DOE community, it has also been found useful by state and local governments, the academic community, and a number of private citizens. To sustain the objectives of this program in providing accurate and complete data in this field of operation, comments and suggestions to improve the quality and coverage are encouraged. Such comments and any general inquiries should be directed to:

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Route Symbol RW-432
Washington, DC 20585

This report was prepared by the Integrated Data Base Program, which is jointly sponsored by the Office of Civilian Radioactive Waste Management and the Office of Environmental Restoration and Waste Management. Suggestions, questions, and requests for information may be directed to any of the following:

M. L. Payton, DOE/RW-432, Washington, DC 20585
Telephone: (202) 586-9867

J. S. Kang, DOE/EM-35, Washington, DC 20545
Telephone: (301) 353-7178

J. W. Gatrell, DOE/EM-451, Washington, DC 20545
Telephone: (301) 353-7221

J. A. Klein, ORNL, P.O. Box 2008, Oak Ridge, TN 37831-6495
Telephone: (615) 574-6823

An important part of the Integrated Data Base Program is the Steering Committee, whose members provide both generic guidance and technical input. The membership of this Committee, shown on the following page, represents all of the major DOE sites and programs for spent fuel and radioactive waste management. Each support committee member is assisted by a technical liaison as needed and by a DOE liaison as appropriate. The participation and assistance of these individuals are acknowledged with appreciation.

Ronald A. Milner
Associate Director
Office of Storage and Transportation
Office of Civilian Radioactive
Waste Management

Jill E. Lytle
Associate Director
Office of Waste Operations
Office of Environmental Restoration
and Waste Management

Roger P. Whitfield
Associate Director
Office of Environmental Restoration
Office of Environmental Restoration
and Waste Management

Integrated Data Base Steering Committee

Executive Committee

Voting members	Advisory members
J. S. Kang, DOE/EM	J. A. Disbrow, DOE/EIA
J. W. Gatrell, DOE/EM	J. A. Klein, ORNL
M. L. Payton, DOE/RW	

Support Committee

Chapter title	Committee member	Technical liaison	DOE liaison
Spent fuel	R. C. Walling, PNL	W. D. Liggett, DOE/EIA	D. C. Langstaff, DOE/RL
High-level waste	M. Dev, DOE/RL	J. L. Nelson, WHC	M. Dev, DOE/RL
Transuranic waste	H. M. Batchelder, W/WIPP	K. S. Donovan, W/WIPP	J. Lippis, DOE/WIPP
Low-level waste			
DOE	J. S. Ford, DOE/OR	J. D. Wilson, MMES	J. S. Ford, DOE/OR
Commercial	R. H. Sandwina, DOE/ID	R. L. Fuchs, EG&G/ID	T. Plummer, DOE/EM
Uranium mill tailings	J. A. Disbrow, DOE/EIA	T. Chung, DOE/EIA	J. A. Disbrow, DOE/EIA
Environmental restoration wastes			
DOE ER Projects	M. Tolbert-Smith, BDM	J. L. Turek, OTS/H&R	G. P. Turi, DOE/EM
UMTRAP	D. P. Dubois, Jacobs Engr.	M. L. Matthews, DOE/AL	J. W. Gatrell, DOE/EM
FUSRAP	R. R. Harbert, BNI	B. A. Hughlett, DOE/OR	L. K. Price, DOE/OR
Mixed low-level waste	J. S. Ford, DOE/OR	J. D. Wilson, MMES	J. S. Ford, DOE/OR

Authors and contributors providing direct support for the
1991 Integrated Data Base Program report

Chapter topic	Author(s)
Overview	J. A. Klein and S. N. Storch
Spent fuel	R. C. Ashline
High-level waste	H. W. Godbee and T. C. Wright
Transuranic waste	R. L. Pearson
Low-level waste	H. W. Godbee, T. C. Wright, S. N. Storch, and S. M. DePaoli
Uranium mill tailings	T. Chung (DOE/EIA)
Environmental restoration wastes	R. L. Pearson
Commercial decommissioning wastes	S. N. Storch
Miscellaneous radioactive materials	R. L. Pearson
Mixed low-level waste	S. N. Storch
Waste source terms	H. W. Godbee
Direct support service	**Contributor**
Clerical/IDB report	D. T. Brooksbank
Clerical/IDB Program	S. L. McDaniel
Computer support (data base setup and analysis)	T. C. Wright
Computer graphics	C. R. Myers
Editing	D. R. Reichle

CONTENTS

PREFACE iii

LIST OF PHOTOS xi

LIST OF FIGURES xiii

LIST OF TABLES xvii

GLOSSARY OF ABBREVIATIONS AND ACRONYMS xxv

ABSTRACT 1

0. OVERVIEW 1
   0.1 INTRODUCTION 1
   0.2 CHARACTERIZATION OF WASTE FORMS 2
   0.3 METHODS AND ASSUMPTIONS USED IN REPORT PREPARATION 4
   0.4 CHAPTER OVERVIEWS 5
      0.4.1 Spent Fuel 5
      0.4.2 High-Level Waste 5
      0.4.3 TRU Waste 5
      0.4.4 Low-Level Waste 5
      0.4.5 Commercial Uranium Mill Tailings 6
      0.4.6 Environmental Restoration Wastes 6
      0.4.7 Commercial Decommissioning Wastes 6
      0.4.8 Miscellaneous Radioactive Materials 7
      0.4.9 Mixed Low-Level Waste 7
      0.4.10 Appendixes 7
   0.5 REFERENCES 7

1. SPENT FUEL 17
   1.1 INTRODUCTION 17
   1.2 INVENTORIES AND PROJECTIONS 17
   1.3 CHARACTERIZATION 18
   1.4 DISPOSAL 18
   1.5 REFERENCES 18

2. HIGH-LEVEL WASTE 39
   2.1 INTRODUCTION 39
   2.2 INVENTORIES 40
      2.2.1 HLW Inventories at SRS (DOE) 40
      2.2.2 HLW Inventories at INEL (DOE) 40
      2.2.3 HLW Inventories at HANF (DOE) 40
      2.2.4 HLW Inventories at WVDP (Commercial) 40
   2.3 WASTE CHARACTERIZATION 40
   2.4 PROJECTIONS 41
   2.5 REFERENCES 41

3. TRANSURANIC WASTE 77
3.1 INTRODUCTION 77
3.2 INVENTORIES 77
3.3 WASTE CHARACTERIZATION 78
3.3.1 Physical Composition 78
3.3.2 Isotopic Composition 78
3.4 SHIPMENT AND DISPOSAL 78
3.5 REFERENCES 79

4. LOW-LEVEL WASTE 99
4.1 INTRODUCTION 99
4.2 DOE LLW 99
4.2.1 Inventories at DOE LLW Disposal Sites 99
4.2.2 Characterization of LLW at DOE Sites 99
4.2.3 DOE LLW Disposal Sites 100
4.2.4 DOE LLW Projections 100
4.3 COMMERCIAL LLW 100
4.3.1 Inventories at Commercial LLW Disposal Sites 100
4.3.2 Characterization of LLW at Commercial Disposal Sites 100
4.3.3 Greater-Than-Class-C Low-Level Waste (GTCC LLW) 101
4.3.4 Commercial LLW Disposal Sites 102
4.3.5 Commercial LLW Projections 102
4.4 REFERENCES 103

5. URANIUM MILL TAILINGS FROM COMMERCIAL OPERATIONS 133
5.1 INTRODUCTION 133
5.2 INVENTORIES 133
5.3 WASTE CHARACTERIZATION 134
5.4 PROJECTIONS 134
5.5 REFERENCES 134

6. ENVIRONMENTAL RESTORATION WASTES 143
6.1 INTRODUCTION 143
6.2 THE OFFICE OF ENVIRONMENTAL RESTORATION 143
6.2.1 Activities 144
6.2.1.1 Remedial action 144
6.2.1.2 Decontamination and decommissioning 144
6.2.2 Programs 144
6.2.2.1 Uranium Mill Tailings Remedial Action Program 144
6.2.2.2 Formerly Utilized Sites Remedial Action Program 145
6.3 REFERENCES 146

7. COMMERCIAL DECOMMISSIONING WASTES 169
7.1 INTRODUCTION 169
7.2 WASTE CHARACTERIZATION 169
7.3 INVENTORIES AND PROJECTIONS 170
7.4 REFERENCES 172

8. MIXED LOW-LEVEL WASTE 199
8.1 INTRODUCTION 199
8.2 WASTE CHARACTERIZATION 199
8.3 DOE SITE INVENTORIES AND GENERATION RATES 199
8.4 COMMERCIAL MIXED LOW-LEVEL WASTES 200
8.5 REFERENCES 201

APPENDIX A. WASTE FLOWSHEETS, SOURCE TERMS, AND CHARACTERISTICS 221
A.1 DISCUSSION 223
A.2 REFERENCES 223

APPENDIX B. CHARACTERISTICS OF IMPORTANT RADIONUCLIDES 253
B.1 DISCUSSION 255
B.2 REFERENCES 255

APPENDIX C. MISCELLANEOUS RADIOACTIVE MATERIALS 263
C.1 INTRODUCTION 265
C.2 INVENTORIES 265
C.3 REFERENCES 266

APPENDIX D. REFERENCE SITES AND FACILITIES 287
D.1 DISCUSSION 289

GLOSSARY OF TERMS 295

INDEX 301

DISTRIBUTION 307

LIST OF PHOTOS

SPENT FUEL

1.1 The Sequoyah Nuclear Power Station, two 1220-MW(e) pressurized-water reactors, located about 10 miles north of Chattanooga, Tennessee 16

HIGH-LEVEL WASTE

2.1 Methodology used at the Hanford Site for collecting a core sample from the solids layer in a typical single-shell or double-shell high-level waste tank 38

TRANSURANIC WASTE

3.1 An artist's layout of the Hanford Central Waste Complex to be used, in part, for storage of certified transuranic waste 76

LOW-LEVEL WASTE

4.1 A shielded cell at the West Valley Demonstration Project for storage (in drums, of square cross section) of cement-solidified Class-B and Class-C low-level waste generated in the Radwaste Treatment System 98

URANIUM MILL TAILINGS FROM COMMERCIAL OPERATIONS

5.1 A uranium mill tailings pond at the Panna Maria site in Karnes County, Texas 132

ENVIRONMENTAL RESTORATION WASTES

6.1 Environmental isolation activities being performed on uranium mill tailings deposited at Durango, Colorado 142

COMMERCIAL DECOMMISSIONING WASTES

7.1 Removal from containment of the 245-ton Pathfinder boiling-water reactor pressure vessel on May 14, 1991 168

MIXED LOW-LEVEL WASTE

8.1 The Controlled Air Incinerator at Los Alamos National Laboratory, which is used to treat both radioactive and mixed waste 198

LIST OF FIGURES

OVERVIEW

0.1 Volumes of commercial and DOE wastes and spent fuel accumulated through 1990 9

0.2 Radioactivities of commercial and DOE wastes and spent fuel accumulated through 1990 9

0.3 Projections of annual volume additions for various wastes and spent fuel – DOE and commercial fuel cycle 10

0.4 Projections of annual radioactivity additions for various wastes and spent fuel – DOE and commercial fuel cycle 10

0.5 Projections of cumulative volumes for various wastes and spent fuel – DOE and commercial fuel cycle 11

0.6 Projections of cumulative radioactivity for various wastes and spent fuel – DOE and commercial fuel cycle 11

SPENT FUEL

1.1 Locations of existing and planned commercial reactors as of December 31, 1990 20

1.2 Projected mass (MTIHM) of annual commercial spent fuel discharges for the DOE/EIA No New Orders and Lower Reference cases 21

1.3 Projected accumulated radioactivity of commercial spent fuel discharges for the DOE/EIA No New Orders and Lower Reference cases 21

1.4 Projected cumulative mass (MTIHM) of commercial spent fuel discharges for the DOE/EIA No New Orders Case 22

1.5 Projected cumulative mass (MTIHM) of commercial spent fuel discharges for the DOE/EIA Lower Reference Case 22

1.6 Radioactivity and thermal power of 1 metric ton of heavy metal of BWR and PWR spent fuel as a function of burnup and time from reactor discharge 23

HIGH-LEVEL WASTE

2.1 Total volume of HLW through 1990 43

2.2 Total radioactivity of HLW through 1990 43

2.3 Distribution of total accumulative volume and radioactivity of HLW by site and type through 1990 44

2.4 Locations and total volumes of HLW through 1990 44

2.5 Treatment methods for HLW in tanks and canisters at SRS 45

2.6 Treatment methods for HLW in tanks, bins, and canisters at INEL 45

2.7 Treatment methods for HLW in tanks, capsules, and canisters at HANF 46

2.8 Treatment methods for HLW in tanks and canisters at WVDP 46

TRANSURANIC WASTE

3.1 Locations and total volumes of buried and stored DOE TRU waste through 1990 80

3.2 Points of origin and storage sites of DOE TRU waste 80

3.3 Total volume of buried DOE TRU waste through 1990 81

3.4 Total mass of TRU elements in buried DOE TRU waste through 1990 81

3.5 Total volume of retrievably stored DOE TRU waste through 1990 82

3.6 Total mass of TRU elements in retrievably stored DOE TRU waste through 1990 82

3.7 TRU waste volume data relationships applicable to both CH and RH waste 83

LOW-LEVEL WASTE

4.1 Volume of LLW disposed in 1990 105

4.2 Total volume of LLW disposed through 1990 105

4.3 Historical and projected accumulated volume of LLW 106

4.4 Total volume of DOE LLW disposed through 1990 107

4.5 Locations and total volumes of DOE LLW disposed through 1990 107

4.6 Total volume of commercial LLW disposed through 1990 108

4.7 Locations and total volumes of commercial LLW disposed through 1990 108

URANIUM MILL TAILINGS FROM COMMERCIAL OPERATIONS

5.1 Locations of uranium mill tailings sites active during at least part of 1990 136

5.2 Historical and projected accumulated volume of commercial mill tailings 136

ENVIRONMENTAL RESTORATION WASTES

6.1 Projected total volumes of remaining TRU wastes from DOE defense-funded environmental restoration projects in various states 147

6.2 Projected total volumes of remaining low-level wastes from DOE defense-funded environmental restoration projects in various states 147

6.3 Locations of DOE defense-funded environmental restoration projects 148

6.4 Projected total volumes of remaining TRU wastes from DOE non-defense-funded environmental restoration projects in various states 149

6.5 Projected total volumes of remaining low-level wastes from DOE non-defense-funded environmental restoration projects in various states 149

6.6 Locations of DOE non-defense-funded environmental restoration projects 150

6.7 Projected total volumes of remaining residual radioactive materials from UMTRAP activities in various states 151

6.8 Locations of UMTRAP sites 152

6.9 Projected total volumes of remaining low-level wastes from FUSRAP activities in various states 153

6.10 Locations of FUSRAP sites 154

MIXED LOW-LEVEL WASTE

8.1 Total volume inventory of DOE mixed LLW through 1990 203

8.2 Volume generation of DOE mixed LLW during 1990 203

APPENDIX A. WASTE FLOWSHEETS, SOURCE TERMS, AND CHARACTERISTICS

A.1 Principal waste and product streams from a uranium mine/mill complex 225

A.2 Principal waste and product streams from a direct-fluorination UF_6 conversion plant 226

A.3 Principal waste and product streams from a solvent extraction-fluorination UF_6 conversion plant 227

A.4 Principal waste and product streams from a gaseous diffusion uranium enrichment plant 228

A.5 Principal waste and product streams from a fuel fabrication plant 229

A.6 Principal waste and product streams from a boiling-water reactor 230

A.7 Principal waste and product streams from a pressurized-water reactor 231

A.8 Boiling-water reactor decommissioning wastes per 1-MW(e) capacity 232

A.9 Pressurized-water reactor decommissioning wastes per 1-MW(e) capacity 233

A.10 Waste flow diagram for the SRS Defense Waste Processing Facility 234

MISCELLANEOUS RADIOACTIVE MATERIALS

C.1 Locations and total masses of miscellaneous radioactive materials through 1990 268

C.2 Mass and locations of miscellaneous radioactive materials as of December 31, 1990 268

C.3 Types of miscellaneous radioactive materials in storage through 1990 269

LIST OF TABLES

OVERVIEW

0.1 Major sources of information for the IDB program 12

0.2 Major assumptions used in this report 13

0.3 Spent fuel and radioactive waste inventories as of December 31, 1990 14

0.4 Current and projected cumulative quantities of radioactive waste and spent fuel 15

SPENT FUEL

1.1 Historical and projected installed LWR electric power generating capacity for the DOE/EIA No New Orders and Lower Reference cases 24

1.2 Projected cumulative mass of commercial spent fuel discharges for alternative DOE/EIA scenarios 25

1.3 Historical and projected mass, radioactivity, and thermal power of permanently discharged spent fuel by reactor type for the DOE/EIA No New Orders Case 26

1.4 Historical and projected mass, radioactivity, and thermal power of permanently discharged spent fuel by reactor type for the DOE/EIA Lower Reference Case 29

1.5 Projected number of permanently discharged LWR spent fuel assemblies for the DOE/EIA No New Orders Case 32

1.6 Projected number of permanently discharged LWR spent fuel assemblies for the DOE/EIA Lower Reference Case 33

1.7 Historical and projected spent fuel discharged from the Fort St. Vrain HTGR 34

1.8 IDB reference characteristics of LWR fuel assemblies 34

1.9 Historical mass of commercial BWR spent fuel discharged at various ranges of burnup 35

1.10 Historical mass of commercial PWR spent fuel discharged at various ranges of burnup 36

HIGH-LEVEL WASTE

2.1 Historical and projected total accumulative volume, radioactivity, and thermal power of HLW stored in tanks, bins, and capsules by source 47

2.2 Projected volume, radioactivity, and thermal power of HLW glass stored in canisters by source 49

2.3 Estimated potential number of HLW canisters by source 51

2.4 The 1988 estimate of the number of DOE HLW canisters that could be produced from stored and projected HLW 52

2.5 Current volume of HLW in storage by site through 1990 53

2.6 Current radioactivity of HLW in storage by site through 1990 54

2.7 Historical and projected total accumulative volume of HLW in storage by site through 2020 55

2.8 Historical and projected total accumulative radioactivity of HLW in storage by site through 2020 57

2.9 Historical and projected total accumulative thermal power of HLW in storage by site through 2020 59

2.10 Significant revisions and changes in the current values for HLW compared to the values in the previous year 61

2.11 Representative chemical composition of current and future HLW at SRS 62

2.12 Representative radionuclide composition of current (end of 1990) HLW and HLW glass to be generated in 1993 at SRS 63

2.13 Representative chemical composition of current and future HLW liquid at ICPP 64

2.14 Representative chemical composition of current and future HLW calcine at ICPP 65

2.15 Representative radionuclide composition of current HLW at ICPP 66

2.16 Representative chemical composition of current and future HLW at HANF 67

2.17 Representative radionuclide composition (Ci) of current HLW at HANF 68

2.18 Chemical composition of alkaline liquid HLW (from reprocessing via a PUREX flowsheet) at WVDP 70

2.19 Chemical composition of alkaline sludge HLW (from reprocessing via a PUREX flowsheet) at WVDP 71

2.20 Chemical composition of acid liquid HLW (from reprocessing via a THOREX flowsheet) at WVDP 72

2.21 Reference (end of 1990) radionuclide composition of HLW at WVDP 73

TRANSURANIC WASTE

3.1 Total system inventories, projections, and characteristics of all buried contaminated soil and stored DOE TRU waste in 5-year increments 84

3.2 Inventories and characteristics of DOE buried TRU waste through 1990 85

3.3 Inventories and characteristics of soil contaminated by DOE TRU solid waste through 1990 85

3.4 Inventories and characteristics of soil contaminated by DOE TRU liquid waste through 1990 86

3.5 Inventories and characteristics of retrievable DOE TRU waste at each storage site through 1990 87

3.6 Revisions and changes in historical inventories of stored DOE TRU waste from previous IDB report 88

3.7 Estimated physical composition of retrievably stored, newly generated, and buried TRU waste at DOE sites 89

3.8 Calculated isotopic composition (wt %) of buried and retrievably stored TRU waste for each site 91

3.9 Volume, mass, radioactivity, and thermal power of DOE TRU waste at each burial and storage site through 1990 94

3.10 Projected volume, mass, and activity of TRU waste to be generated during 1991–2013 95

3.11 Total TRU waste volume as packaged for shipment to WIPP through 2013 96

LOW-LEVEL WASTE

4.1 A summary of characteristics for buried/disposed LLW as of December 31, 1990 109

4.2 Historical and projected volume, radioactivity, and thermal power of DOE LLW 110

4.3 Historical and projected volume, radioactivity, and thermal power of commercial LLW shipped for disposal 111

4.4 Historical annual additions and total volume of LLW buried at DOE sites 112

4.5 Summary of radionuclide characteristics for LLW at DOE sites 113

4.6 Summary of physical characteristics for LLW at DOE sites 114

4.7 Breakdown of cumulative volumes of LLW buried at DOE sites by radionuclide characteristic 115

4.8 Breakdown of total gross activity of LLW buried at DOE sites by radionuclide characteristic 116

4.9 DOE LLW disposed by methods other than shallow-land burial 117

4.10 Status of land usage at LLW burial and disposal sites 118

4.11 Significant revisions and changes in the current values for LLW compared to the values in the previous year 119

4.12 Historical and projected volume, radioactivity, and thermal power characteristics of DOE LLW, except SRS saltstone 120

4.13 Projected volume, radioactivity, and thermal power characteristics of DOE LLW saltstone at SRS 121

4.14 Historical annual additions and total volume of LLW at commercial disposal sites 122

4.15 Historical annual additions and total undecayed radioactivity of LLW at commercial disposal sites 123

4.16 Distribution of total volume and radioactivity, by state, of LLW shipped to commercial disposal sites in 1990 124

4.17 Summary of projected GTCC wastes for LWRs based on packaged waste volume 125

4.18 Historical and projected volume, radioactivity, and thermal power of LLW shipped for disposal from I/I activities 126

4.19 Historical and projected volume, radioactivity, and thermal power of routine LLW shipped for disposal from BWRs 127

4.20 Historical and projected volume, radioactivity, and thermal power of routine LLW shipped for disposal from PWRs 128

4.21 Historical and projected volume, radioactivity, and thermal power of nonroutine LLW shipped for disposal from LWRs 129

4.22 Historical and projected volume, radioactivity, and thermal power of LLW shipped for disposal from UF_6 conversion for LWRs 130

4.23 Historical and projected volume, radioactivity, and thermal power of LLW shipped for disposal from fuel fabrication for LWRs 131

URANIUM MILL TAILINGS FROM COMMERCIAL OPERATIONS

5.1 Historical and projected volume of uranium mill tailings 137

5.2 Status of conventional uranium mill sites at the end of 1990 138

5.3 Uranium ore processed, recovery rate, and tailings generated through 1990 140

5.4 Typical characteristics of uranium mill tailings 141

ENVIRONMENTAL RESTORATION WASTES

6.1 Summary of waste volumes from environmental restoration activities 155

6.2 Projected remaining volumes (m^3) of low-level and transuranic wastes, status, and schedule for completion of defense-funded environmental restoration projects, as of December 31, 1990 156

6.3 Projected remaining volumes (m^3) of low-level and transuranic wastes, status, and schedule for completion of non-defense-funded environmental restoration projects, as of December 31, 1990 158

6.4 UMTRAP site descriptions, status, scheduled duration, and volume of permanently stored residual radioactive material 160

6.5 Projected waste characteristics at uncompleted UMTRAP sites as of December 31, 1990 162

6.6 FUSRAP site descriptions, status, schedule, and volume of stored wastes 163

6.7 Projected waste characteristics at uncompleted FUSRAP sites 165

COMMERCIAL DECOMMISSIONING WASTES

7.1 Schedule of final shutdown dates for commercial light-water reactors 176

7.2 Projections of cumulative volume, radioactivity, and thermal power of wastes from decommissioning commercial light-water reactors shut down during 1991–2020 177

7.3 Projections of wastes from decommissioning of reference commercial fuel cycle facilities and power reactors 178

7.4 List of U.S. civilian reactors shut down or dismantled as of December 31, 1990 179

7.5 Types and quantities of wastes from decommissioning the Elk River reactor site 181

7.6 Types and volumes of wastes from decommissioning the Santa Susana Sodium Reactor Experiment site 182

7.7 Estimated volumes and activities of wastes from decommissioning alternatives considered for reference LWRs 183

7.8 Characteristics of wastes from decommissioning activities at the Shippingport Station Decommissioning Project 184

7.9 Inventories and projections of wastes from various activities at the West Valley Demonstration Project 185

7.10 Characteristics of wastes from decontamination activities at the Three Mile Island–Unit 2 reactor site 186

7.11 Projected characteristics of radioactive wastes from Dresden Unit 1 decommissioning activities 187

7.12 Inventories and projections of low-level radioactive wastes from La Crosse BWR decommissioning activities 188

7.13 Projected volumes of wastes from Saxton PWR decommissioning activities 189

7.14 Projected volumes of radioactive wastes from SAFSTOR (mothballing/delayed dismantling) of Humboldt Bay Unit 3 190

7.15 Projected volumes of radioactive wastes from DECON (prompt removal/dismantling) of Diablo Canyon Power Plant Units 1 and 2 191

7.16 Projected volumes of wastes from Rancho Seco PWR decommissioning activities 192

7.17 Projected characteristics of wastes from DECON (dismantling) of the Fort St. Vrain HTGR 193

7.18 Projected volumes of radioactive wastes from DECON (prompt removal/dismantling) of the Peach Bottom reactors 194

7.19 Characteristics of radioactive wastes associated with decommissioning the Pathfinder reactor 194

7.20 Projected characteristics of wastes from Shoreham BWR decommissioning activities 195

7.21 Characteristics of wastes from decommissioning activities at the Cimarron Fuel Fabrication Facility 196

MIXED LOW-LEVEL WASTE

8.1 States and territories with EPA mixed waste authorization 204

8.2 Cumulative mass (kg) inventories of DOE site mixed LLW, by physical category, through 1990 205

8.3 Cumulative volume (m^3) inventories of DOE site mixed LLW, by physical category, through 1990 206

8.4 Mass generation rates (kg/year) of DOE site mixed LLW, by physical category, for 1990 207

8.5 Volume generation rates (m^3/year) of DOE site mixed LLW, by physical category, for 1990 208

8.6 Chemical categories used in this report for characterizing DOE site mixed LLW 209

8.7 Cumulative mass (kg) inventories of DOE site mixed LLW, by chemical category, through 1990 210

8.8 Cumulative volume (m^3) inventories of DOE site mixed LLW, by chemical category, through 1990 211

8.9 Mass generation rates (kg/year) of DOE site mixed LLW, by chemical category, for 1990 212

8.10 Volume generation rates (m^3/year) of DOE site mixed LLW, by chemical category, for 1990 213

8.11 Projected annual mixed LLW mass generation rates (kg/year) for various DOE sites 214

8.12 Projected annual mixed LLW volume generation rates (m^3/year) for various DOE sites 215

8.13 Projections of commercial mixed LLW volumes after 1992 216

8.14 Summary of OTA-estimated characteristics of annually generated mixed LLW from industrial facilities 217

8.15 Summary of OTA-estimated characteristics of annually generated mixed LLW from medical/academic facilities 218

8.16 Summary of OTA-estimated characteristics of annually generated mixed LLW from commercial LWR power plants 219

8.17 Summary of NUMARC-estimated characteristics of mixed LLW from commercial LWR operations 219

APPENDIX A. WASTE FLOWSHEETS, SOURCE TERMS, AND CHARACTERISTICS

A.1 Estimated representative unit activity and thermal power characteristics of various types of radioactive materials and wastes 235

A.2 Basic factors used for fuel cycle, DOE waste, and I/I waste projections 236

A.3 Lifetime radioactive waste generation by light-water reactors and supporting fuel cycle activities 237

A.4 Mass, radioactivity, and thermal power of nuclides in domestic commercial LWR spent fuel at the end of calendar year 1990 238

A.5 Representative DOE LLW radionuclide composition by percent activity 245

A.6 Average concentrations for representative radionuclides in LLW at commercial disposal sites 246

A.7 Projected chemical and radionuclide composition of saltstone at SRS 247

A.8 Historical and projected DOE/EIA No New Orders Case commercial LWR net annual electrical generation 248

A.9 Estimated sources and characteristics of commercial greater-than-Class-C LLW 249

A.10 Projected number and volume of drums and classes of LLW incorporated in cement to be generated in the WVDP Low-Level Radwaste Treatment System 250

A.11 Composition of industrial and institutional waste by category 251

APPENDIX B. CHARACTERISTICS OF IMPORTANT RADIONUCLIDES

B.1 Characteristics of important radionuclides 256

APPENDIX C. MISCELLANEOUS RADIOACTIVE MATERIALS

C.1 Inventory of miscellaneous radioactive materials that may require geologic disposal, as of December 31, 1990 270

C.2 Miscellaneous radioactive materials stored at Argonne National Laboratory-West, as of December 31, 1990 271

C.3 Miscellaneous radioactive materials stored at Babcock & Wilcox, Lynchburg Technology Center, as of December 31, 1990 272

C.4 Miscellaneous radioactive materials stored at Battelle Pacific Northwest Laboratory, as of December 31, 1990 273

C.5 Miscellaneous radioactive materials stored at the Hanford 200 Area burial grounds, as of December 31, 1990 274

C.6 Miscellaneous radioactive materials stored at the Idaho National Engineering Laboratory, as of December 31, 1990 275

C.7 Miscellaneous radioactive materials stored at the Los Alamos National Laboratory, as of December 31, 1990 279

C.8 Miscellaneous radioactive materials stored at the Oak Ridge National Laboratory, as of December 31, 1990 280

C.9 Miscellaneous radioactive materials stored at the Savannah River Site, as of December 31, 1990 282

C.10 Estimated current and projected volumes of TRU-type wastes from commercial sources 286

APPENDIX D. REFERENCE SITES AND FACILITIES

D.1 Major DOE sites and facilities referred to in this report 290

D.2 Major commercial radioactive waste disposal sites included in this report 294

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AEA	Atomic Energy Act (of 1954)
AEC	Atomic Energy Commission
AMES	Ames Laboratory; Ames, Iowa
AMI	Academic/Medical/Industrial wastes
ANL-E	Argonne National Laboratory-East; Argonne, Illinois
ANL-W	Argonne National Laboratory-West; INEL, Idaho
ATL 1	Atlantic Site 1 (38'31'N, 72'06'W)
ATL 2	Atlantic Site 2 (37'50'N, 70'35'W)
BAPL	Bettis Atomic Power Laboratory; West Mifflin, Pennsylvania
BARN	Barnwell, South Carolina (commercial waste site)
BCLDP	Battelle Columbus Laboratories Decommissioning Project; Columbus, Ohio
BDM	BDM Corporation
BETY	Beatty, Nevada (commercial waste site)
BNI	Bechtel National, Inc.; Oak Ridge, Tennessee
BNL	Brookhaven National Laboratory; Brookhaven, New York
BWR	Boiling-water reactor
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (of 1980)
CFC	Chlorinated fluorocarbon
CH	Contact-handled (TRU waste)
CISS	Colonie Interim Storage Site; Colonie, New York
CY	Calendar year
DOD	Department of Defense
DOE	Department of Energy
DOE/AL	DOE Field Office, Albuquerque; Albuquerque, New Mexico
DOE/CH	DOE Field Office, Chicago; Argonne, Illinois
DOE/DP	DOE/Office of Defense Programs (Headquarters); Germantown, Maryland
DOE/EIA	DOE/Energy Information Administration; Washington, D.C.
DOE/EM	DOE/Office of Environmental Restoration and Waste Management (Headquarters); Germantown, Maryland
DOE/HQ	DOE Headquarters; Washington, D.C. and Germantown, Maryland
DOE/ID	DOE Field Office, Idaho; Idaho Falls, Idaho
DOE/NV	DOE Field Office, Nevada; Las Vegas, Nevada
DOE/OR	DOE Field Office, Oak Ridge; Oak Ridge, Tennessee
DOE/OSTI	DOE/Office of Scientific and Technical Information; Oak Ridge, Tennessee
DOE/RL	DOE Field Office, Richland; Richland, Washington
DOE/RW	DOE/Office of Civilian Radioactive Waste Management (Headquarters); Washington, D.C.
DOE/SAN	DOE Field Office, San Francisco; Oakland, California
DOE/SR	DOE Field Office, Savannah River; Aiken, South Carolina
DOE/WIPP	DOE/WIPP Project Office; Carlsbad, New Mexico
DOE/WVP	DOE/West Valley Demonstration Project Office; West Valley, New York
DOT	Department of Transportation
DWMP	Defense Waste Management Plan
DWPF	Defense Waste Processing Facility
D&D	Decontamination and decommissioning
EA	Environmental assessment

EG&G/ID	EG&G Idaho, Inc.; Idaho Falls, Idaho
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ER	Environmental restoration
FFTF	Fast Flux Test Facility; Hanford, Washington
FMPC	Feed Materials Production Center; Fernald, Ohio [recently changed to Fernald Environmental Management Project (FEMP)]
FIS	Farallon Islands (Pacific Ocean off Central California)
FNAL	Fermi National Accelerator Laboratory; Batavia, Illinois
FSVR	Fort St. Vrain Reactor; Platteville, Colorado
FUSRAP	Formerly Utilized Sites Remedial Action Program
FY	Fiscal year
GDP	Gaseous diffusion plant
GJPO	(DOE) Grand Junction Project Office; Grand Junction, Colorado
GJRAP	Grand Junction Remedial Action Project
GPU	General Public Utilities Corporation; Parsippany, New Jersey
GTCC	Greater-than-Class-C (low-level waste)
HANF	Hanford Site; Richland, Washington
HAZWRAP	Hazardous Waste Remedial Actions Program
HEN	Cape Henry (Atlantic Ocean off Virginia)
HLW	High-level waste
HTGR	High-temperature, gas-cooled reactor
HWVP	Hanford Waste Vitrification Plant; Hanford Site
ICPP	Idaho Chemical Processing Plant; Idaho National Engineering Laboratory
IDB	Integrated Data Base (Program)
I/I	Industrial and institutional (waste)
INEL	Idaho National Engineering Laboratory; Idaho Falls, Idaho
ITRI	Inhalation Toxicology Research Institute, Kirtland Air Force Base; Albuquerque, New Mexico
JIO	Joint Integration Office; Albuquerque, New Mexico
K-25	K-25 Site; Oak Ridge, Tennessee (formerly called the Oak Ridge Gaseous Diffusion Plant)
KAPL	Knolls Atomic Power Laboratory; Schenectady, New York
KCP	Kansas City Plant; Kansas City, Missouri
LANL	Los Alamos National Laboratory; Los Alamos, New Mexico
LBL	Lawrence Berkeley Laboratory; Berkeley, California
LGR	Light-water cooled, graphite-moderated reactor
LLNL	Lawrence Livermore National Laboratory; Livermore, California
LLRWPA	Low-Level Radioactive Waste Policy Act (of 1980)
LLRWPAA	Low-Level Radioactive Waste Policy Amendments Act (of 1985)
LLW	Low-level waste
LLWMP	Low-Level Waste Management Program
LSA	Low specific activity
LTC	Lynchburg Technology Center; Lynchburg, Virginia
LWR	Light-water reactor
LWBR	Light-water breeder reactor
MASS	Massachusetts Bay
MED	Manhattan Engineer District (Manhattan Project)
MFKY	Maxey Flats, Kentucky (commercial waste site)
MFRP	Midwest Fuel Recovery Plant; Morris, Illinois (commercial spent fuel storage site)
MIMS	Manifest Information Management System
MMES	Martin Marietta Energy Systems, Inc.
MOUND	Mound Plant; Miamisburg, Ohio
MRM	Miscellaneous radioactive material
MRS	Monitored retrievable storage
MTIHM	Metric tons initial heavy metal
MTU	Metric tons uranium
MW	Mixed waste

NA	Not applicable
NARM	Nuclear accelerator-generated radioactive material
NEPA	National Environmental Policy Act (of 1969)
NFS	Nuclear Fuel Services; Erwin, Tennessee
NORM	Naturally occurring radioactive material
NR	Naval reactor
NRC	Nuclear Regulatory Commission
NRF	Naval Reactor Facility; INEL, Idaho
NTIS	National Technical Information Service; Springfield, Virginia
NTS	Nevada Test Site; Mercury, Nevada
NUMARC	Nuclear Management and Resources Council; Washington, D.C.
NUS	NUS Corporation; Gaithersburg, Maryland
NWPA	Nuclear Waste Policy Act (of 1982)
NWPAA	Nuclear Waste Policy Amendments Act (of 1987)
NYSERDA	New York State Energy Research and Development Authority; Albany, New York
OR	Oak Ridge complex: ORNL, K-25 Site, and Y-12 Plant; Oak Ridge, Tennessee
ORAU	Oak Ridge Associated Universities; Oak Ridge, Tennessee
ORIGEN2	Oak Ridge Isotope Generation and Depletion Code (Version 2)
ORNL	Oak Ridge National Laboratory; Oak Ridge, Tennessee
OTA	U.S. Congress, Office of Technology Assessment; Washington, D.C.
OTS	Office of Technical Services, Roy F. Weston, Inc./H&R Technical Associates, Inc.; Germantown, Maryland
PAD	Paducah Gaseous Diffusion Plant; Paducah, Kentucky
PANT	Pantex Plant; Amarillo, Texas
PCB	Polychlorinated biphenyl
PNL	Pacific Northwest Laboratory; Richland, Washington
PNRO	DOE Pittsburgh Naval Reactor Office; West Mifflin, Pennsylvania
PORTS	Portsmouth Gaseous Diffusion Plant; Portsmouth, Ohio
PPPL	Princeton Plasma Physics Laboratory; Princeton, New Jersey
PWR	Pressurized-water reactor
PUREX	Plutonium uranium extraction
RA	Remedial action
RAP	Remedial action project
RCRA	Resource Conservation and Recovery Act (of 1976)
REECO	Reynolds Electrical and Engineering Co., Inc.; Mercury, Nevada
RFP	Rocky Flats Plant; Golden, Colorado
RH	Remote-handled (TRU waste)
RI	Rockwell International Corporation; Pittsburgh, Pennsylvania
RICH	Richland, Washington (commercial waste site)
RMI	Reactive Metals, Inc.; Astabula, Ohio
SCB	Santa Cruz Basin (Pacific Ocean off Santa Cruz, California)
SDG	San Diego (Pacific Ocean off San Diego, California)
SEG	Scientific Ecology Group, Inc.; Oak Ridge, Tennessee
SF	Spent fuel
SFMP	Surplus Facilities Management Program
SHEF	Sheffield, Illinois (commercial waste site)
SIS	Special Isotope Separation Project (Idaho National Engineering Laboratory)
SLAC	Stanford Linear Accelerator Center; Palo Alto, California
SNLA	Sandia National Laboratory; Albuquerque, New Mexico
SNLL	Sandia National Laboratory; Livermore, California
SNM	Special nuclear material
SRS	Savannah River Site; Aiken, South Carolina
SSFL	Santa Susana Field Laboratory; Canoga Park, California
SWIMS	Solid Waste Information Management System
SWU	Separative work unit
TBD	To be determined

THOREX	Thorium extraction
TMI	Three Mile Island reactor site; Middletown, Pennsylvania
TRIGA	Training Reactor, Isotopes, General Atomic
TRU	Transuranic
TSCA	Toxic Substances Control Act (of 1976)
T/S/D	Treatment, storage, and disposal
TVA	Tennessee Valley Authority; Knoxville, Tennessee
UMTRAP	Uranium Mill Tailings Remedial Action Program
WEC	Westinghouse Electric Corporation; Pittsburgh, Pennsylvania
WHC	Westinghouse Hanford Company; Richland, Washington
WHPP	(TRU) Waste Handling and Packaging Plant; Oak Ridge National Laboratory
WIPP	Waste Isolation Pilot Plant; Carlsbad, New Mexico
WMIS	Waste Management Information System
WSSRAP	Weldon Spring Site Remedial Action Project; Weldon Spring, Missouri
WVDP	West Valley Demonstration Project; New York (DOE site since 1982)
WVNS	West Valley Nuclear Services Company, Inc.; West Valley, New York
WVNY	West Valley, New York (commercial waste site from 1963–1981)
W/WIPP	Westinghouse/WIPP Project; Carlsbad, New Mexico
Y-12	Y-12 Plant; Oak Ridge, Tennessee

INTEGRATED DATA BASE FOR 1991: U.S. SPENT FUEL AND RADIOACTIVE WASTE INVENTORIES, PROJECTIONS, AND CHARACTERISTICS

ABSTRACT

The Integrated Data Base (IDB) Program has compiled current data on inventories and characteristics of commercial spent fuel and both commercial and U.S. government-owned radioactive wastes through December 31, 1990. These data are based on the most reliable information available from government sources, the open literature, technical reports, and direct contacts. The current projections of future waste and spent fuel to be generated generally through the year 2020 and characteristics of these materials are also presented. The information forecasted is consistent with the latest U.S. Department of Energy/Energy Information Administration (DOE/EIA) projections of U.S. commercial nuclear power growth and the expected DOE-related and private industrial and institutional (I/I) activities.

The radioactive materials considered, on a chapter-by-chapter basis, are spent fuel, high-level waste, transuranic waste, low-level waste, commercial uranium mill tailings, environmental restoration wastes, commercial reactor and fuel cycle facility decommissioning wastes, and mixed (hazardous and radioactive) low-level waste. For most of these categories, current and projected inventories are given through the year 2020, and the radioactivity and thermal power are calculated based on reported or estimated isotopic compositions. In addition, characteristics and current inventories are reported for miscellaneous radioactive materials that may require geologic disposal.

0. OVERVIEW

0.1 INTRODUCTION

This report is an update of the previous document on radioactive waste inventories and projections that was prepared for use in the planning and analysis of waste management functions.[1] Historical waste inventories compiled as of December 31, 1990, are reported. Projections of future wastes are generally reported through the year 2020. Such projections may change in future revisions of this report as waste minimization programs at various government and commercial sites become operative.

This document contains information that has been assembled as a part of the Integrated Data Base (IDB) Program at Oak Ridge National Laboratory (ORNL), which has the lead responsibility for establishing and maintaining files of pertinent data on current and projected inventories and characteristics of permanently discharged domestic spent nuclear fuel and radioactive wastes. The data presented in this report were obtained through the cooperation and assistance of the offices and programs that were established by the U.S. Department of Energy (DOE) to oversee the management of the various radioactive wastes and spent fuels. In addition, the recent literature was reviewed to aid in selecting the data that are presented here and to help establish a basis for many of the calculated radioactivity levels and heat generation rates that are included. In this report, spent fuel and radioactive wastes are characterized from the standpoint of their volumes (or masses) and their nuclear, physical, and

chemical properties. The data reported are selected from more extensive information that is available upon request.

This annual inventory report contains summarized or executive-level data found to be useful for programmatic planning purposes within the DOE community. It does not contain detailed package-by-package waste information that might be required for design or cost analyses. Such information is available from the appropriate waste site or program office. These sources can be identified by consulting the references within this document or by contacting the IDB Program. Because of the summary-level nature of this report, detailed discussions of specific analyses are avoided. Although some analyses for determining source terms and projections are needed, those involving transportation requirements, costs, shielding, packaging efficiencies, and health and environmental effects are purposely avoided. This report is intended to provide a common basis for management-level program planning and analysis by DOE contractors and field offices. It is expected that individuals involved with various DOE waste program analyses will use data that are in agreement with those maintained by the IDB Program.

Information for this report is provided by a variety of sources. Most waste data are received from DOE contractors through DOE field offices. DOE Headquarters assigns to selected organizations major responsibilities for providing information on particular topics involving spent fuel and radioactive waste management. Table 0.1 lists the technical areas and major sources of raw data input required by the IDB Program for this annual report. Further detailed information is generally available from data bases maintained at the specific DOE and commercial sites. A list of reference sites and facilities referred to in this report is provided in Appendix D.

Radioactive waste originates from five major sources: (1) the commercial nuclear fuel cycle; (2) DOE-related activities; (3) institutions such as hospitals, universities, and research foundations; (4) industrial uses of radioisotopes; and (5) mining and milling of uranium ore. The waste is broadly categorized as high-level waste (HLW), transuranic (TRU) waste, low-level waste (LLW), and uranium mill tailings.

In addition, future inventories of spent reactor fuel may require either storage expansion or construction of additional facilities for interim storage, pending the availability of monitored retrievable storage (MRS) or permanent disposal facilities. Large quantities of radioactive waste will also result from future activities such as DOE environmental restoration activities and the decontamination and decommissioning (D&D) of commercial nuclear facilities.

0.2 CHARACTERIZATION OF WASTE FORMS

The major characteristics of radioactive materials and wastes are described below.

- Spent fuel consists of irradiated fuel discharged from a nuclear reactor. Unless otherwise identified, all spent fuels discussed in this report are assumed to be permanently discharged and eligible for repository disposal. Three categories of permanently discharged spent fuel are considered: (1) fuel from commercial light-water reactors (LWRs); (2) fuel from non-LWR commercial reactors [e.g., the Fort St. Vrain high-temperature, gas-cooled reactor (HTGR)]; and (3) special fuels associated with government-sponsored research and demonstration programs, universities, and private industries. This report does not track the inventories of government production reactor spent fuels, which are reprocessed in the manufacture of nuclear weapons for national defense. However, the inventories of high-level wastes resulting from the reprocessing of these fuels are reported in Chapter 2.

  Currently, most LWR spent fuel assemblies are stored in pools at the reactor sites. The bulk of the remainder are in storage at the West Valley Demonstration Project (WVDP) site at West Valley, New York, and at the Midwest Fuel Recovery Plant (MFRP) at Morris, Illinois. The WVDP facility is currently being decommissioned. All utility-owned spent fuel assemblies previously stored there have been returned to the utilities, and the fuel remaining is DOE-owned material.

  Spent fuels discharged from a variety of reactors are currently stored at the Hanford Site and the Idaho National Engineering Laboratory (INEL). For example, some of the spent fuel from the Fort St. Vrain HTGR is stored at the Idaho Chemical Processing Plant (ICPP) at INEL. Some special spent fuels are stored at the Savannah River Site (SRS) and INEL. These special fuels are government owned and are not scheduled for reprocessing in support of DOE activities.

- For this report, HLW means the highly radioactive material resulting from the reprocessing of spent nuclear fuel. This includes mainly the liquid wastes remaining from the recovery of uranium and plutonium in a fuel reprocessing plant. This HLW may also be in the form of sludge, calcine, or other products into which such liquid wastes are converted to facilitate their handling and storage. Such waste contains fission products that result in the release of considerable decay energy.[2,3] For this reason, heavy shielding is required to control penetrating radiation and to dissipate decay heat from HLW.

- Transuranic wastes refer to radioactive wastes that contain more than 100 nCi/g of alpha-emitting isotopes with atomic numbers greater than 92 and half-lives greater than 20 years.[3,4] Such wastes result primarily from fuel reprocessing and from the fabrication of plutonium weapons and plutonium-bearing reactor fuel. Generally, little or no shielding is required ("contact-handled" TRU waste), but energetic gamma and neutron emissions from certain TRU nuclides and fission-product contaminants may require shielding or remote handling ("remote-handled" TRU waste).

- Low-level waste is radioactive waste not classified as spent fuel, HLW, TRU waste, or by-product material (such as uranium mill tailings). The radiation level from this waste may sometimes be high enough to require shielding for handling and transport. In ref. 5, the U.S. Nuclear Regulatory Commission (NRC) has defined four disposal categories of LLW that require differing degrees of confinement and/or monitoring: classes A, B, C, and greater-than-Class-C (GTCC). The NRC also excludes naturally occurring and accelerator-produced radioactive material from the LLW category. This report documents only those inventories of solid LLW destined for burial. It does not include any liquid or gas waste in storage, nor inventories of soils contaminated with LLW.

- Commercial uranium mill tailings are the earthen residues that remain after the extraction of uranium from ores. Tailings are generated in very large volumes and contain low concentrations of naturally occurring radioactive materials. Because they provide a potential health hazard, the isotopes of major concern are ^{226}Ra and its daughter, ^{222}Rn.

- Miscellaneous radioactive materials (MRM) that could possibly require geologic disposal are presently stored at some DOE and commercial sites. These materials include spent fuel elements for which no reprocessing is planned and "TRU"-type wastes from commercial sources.

- Mixed LLW contains concentrations of both low-level radioactive materials and hazardous chemicals. The latter may include polychlorinated biphenyls (PCBs). The hazardous component of mixed waste has characteristics identified by either or both of the following federal statutes: the Resource Conservation and Recovery Act (RCRA), as amended;[6] or the Toxic Substance Control Act (TSCA).[7] Typically, mixed LLW from activities supporting DOE programs includes a variety of contaminated materials, such as air filters, cleaning solutions, engine oils and grease, epoxies and resins, laser dyes, paint residues, soils, asphalt, roofing and wall materials, water treatment chemicals, and decommissioned weapons manufacturing equipment.[8] This report documents inventories and generation rates of various types of mixed wastes stored at DOE sites based on information summarized and reported by the Waste Management Information System (WMIS). The WMIS contains information on hazardous and mixed wastes generated and stored at DOE sites and is maintained by the Hazardous Wastes Remedial Actions Program (HAZWRAP) in support of the DOE Office of Environmental Restoration and Waste Management.

It should be emphasized that all of the types of radioactive materials and wastes discussed in this report can exist either as material generated, treated, stored, or disposed. The distinctions among these various waste conditions or "states" are as follows:

- Generated waste. A material stream recently discharged from a facility production process or operation that can be regarded as a waste because it has no economic value. In this report, quantities of generated waste are measured in units of volume (m^3) or mass (kg) produced during a calendar year.

- Treated waste. A waste stream that, following generation, has been altered chemically or physically to reduce its toxicity or prepare it for storage or disposal on- or off-site. Waste treatment can include volume reduction activities, such as incineration or compaction, which may be performed on a waste prior to either storage or disposal or both (discussed below). Inventories and projections of waste materials undergoing treatment at various sites are not reported in this document.

- Stored waste. A waste that, following generation (and usually some treatment), is being (temporarily) retained and monitored in a retrievable manner pending disposal. In this report, inventories and projections of stored radioactive materials or wastes are reported in volume (m^3) or mass (kg) units or both.

- Disposed waste. A waste that has been put in final emplacement to ensure its isolation from the biosphere, with no intention of retrieval. Deliberate action is required to regain access to the waste. Disposed waste includes materials placed in a geologic repository, buried in shallow-land pits, dumped at sea, or discarded by hydrofracture injection. The latter two techniques were past practices and are no longer performed.

Throughout this report, the reader is urged to note the distinctions between these waste conditions. Such

conditions have a great impact on the regulatory status of the waste materials considered in this report.

0.3 METHODS AND ASSUMPTIONS USED IN REPORT PREPARATION

This report consolidates a large amount of information from many sources. Some of these data are historical in nature, some are current, and some are calculated; some have been estimated, and some have been measured. Over the years, waste regulations have been revised, waste category definitions have changed, measurement instruments and calibration methods have been improved, and record-keeping has been upgraded at all waste generating and receiving sites. In preparing this report, a major effort has been made to integrate waste data from many sources, striving for a consistent and technically rational approach for the entire scope of coverage. Our primary sources of data are referenced, and, for calculated values (e.g., radioactive decay and thermal power), the bases for the calculations are identified. To achieve adequate integration of data, numerous factors had to be considered; these are cited in footnotes that generally accompany the tables and figures of this report. In some cases, a more thorough explanation is provided in the text.

Each individual chapter details the assumptions on which waste inventories and projections are based. The broader assumptions are mentioned here and are listed in Table 0.2. For the commercial fuel cycle, the spent fuel and waste projections depend upon the nuclear power growth scenario. The commercial fuel cycle waste projections reported in this document assume a reference projection of nuclear power growth and no spent fuel reprocessing. The reference nuclear power electrical growth projection (and associated discharged spent fuel schedule) used throughout this report is the 1991 DOE/EIA "No New Orders Without (Plant) License Renewal" Case.[9] Throughout this report, this projection scenario will be generally referred to as the No New Orders Case. In addition, this document also includes a set of nuclear capacity and spent fuel projections associated with the 1991 DOE/EIA "Lower Reference" Case to illustrate, for planning purposes, a conservative upper bound of commercial nuclear power growth.[9,10] The No New Orders and Lower Reference spent fuel and power capacity projection cases are each based on a unique set of assumptions involving nuclear electricity generation growth, reactor fuel burnup levels, reactor construction schedules, and reactor operating lifetimes and capacity factors. In particular, the No New Orders Without License Renewal Case assumes a standard 40-year reactor operating life. By contrast, the 1991 Lower Reference Case assumes that 70% of the reactors will have an extended 60-year operating life.

Detailed information about reactors already built, being built, or planned in the United States for domestic use or export as of December 31, 1990, is provided in report DOE/OSTI-8200-R54 (ref. 11). This document contains a comprehensive listing of all domestic reactors as categorized by primary function or purpose: civilian, production, military, export, and critical assembly.

The data for total waste inventories (which comprise historical data) are obviously less accurate than the values recorded for recent waste additions. The number of digits used in reporting these values is generally greater than justified in terms of numerical significance, but this proves useful and necessary for bookkeeping purposes. In some cases, the values cited are significantly different from those previously reported. This is generally a result of improved estimates, new measurements, or redefinition of terms. Explanations are given in such cases. Many of the comments received during the final review stage of this report deal with changes that have occurred after December 31, 1990 – some as recently as mid-August 1991. These changes are generally cited in footnotes.

For the sake of brevity, many of the figures and tables of this report use the exponential (E) notation. As examples of this notation, the constant 1.234E+2 means 1.234×10^2, or 123.4; and 1.234E-4 means 1.234×10^{-4}, which is 0.0001234.

It should be noted that waste volumes accumulate with time by conventional addition, while total radioactivity and total heat do not, because radionuclides decay over time to nonradioactive, stable isotopes. The short-lived radionuclides found in spent fuel decay rapidly during the first few years after the fuel is removed from a reactor. In this report, radionuclide decay is fully accounted for using a simplified version of the ORIGEN2 code[12] for radionuclide decay calculations.

The primary purpose of this document is to report U.S. spent fuel and radioactive waste inventories, projections, and characteristics. A few graphical presentations and summary tables are included in this chapter to provide a broad overview. Figures 0.1 and 0.2, respectively, show the volumes and activities of commercial and DOE wastes and spent fuel accumulated through 1990. Annual volume and radioactivity projections for various DOE and commercial wastes and spent fuel are shown in Figs. 0.3 and 0.4, respectively. These results exclude contributions from uranium mill tailings, wastes from commercial LWR decontamination and decommissioning (D&D) activities, and wastes from DOE environmental restoration activities. In addition, the spent fuel projections in Figs. 0.3 and 0.4 exclude DOE fuel to be reprocessed. The commercial projections represent fuel cycle requirements without reprocessing. Cumulative waste projections are shown in Figs. 0.5 and 0.6.

The major assumptions used in preparation of this report are given in Table 0.2. These include the projection time frame and specific assumptions used for estimating government (DOE) and commercial waste projections.

Summaries of spent fuel and radioactive waste inventories and projections are provided in Tables 0.3 and

0.4. In general, material to be sent to research and development (R&D) facilities or to the national geologic repository for spent fuel and HLW is still listed in each individual site's inventory.

0.4 CHAPTER OVERVIEWS

A brief summary of each chapter in this report is presented in the following paragraphs.

0.4.1 Spent Fuel

Chapter 1 of this report presents national data on the quantities of permanently discharged spent fuel from commercial nuclear power reactors. Historical data on commercial spent fuel inventories[13] are reported along with two sets of DOE/EIA projections,[10] the No New Orders and Lower Reference cases. The No New Orders Case (without reactor license renewal) is the baseline commercial scenario used throughout this report to make waste projections. In contrast, the Lower Reference Case (with reactor license renewal) represents a conservative upper limit of spent fuel projections. For the projection period considered in this report (1991-2020), the No New Orders Case assumes that no new reactors will be ordered.

Government spent fuel inventories that are not scheduled for reprocessing are reported in Appendix C. These include various types of research reactor spent fuel which are stored at the SRS and the INEL.

In this report, the mass of discharged spent fuel is measured in metric tons of initial heavy metal (MTIHM). The term "initial heavy metal" refers to the original mass of the actinide elements of the fuel, most of which is uranium. (Elements of the actinide group are those with atomic numbers greater than 89.)

0.4.2 High-Level Waste

The inventories of HLW in storage at the end of 1990 and generally projected through the year 2020 are given in Chapter 2. The waste forms include liquid, sludge, salt cake, slurry, calcine, precipitate, zeolite, glass, and capsules of separated strontium and cesium. Vitrified defense HLW is projected after the startup of the Defense Waste Processing Facility (DWPF) at Savannah River in 1993. Projections of vitrified civilian HLW are also given for the WVDP. Projections recently made of the number of canisters containing the final immobilized form for the DOE HLW at Hanford and the INEL are also reported. Locations, volumes, and radioactivities of HLW are also given in Chapter 2.

0.4.3 TRU Waste

Inventories of TRU waste and projected quantities through the year 2013 are presented in Chapter 3, along with waste volumes, masses of the contained TRU waste elements, and locations. Prior to 1970, waste disposal procedures did not require segregation of TRU waste from LLW, and a considerable volume of LLW that contained TRU elements was buried in shallow trenches and pits at DOE sites. Transuranic waste was buried at six DOE sites until 1970, mostly at western locations.

In 1970, the U.S. Atomic Energy Commission (AEC) began retrievable storage of all government waste containing TRU radioactivity concentrations greater than 10 nCi/g. About 2% of this stored waste requires remote handling due to beta-gamma activity from fission products. Present inventories of TRU waste are virtually all from government operations. In 1984, DOE revised the minimum radioactivity concentration level for TRU waste from greater than 10 nCi/g to greater than 100 nCi/g.[14] This redefinition, as well as the development of instrumentation to detect these low levels of radioactivity, has reduced the volume of TRU waste in retrievable storage. As the waste is assayed, some fraction of it will be reclassified to other waste categories. The forecasted effect of this reclassification is provided in Chapter 3.

0.4.4 Low-Level Waste

Commercial fuel cycle LLW is generated from the conversion of yellowcake to UF_6, fuel fabrication, and reactor operation. Low-level waste also results from commercial operations by private organizations that are licensed to use radioactive materials. These include institutions and industries engaged in research and various medical and industrial activities. Government LLW is similar in nature to the industrial and institutional (I/I) waste and the commercial fuel cycle LLW.

A wide variety of radionuclides is found in LLW. Uranium isotopes and their daughters dominate in the conversion, enrichment, and fuel fabrication steps of the nuclear fuel cycle. Reactor operations produce LLW containing mostly activation products and fission products. A significant fraction of institutional LLW that is shipped to disposal sites is contaminated with small quantities of ^{3}H and ^{14}C.

By the end of 1990, approximately 66% of the cumulative volume of disposed LLW resulted from various DOE activities. The remaining 34% resulted from domestic commercial activities. During 1990, 37% of the volume of LLW disposed resulted from commercial activities. Approximately 76% of the annual commercial portion resulted from fuel cycle activities and reactor operations, while the remaining 24% resulted from I/I activities. In the future, these ratios may change according to the number of operating power reactors. Data for LLW from commercial and government activities are given in Chapter 4 and Appendix A.

0.4.5 Commercial Uranium Mill Tailings

Current inventories and projections of tailings from commercial uranium mill operations are summarized in Chapter 5. Twenty-six licensed uranium mills have accumulated tailings from their operations. Half of these mills have both commercial and government tailings. By the end of 1990, only four of the NRC-licensed mills were still active. To date, about 90% of all domestic uranium has been produced by conventional mining and milling methods, from which these tailings derive. The remainder has been obtained via in situ leaching, recovery from mine water, recovery from copper/vanadium dump leach liquor, and recovery from wet-process phosphoric acid effluents. Projections of uranium mill tailings are based on commercial fuel cycle requirements, adjusted for foreign imports, as specified by the DOE/EIA No-New-Orders-Case projection of commercial reactor power growth. Tailings from the now-inactive mills that produced uranium only for government operations are classified as environmental restoration wastes (see Chapter 6).

0.4.6 Environmental Restoration Wastes

The DOE Office of Environmental Restoration and Waste Management (DOE/EM) oversees the assessment and cleanup (environmental restoration) of inactive waste facilities at all DOE sites and some non-DOE sites for which DOE has responsibility. In recent years, waste assessment and cleanup activities have proceeded in three major areas:

1. Environmental Restoration (ER) projects,
2. Uranium Mill Tailings Remedial Action Program (UMTRAP), and
3. Formerly Utilized MED/AEC Sites Remedial Action Program (FUSRAP).

An overview of each of these particular restoration activities and programs is given below, and further details are provided in Chapter 6.

The major objective for DOE Environmental Restoration projects is to ensure that risks to the environment and to human health and safety posed by inactive and surplus installations contaminated by radioactive, hazardous, or mixed wastes are either eliminated or reduced to prescribed, safe levels. The ER projects are comprised of remedial action (RA) and decontamination and decommissioning (D&D) activities. Remedial action involves the assessment and cleanup of inactive sites and deals mainly with contaminated soil and groundwater. There are about 3,700 sites currently included under the RA portion of ER project activities. Decontamination and decommissioning activities include the safe caretaking of surplus nuclear facilities and their complete dismantling and removal or in-place stabilization and isolation. About 500 contaminated facilities are currently included under D&D. Some of these were part of projects previously included under the Surplus Facilities Management Program (SFMP) and the Defense D&D Program described in previous DOE Integrated Data Base reports. (Both the SFMP and Defense D&D Program were discontinued following the establishment of the DOE Office of Environmental Restoration and Waste Management.)

Activities associated with ER projects are presently found in 17 states. In this report, projections of wastes from ER projects are reported separately for defense- and non-defense-funded activities. Both the defense and nondefense categories include projections of wastes from RA and D&D activities.

DOE environmental restoration goals and objectives are detailed in the 1991 Five-Year Environmental Restoration and Waste Management Plan report[15] developed (and updated annually) for DOE sites. This document provides a detailed update of the mission and objectives for the DOE Office of Environmental Restoration and Waste Management.

The UMTRAP is involved with stabilizing uranium mill tailings at 25 mill sites that are licensed but not active. The total volume of tailings at UMTRAP sites is nearly 40 million m^3. All UMTRAP wastes (depending on specific site circumstances) may be either stabilized on-site or removed to another location and stabilized.

Existing congressional legislation has identified 33 FUSRAP sites to be restored as nearly as practicable for unrestricted use. Most of these sites were used by the Manhattan Engineer District (MED) of the Manhattan Project and the AEC for work with nuclear materials. Site sizes vary considerably, from a small area within a building (e.g., a laboratory) to a large outdoor tract (such as a former storage site). Only LLW is projected, and this consists primarily of contaminated soil and building rubble. Most of the projected volume of this waste is expected to originate from the states of Missouri, New Jersey, and New York.

0.4.7 Commercial Decommissioning Wastes

Chapter 7 presents waste projections for the decommissioning of commercial power reactors and fuel cycle facilities. The D&D activities at such installations may result in very large volumes of LLW, depending on the methods selected. The major LLW volumes will result from the decommissioning of power reactors, which will also produce a small volume of high-activity waste. Unlike that for other waste generation activities, the timing of decommissioning operations is very uncertain, since facilities may be either decommissioned upon shutdown or put into a mothballed or protective storage condition to allow for sufficient radioactive decay before decommissioning. Chapter 7 reports a set of projected characteristics for wastes from commercial LWR decommissioning activities. These projections are based on the assumption that each power reactor is immediately

decommissioned after it is shut down. To date, only a few commercial reactors have been fully decommissioned, and several have been placed in protective storage. Wastes from completed decommissioning actions have been included with existing inventories discussed in other chapters. Because of timing uncertainties, projected decommissioning wastes are not included in the projections of either LLW (Chapter 4) or wastes from environmental restoration programs (Chapter 6). Rather, decommissioning waste projections are reported separately in Chapter 7.

0.4.8 Miscellaneous Radioactive Materials

Inventories and characteristics of miscellaneous radioactive materials that may require geologic disposal are reported in Appendix C. Such materials consist mainly of permanently discharged or damaged spent fuel (pellets, rods, and other fuel assembly components) from civilian and government-sponsored nuclear programs.

0.4.9 Mixed Low-Level Waste

Current inventories and generation rates of mixed LLW from both DOE and commercial sources are summarized in Chapter 8. These wastes are comprised of mixed materials that are both low-level radioactively contaminated and chemically hazardous. The radioactive components are defined by the Atomic Energy Act,[16] while the hazardous components are defined by the Resource Conservation and Recovery Act[6] and the Toxic Substances Control Act.[7] As of the end of 1990, DOE site mixed LLW inventories totaled about 106,800 m^3. During 1990, 22,160 m^3 of mixed LLW was generated at DOE sites.

0.4.10 Appendixes

Several appendixes are included in this report. Appendix A is a compilation of waste flowsheets, source terms, and characteristics used for waste projections. Source terms include both quantitative and descriptive characteristics used to describe radioactive wastes. As developed and used in the IDB Program, the source term for a particular waste is comprised of two components unique to that waste: (1) the number of curies of radioactivity, expressed either per unit of facility production or per unit of waste volume or mass; and (2) a listing of the relative contributions of component radioisotopes per curie of radioactivity of the waste. A tabulation of the properties of important radionuclides is given in Appendix B. Data on the quantities of miscellaneous radioactive materials that may require geologic disposal are reported in Appendix C. Finally, Appendix D lists the sites and facilities referred to in this report.

0.5 REFERENCES

1. U.S. Department of Energy, Integrated Data Base for 1990: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 6, Oak Ridge National Laboratory, Oak Ridge, Tennessee (October 1990).

2. U.S. Congress, Nuclear Waste Policy Act of 1982, Pub. L. 97-425, Jan. 7, 1983, as amended by the Budget Reconciliation Act for Fiscal Year 1988, Title V – Energy and Environment Programs, Pub. L. 100-203, Dec. 22, 1987.

3. U.S. Environmental Protection Agency, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Code of Federal Regulations, 40 CFR Part 191 (1985).

4. U.S. Department of Energy, DOE Order 5820.2A, Radioactive Waste Management, Sept. 26, 1988.

5. U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste – Waste Classification," Code of Federal Regulations, 10 CFR Part 61, Section 61.55 (1982).

6. U.S. Congress, Resource Conservation and Recovery Act of 1976, Pub. L. 94-580, Oct. 21, 1976, as amended by the Hazardous and Solid Waste Amendments Acts of 1984, Pub. L. 98-616, Nov. 9, 1984.

7. U.S. Congress, Toxic Substances Control Act (of 1976), Pub. L. 94-469, Oct. 11, 1976.

8. C. S. Fore et al., DOE Waste Information Network: DOE/DP Hazardous and Mixed Waste Data Base – A User's Guide, DOE/HWP-15, Oak Ridge National Laboratory, Oak Ridge, Tennessee (August 1986).

9. U.S. Department of Energy, Energy Information Administration, Commercial Nuclear Power 1991: Prospects for the United States and the World, DOE/EIA-0438(91), Washington, D.C. (August 1991).

10. U.S. Department of Energy, Energy Information Administration, World Nuclear Fuel Cycle Requirements 1991, DOE/EIA-0436(91), Washington, D.C. (October 1991).

11. U.S. Department of Energy, Office of Scientific and Technical Information, Nuclear Reactors Built, Being Built, or Planned: 1990, DOE/OSTI-8200-R54, Oak Ridge, Tennessee (July 1991).

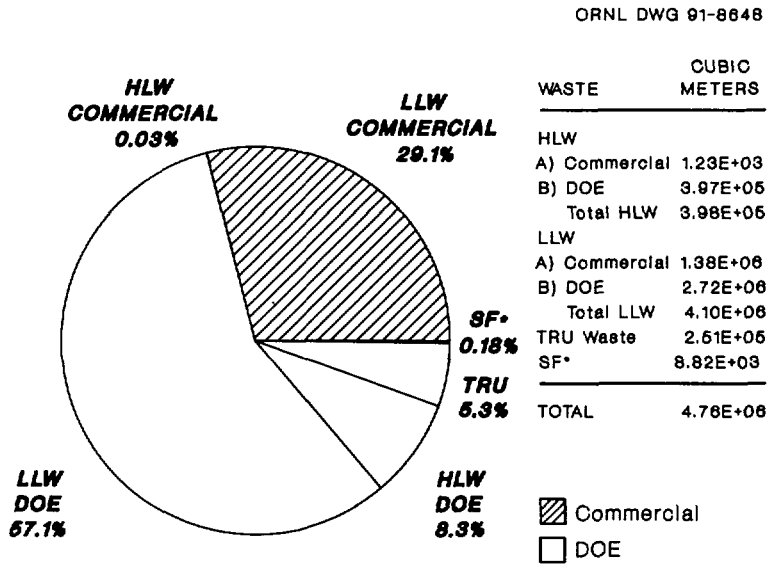
12. A. G. Croff, ORIGEN2 – A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code, ORNL-5621, Oak Ridge National Laboratory, Oak Ridge, Tennessee (July 1980).

13. U.S. Department of Energy, Energy Information Administration, Nuclear Fuel Data Form RW-859 (data as of Dec. 31, 1990).

14. U.S. Department of Energy, DOE Order 5820.2, Radioactive Waste Management, Feb. 6, 1984.

15. U.S. Department of Energy, Environmental Restoration and Waste Management Five-Year Plan – Fiscal Years 1993-1997, FYP-DOE/S-0089P, Washington, D.C. (August 1991).

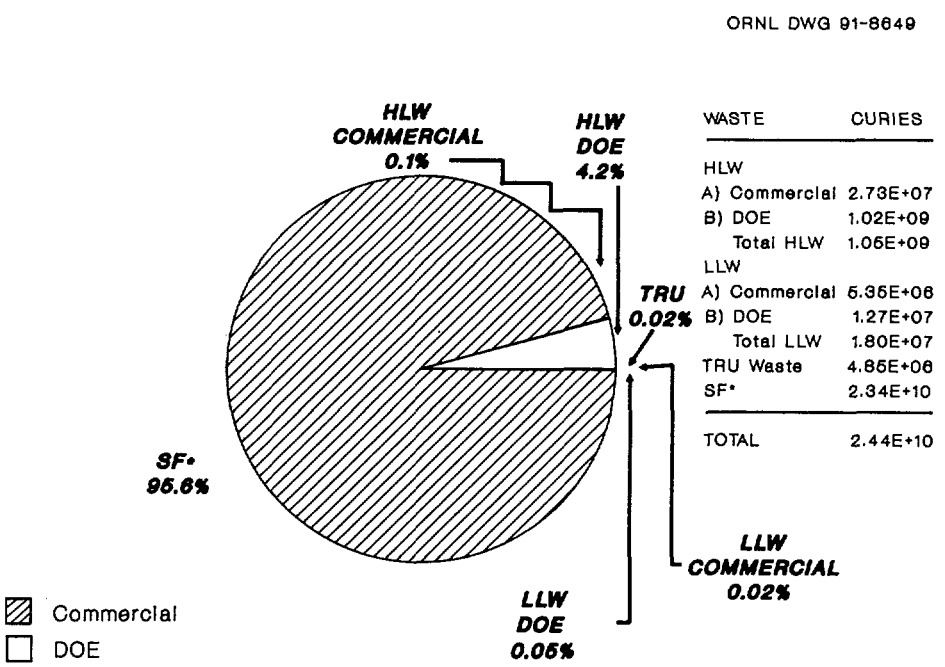
16. U.S. Congress, Atomic Energy Act of 1954, Pub. L. 83-703, Aug. 15, 1954.



WASTE	CUBIC METERS
HLW	
A) Commercial	1.23E+03
B) DOE	3.97E+05
Total HLW	3.98E+05
LLW	
A) Commercial	1.38E+06
B) DOE	2.72E+06
Total LLW	4.10E+06
TRU Waste	2.51E+05
SF*	8.82E+03
TOTAL	4.76E+06

*Includes spacing between fuel assembly rods.
Does not include DOE spent fuel to be reprocessed.

Fig. 0.1. Volumes of commercial and DOE wastes and spent fuel accumulated through 1990.



WASTE	CURIES
HLW	
A) Commercial	2.73E+07
B) DOE	1.02E+09
Total HLW	1.05E+09
LLW	
A) Commercial	5.35E+06
B) DOE	1.27E+07
Total LLW	1.80E+07
TRU Waste	4.85E+06
SF*	2.34E+10
TOTAL	2.44E+10

*Does not include DOE spent fuel to be reprocessed.

Fig. 0.2. Radioactivities of commercial and DOE wastes and spent fuel accumulated through 1990.

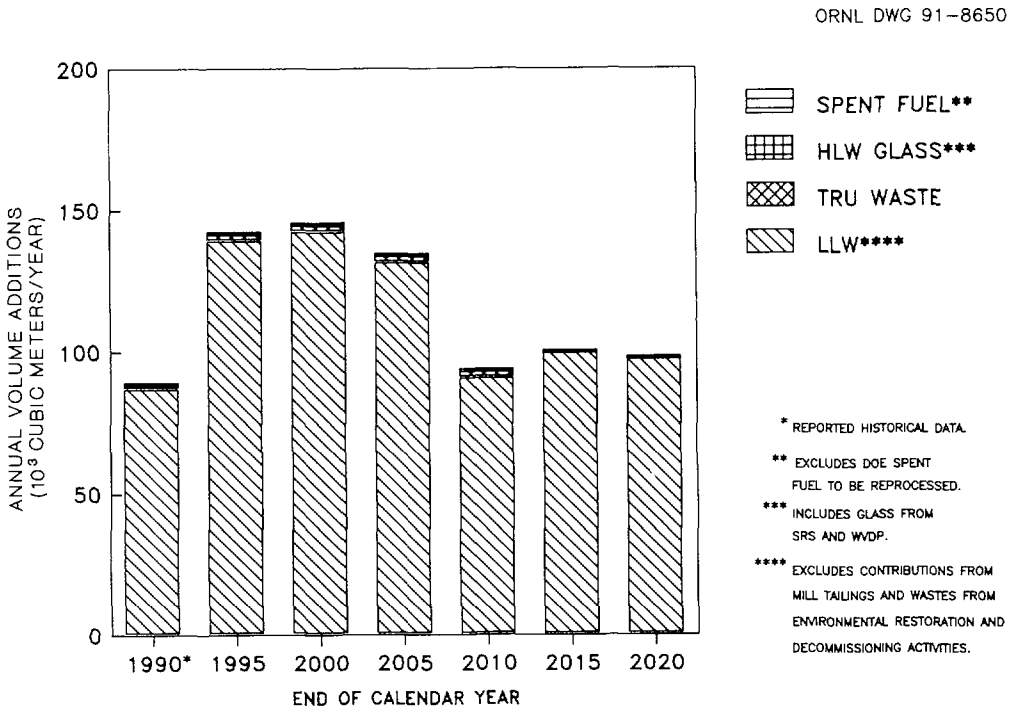


Fig. 0.3. Projections of annual volume additions for various wastes and spent fuel — DOE and commercial fuel cycle.

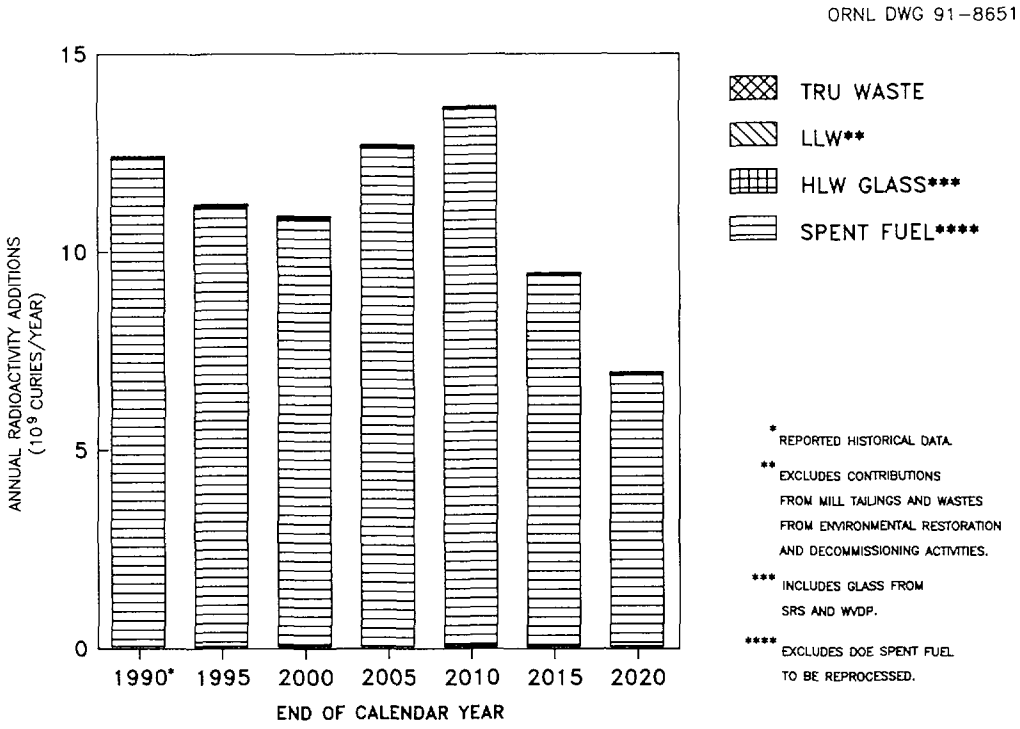


Fig. 0.4. Projections of annual radioactivity additions for various wastes and spent fuel — DOE and commercial fuel cycle.

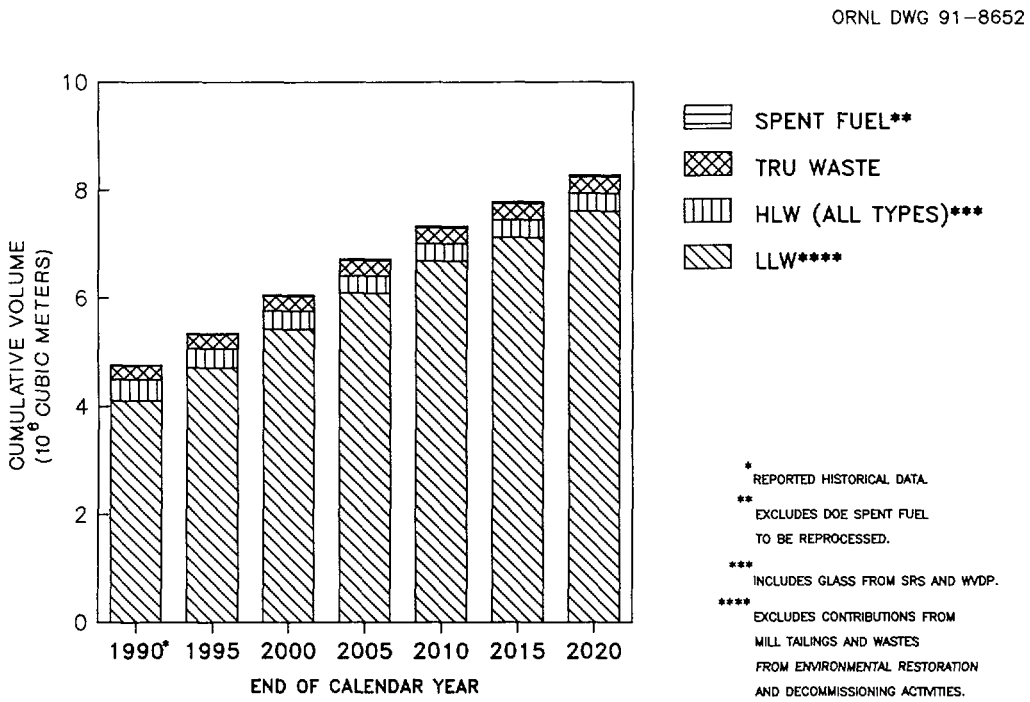


Fig. 0.5. Projections of cumulative volumes for various wastes and spent fuel — DOE and commercial fuel cycle.

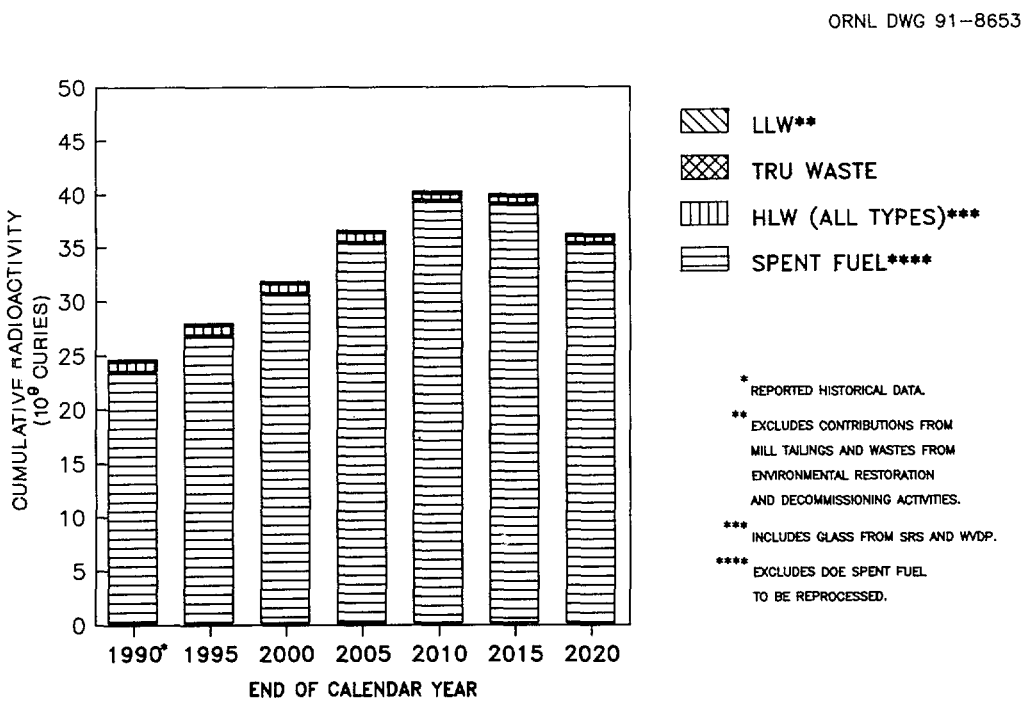


Fig. 0.6. Projections of cumulative radioactivity for various wastes and spent fuel — DOE and commercial fuel cycle.

Table 0.1. Major sources of information for the IDB Program

Technical area	Responsible DOE offices	Principal contractor
Ground rules and assumptions	DOE Headquarters Office of Civilian Radioactive Waste Management Office of Environmental Restoration and Waste Management	
Spent fuel	DOE Headquarters Office of Civilian Radioactive Waste Management Energy Information Administration Field Office, Richland	Pacific Northwest Laboratory
High-level waste (HLW):		
DOE	Field Office, Richland	Westinghouse Hanford Company
Commercial	West Valley Demonstration Project	Westinghouse (West Valley Nuclear Services)
Transuranic (TRU) waste	Field Office, Albuquerque Waste Isolation Pilot Plant (WIPP) Project Office	Westinghouse (WIPP Project)
Low-level waste (LLW)		
DOE	Field Office, Oak Ridge	Hazardous Waste Remedial Actions Program (Martin Marietta Energy Systems, Inc.)
Commercial	Field Office, Idaho	EG&G Idaho, Inc.
Active (licensed) mill tailings	Energy Information Administration	
Environmental restoration wastes:		
DOE Environmental Restoration Projects	DOE Headquarters Office of Environmental Restoration and Waste Management	Office of Technical Services Roy F. Weston, Inc. H&R Technical Associates, Inc.
Uranium Mill Tailings Remedial Action Program	Field Office, Albuquerque	Jacobs Engineering Group, Inc.
Formerly Utilized Sites Remedial Action Program	Field Office, Oak Ridge	Bechtel National, Inc
Nuclear facility decommissioning wastes, principally from the following:		
Three Mile Island-Unit 2 Reactor	Field Office, Idaho	GPU Nuclear Corporation
West Valley Demonstration Project	Field Office, Idaho	Westinghouse (West Valley Nuclear Services)
Mixed LLW (DOE sites)	Field Office, Oak Ridge	Hazardous Waste Remedial Actions Program (Martin Marietta Energy Systems, Inc.)

Table 0.2. Major assumptions used in this report

Projection basis

- Projections are made for the years 1991-2020

Government activities

- Level of waste generating activities remains approximately constant
- The most recent operating campaign of the Hanford Site reprocessing plant began in 1983 and will conclude operations near the end of 2002
- HLW solidification schedules:
  - For WVDP, HLW solidification (glass production) starts in 1996 and is completed in 1998
  - For SRS, HLW solidification [glass production at the Defense Waste Processing Facility (DWPF)] starts in 1993 and continues solidification until 2009
  - For INEL, HLW solidification (immobilization) starts in 2014, achieves full production by 2017, and continues through 2035
  - For HANF, HLW solidification (borosilicate glass production at the Hanford Waste Vitrification Plant) starts in December 1999 and continues through 2010

Commercial activities

- Projections of installed net LWR electrical capacity for the DOE/EIA No New Orders Case[a] of ref. 9:

Year	GW(e)	Year	GW(e)	Year	GW(e)	Year	GW(e)
1991	100	1999	104	2007	106	2015	71
1992	101	2000	105	2008	106	2016	65
1993	102	2001	105	2009	104	2017	62
1994	102	2002	105	2010	101	2018	59
1995	103	2003	106	2011	99	2019	59
1996	103	2004	106	2012	94	2020	57
1997	103	2005	106	2013	86		
1998	104	2006	106	2014	77		

- DOE/EIA projections for both the No New Orders Case and the Lower Reference Case assume that burnup levels of discharged spent fuel will increase from their current average levels of 25,000 and 33,800 MWd/MTIHM for BWR and PWR fuel, respectively, at the rate of about 3.2% per year for BWR fuel and about 3.3% per year for PWR fuel. This increase in burnup is projected to occur from 1990 to 2007 for BWR fuel and from 1990 to 2005 for PWR fuel, at which times the equilibrium cycle discharges will level out at values of roughly 43,000 and 55,000 MWd/MTIHM for BWR and PWR fuel, respectively

- Spent fuel from commercial reactors is not reprocessed. Thus, a fuel cycle without reprocessing is assumed for all commercial projections

- Lead time (number of months prior to startup after refueling) for the following fuel cycle activities:

  - Mining and milling (15) • Conversion (12) • Enrichment (12) • Fabrication (9)

- Annual volume and radioactivity of industrial and institutional (I/I) waste for projections (1991-2020) are taken to be the same as those reported for 1990. The radioactivity added each year is decayed as if it had the composition given in Table A.11 in Appendix A

[a]This case is based on a standard 40-year reactor operating life.

Table 0.3. Spent fuel and radioactive waste inventories as of December 31, 1990

Waste category	TRU isotopes (kg)	Mass (MTIHM)	Volume (m^3)	Activity[a] (10^6 Ci)	Thermal power (10^3 W)
Spent fuel (commercial)					
BWRs		8,226	3,316[b]	6,099	22,300
PWRs		13,641	5,499[b]	17,251	66,300
High-level waste					
Savannah River (DOE)			131,700	562	1,566
Idaho (DOE)			12,000	63	184
Hanford (DOE)[c]			253,600	393	1,078
West Valley (commercial)			1,231	27	81
Transuranic waste (DOE)					
Buried TRU waste	771		190,837	0.07	1.7
Potentially contaminated soil	d		140,000-1,795,000	d	d
Stored TRU waste	2,233		60,607	4.78	74.6
Stored LLW[e]	14		39,197	d	d
Low-level waste					
DOE sites			2,720,000	12.68	15.79
Commercial sites			1,384,000	5.35	25.66
Uranium mill tailings (commercial)					
Licensed mill sites[f]			118,000,000	d	d
Environmental restoration activities (DOE)[g]					
ER projects (defense- and non-defense funded)					
TRU waste			h	d	d
LLW			h	d	d
UMTRAP (25 sites)					
Mill tailings and other waste (permanent storage)			9,765,200	d	d
GJRAP (593 sites)					
Mill tailings			52,070[i]	d	d
FUSRAP (33 sites)					
LLW (permanent and interim storage)			331,800	d	d
Reactor decommissioning			j	j	j
Miscellaneous radioactive materials		253.9	d	d	d
Mixed LLW					
DOE		121,376[k]	106,799	d	d
Commercial		d	d	d	d

[a]Activity data are calculated values as of December 31, 1990.

[b]Includes volume of spacing between the fuel rods of each assembly.

[c]Hanford tank wastes consist of HLW, TRU waste, and LLW. However, in the interim storage mode, the tank wastes are managed as if they contain HLW and, therefore, are included in the HLW inventory.

[d]Information not available.

[e]TRU-contaminated waste in interim storage which may be managed as LLW after retrieval and assay for certification.

[f]Includes contributions from 26 NRC-licensed mills.

[g]Unless otherwise indicated, inventories reported in this table for environmental restoration activities include only contributions from projects completed at the end of 1990.

[h]Should include only inventories of wastes stored at environmental restoration sites. This information is currently not available.

[i]Mill tailings stabilized by the Grand Junction Remedial Action Project (GJRAP) through 1982.

[j]Most of this activity has involved small test reactors. (Exceptions are the Shippingport and Three Mile Island-Unit 2 reactor facilities, whose inventories are reported in Chapter 7.) The LLW collected to date from such small reactors are included in the LLW inventories listed above.

[k]Mass of mixed LLW is expressed in metric tons (t) and includes other elements in addition to heavy metals.

Table 0.4. Current and projected cumulative quantities of radioactive waste and spent fuel

[Quantities are expressed as volume (10^3 m^3) unless otherwise indicated]

Source and type of material	End of calendar year			
	1990	2000	2010	2020
DOE				
HLW				
Interim storage	397	332	325	333
Glass[a]	0	1.7	3.3	3.3
TRU[b]				
Buried	191	191	191	191
Stored	61	84	107	c
LLW[d]	2,720	3,714	4,565	5,291
Environmental restoration (ER) activities[e]				
Defense-funded ER projects				
TRU waste	f	154.8	305.0	440.1
LLW[g]	f	832.8	1,523.6	2,130.2
Non-defense-funded ER projects				
TRU waste	f	2.1	2.1	2.1
LLW[g]	f	2,641.0	3,290.4	3,808.8
UMTRAP and GJRAP				
Mill tailings and other waste[h,i]	9,817	39,470	39,470	39,470
FUSRAP				
LLW[g]	332	1,026	1,587	1,587
Mixed LLW	106.8	c	c	c
Miscellaneous radioactive materials, mass, MTIHM	253.9	c	c	c
Commercial				
LWR spent fuel, mass, MTIHM[j] (no reprocessing)				
No New Orders Case	21,868	41,300	60,300	75,900 →
Lower Reference Case	21,868	41,300	60,100	79,600 →
Commercial HLW (WVDP)				
Interim storage	1.231	0.0	0.0	0.0
Glass	0.0	0.210	0.210	0.210
LLW (no reprocessing)	1,384	1,709	2,043	2,319
D&D (LLW)[k]				
Classes A, B, and C LLW	--	0.00	7.83	641.83
Greater-than-Class-C LLW	--	0.00	0.05	3.44
Mill tailings (no reprocessing)	118,000	119,000	c	c
Mixed LLW	c	c	c	c

[a]Includes projections for glass only at SRS.

[b]Projections are updated mainly as a result of improvements in detection methods. Approximately 39% of the currently stored volume will be managed as LLW.

[c]Information not available.

[d]Projections include contributions from SRS saltstone.

[e]These activities involve environmental restoration activities performed on existing wastes. Projections are based on the scheduled completion of most restoration activities by the year 2000.

[f]Should include only inventories of wastes stored at environmental restoration sites. This information is currently not available. Projected data that follow are cumulatives from future environmental restoration activities.

[g]Projected LLW volumes from environmental restoration activities are not included in the DOE LLW volumes reported above.

[h]Mill tailings stabilized from both GJRAP and UMTRAP activities.

[i]Includes windblown contaminated soil and stabilization material from sites that may require environmental restoration.

[j]Historically, spent fuel has been measured in units of mass (MTIHM) rather than units of volume. The 1990 discharged spent fuel mass is a BWR and PWR mass sum rounded to the nearest metric ton. Such rounding may result in slight differences between the spent fuel inventories and projections reported in this document and those reported by DOE/EIA.

[k]Projected D&D wastes from light-water reactors shut down after 1990. Wastes collected from historical D&D of reactors are included in the LLW inventories listed above.

ORNL PHOTO 7875-91

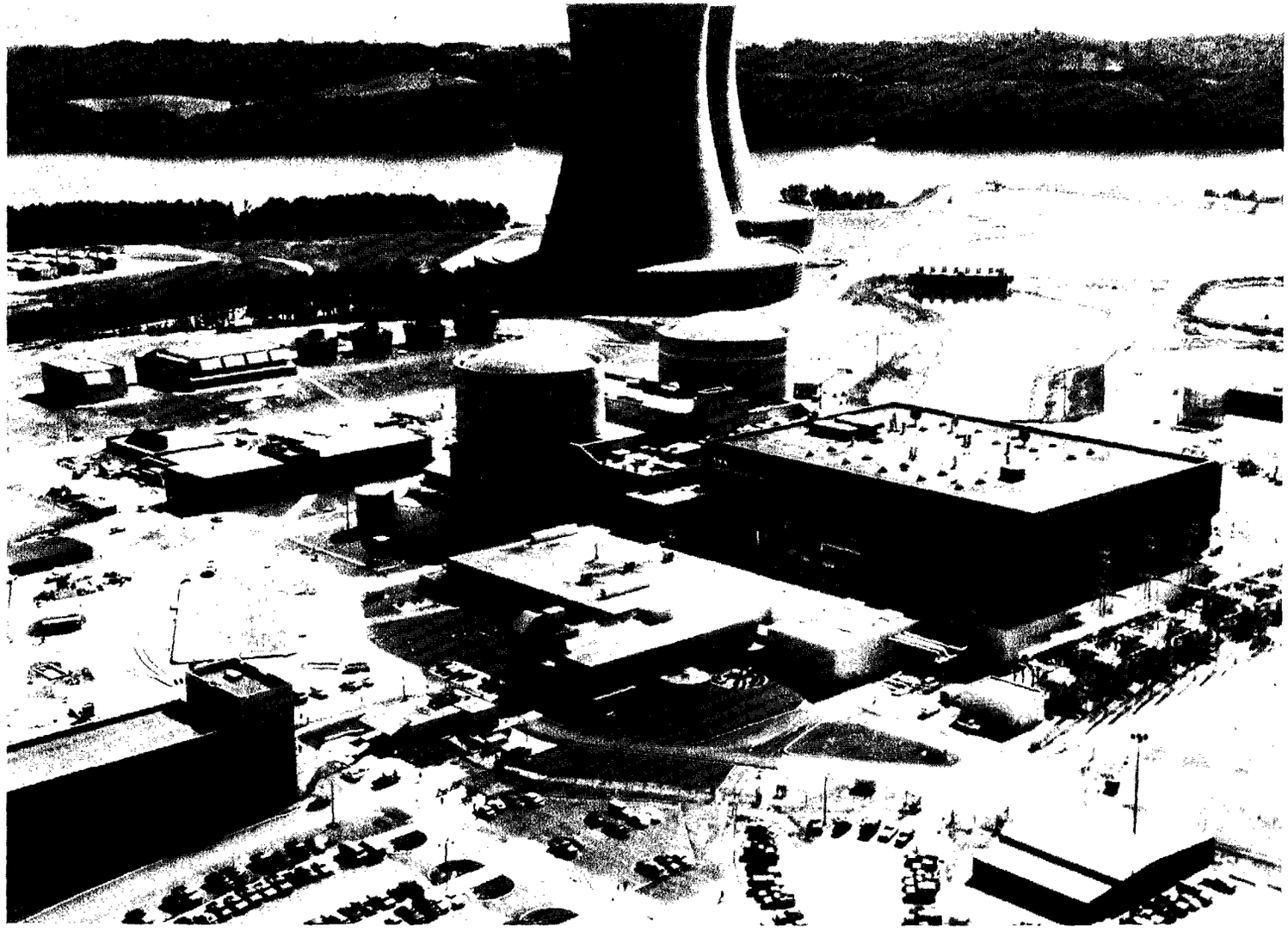


Photo 1.1. The Sequoyah Nuclear Power Station, two 1220-MW(e) pressurized-water reactors, located about 10 miles north of Chattanooga, Tennessee. (Courtesy of the Tennessee Valley Authority, Knoxville, Tennessee.)

1. SPENT FUEL

1.1 INTRODUCTION

This chapter deals exclusively with spent fuel that has been permanently discharged from commercial LWRs and one-of-a-kind reactors and that ultimately requires geologic disposal. While the spent fuel data included in this chapter are believed to be accurate, the reader is advised that the data are still undergoing review for compliance with the formal quality assurance requirements of the Office of Civilian Radioactive Waste Management.

For inventories of special fuels (DOE/civilian development programs) stored at various DOE and commercial sites as of December 31, 1990, the reader is referred to Appendix C. The special fuels listed in Appendix C do not include DOE production and naval reactor fuels that are reprocessed at SRS, ICPP, and Hanford. Though presently in storage at the locations cited in Appendix C, these special fuels also may ultimately require geologic disposal. Additional commercial spent fuel information may be obtained from the DOE/EIA.

Some commercial spent fuel in inventory will be reinserted into reactors for further irradiation. However, this amount is relatively small, and the schedules for reinsertion are not always predictable. Therefore, for the purposes of this report, all spent fuel is considered permanently discharged from the reactors.

Historical inventories of LWR spent fuel have been updated through December 31, 1990.[1] The data reported in this chapter include the inventories of spent fuel stored at the WVDP and the MFRP sites in addition to those stored at the various reactor sites. The map in Fig. 1.1 shows the locations of existing and planned power reactor sites and commercial LWR spent fuel storage facilities. A list of commercial reactors is given also in report DOE/OSTI-8200-R54 (ref. 2).

Projections of nuclear capacity and spent fuel discharges are given for the years 1991–2020 for two forecast schedules, the DOE/EIA No-New-Orders-Case forecast and the DOE/EIA Lower-Reference-Case forecast, reported in refs. 3 and 4. The No-New-Orders-Case forecast projects installed capacity to increase from 99.6 GW(e) at the end of 1990 to 105.4 GW(e) by 2000, ultimately decreasing to 56.8 GW(e) by 2020. The Lower-Reference-Case forecast predicts that the installed U.S. commercial nuclear electrical generating capacity will increase from 99.6 GW(e) at the end of 1990 to 105.4 GW(e) by 2000 and to 122.6 GW(e) by 2020.

The reference scenarios considered for projecting accumulated spent fuel assume a fuel cycle with no reprocessing. Commercial spent fuel projections developed for the DOE/EIA No New Orders Case and the DOE/EIA Lower Reference Case are illustrated, along with historical discharge data, in Figs. 1.2–1.5. Spent fuel discharge projections for both schedules, in terms of annual mass discharged and accumulated radioactivity, are graphically illustrated in Figs. 1.2 and 1.3, respectively. A graph showing the increase in the cumulative mass of discharged spent fuel for the DOE/EIA No New Orders Case is shown in Fig. 1.4. This plot also shows both the age and mass distribution for spent fuel from 1970 to 2020. Figure 1.5 is a similar plot showing the increase in the cumulative mass of discharged spent fuel for the DOE/EIA Lower Reference Case.

DOE/EIA projections for both the No New Orders Case and the Lower Reference Case assume that burnup levels of discharged spent fuel will increase from their current average levels of 25,000 and 33,800 MWd/MTIHM for BWR and PWR fuel, respectively, at the rate of about 3.2% per year for BWR fuel and about 3.3% per year for PWR fuel. This increase in burnup is projected to occur from 1990 to 2007 for BWR fuel and from 1990 to 2005 for PWR fuel, at which times the equilibrium cycle discharges will level out at values of roughly 43,000 and 55,000 MWd/MTIHM for BWR and PWR fuel, respectively. The final cycle discharges will be somewhat lower because most of the final cycle cores will not have achieved the projected design burnups. Figure 1.6 graphically illustrates how the activity and thermal power of BWR and PWR spent fuels vary with burnup and time from discharge.[5]

1.2 INVENTORIES AND PROJECTIONS

The total inventory of commercial LWR spent fuel in storage at the WVDP site, the MFRP, and the reactor sites, as of December 31, 1990, amounted to 21,868 MTIHM. Of this total amount, 27 MTIHM are in storage at the WVDP site[6] and 674 MTIHM are in storage at the MFRP.[1] The remainder is stored at the reactor sites.

These inventories do not include the spent fuel reprocessed at the WVDP site when the facility was operated as a fuel reprocessing plant. Additional information on WVDP spent fuel inventories is given in Chapter 7, Table 7.9. Details concerning the spent fuel reprocessed at West Valley may be obtained from ref. 7.

A BWR/PWR breakdown of the electric power generating capacity for both the No-New-Orders-Case forecast and the Lower-Reference-Case forecast is given in Table 1.1, along with historical reactor capacity data. Table 1.2 gives the projected cumulative mass of commercial spent fuel discharges associated with the DOE/EIA capacity growth scenarios of Table 1.1. The historical and projected buildups of permanently discharged BWR and PWR spent fuel mass, radioactivity, and thermal power are given for the DOE/EIA No New Orders Case in Table 1.3 and for the DOE/EIA Lower Reference Case in Table 1.4. Projections of the number of permanently discharged BWR and PWR spent fuel assemblies for the DOE/EIA No New Orders Case and Lower Reference Case are given in Tables 1.5 and 1.6, respectively.

The historical and projected mass of spent fuel discharged from a one-of-a-kind reactor, the Fort St. Vrain HTGR,[8] is given in Table 1.7. All of the discharged fuel from the Fort St. Vrain reactor that has been shipped off-site is located at the ICPP (see Table C.6 in Appendix C). The Fort St. Vrain reactor was permanently shut down in 1989.

1.3 CHARACTERIZATION

Reference characteristics of BWR and PWR fuel assemblies, obtained from refs. 9 and 10, were used for this report. These characteristics are summarized in Table 1.8. Fuel assembly structural material masses and compositions, nonactinide fuel impurities, and other physical and irradiation characteristics of LWR spent fuel are discussed in ref. 11. More detailed information on spent fuel characteristics may be found in ref. 12. The BWR and PWR spent fuel annually discharged has a broad range of burnup levels, as illustrated in Tables 1.9 and 1.10, respectively. The mass, radioactivity, and thermal power of the nuclides contained in all stored domestic commercial LWR spent fuel as of December 31, 1990, are listed in Table A.4 in Appendix A.

1.4 DISPOSAL

The Department of Energy has made progress in obtaining site access and performing necessary site characterization activities to determine if the Yucca Mountain, Nevada, site is suitable for use as a repository. Study plans have been completed for the first set of tests on geologic stability in Midway Valley and in Trench 14 on the origin and age of calcite silica deposits. DOE recently received from Nevada the first of three court-ordered permits necessary for DOE to gain access to Yucca Mountain. In July 1991, limited trenching work was begun.

In order to expedite and ensure that future activities needed to evaluate the suitability of the Yucca Mountain site can proceed despite the state of Nevada's refusal to issue the requisite permits, DOE has submitted language as part of the National Energy Strategy Act that would allow DOE to proceed with scientific investigations.

1.5 REFERENCES

1. U.S. Department of Energy, Energy Information Administration, Nuclear Fuel Data Form RW-859, Washington, D.C. (data as of December 31, 1990).

2. U.S. Department of Energy, Office of Scientific and Technical Information, Nuclear Reactors Built, Being Built, or Planned: 1990, DOE/OSTI-8200-R54, Oak Ridge, Tennessee (July 1991).

3. U.S. Department of Energy, Energy Information Administration, Commercial Nuclear Power 1991: Prospects for the United States and the World, DOE/EIA-0438(91), Washington, D.C. (August 1991).

4. U.S. Department of Energy, Energy Information Administration, World Nuclear Fuel Cycle Requirements 1991, DOE/EIA-0436(91), Washington, D.C. (October 1991).

5. J. W. Roddy et al., Physical and Decay Characteristics of Commercial LWR Spent Fuel, ORNL/TM-9591/V1&R1, Oak Ridge National Laboratory, Oak Ridge, Tennessee (January 1986).

6. T. J. Rowland, DOE-West Valley Project Office, West Valley, New York, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update to the DOE 1991 Integrated Data Base Report," dated Apr. 15, 1991.

7. E. R. Johnson Associates, Inc., Review of the Operating History of the Nuclear Fuel Services, Inc., West Valley, New York, Irradiated Fuel Reprocessing Plant, ORNL/Sub-81/31066/1, Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 1981).

8. H. L. Brey, Public Service Company of Colorado, Denver, Colorado, letter to R. C. Ashline, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Fort St. Vrain Spent Fuel Data," Docket No. 50-267, dated Mar. 4, 1991.

9. General Electric Company, General Electric Standard Safety Analysis Report, BWR/6, Docket STN 50-447, San Jose, California (1973).

10. Westinghouse Nuclear Energy Systems, Reference Safety Analysis Report, RESAR-3, Docket STN 50-480, Pittsburgh, Pennsylvania (1972).

11. A. G. Croff et al., Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN Computer Code, ORNL/TM-6051, Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 1978).

12. U.S. Department of Energy, Characteristics of Spent Fuel, High-Level Waste, and Other Radioactive Wastes Which May Require Long-Term Isolation, DOE/RW-0184, Vols. 1–8, Oak Ridge National Laboratory, Oak Ridge, Tennessee (December 1987).

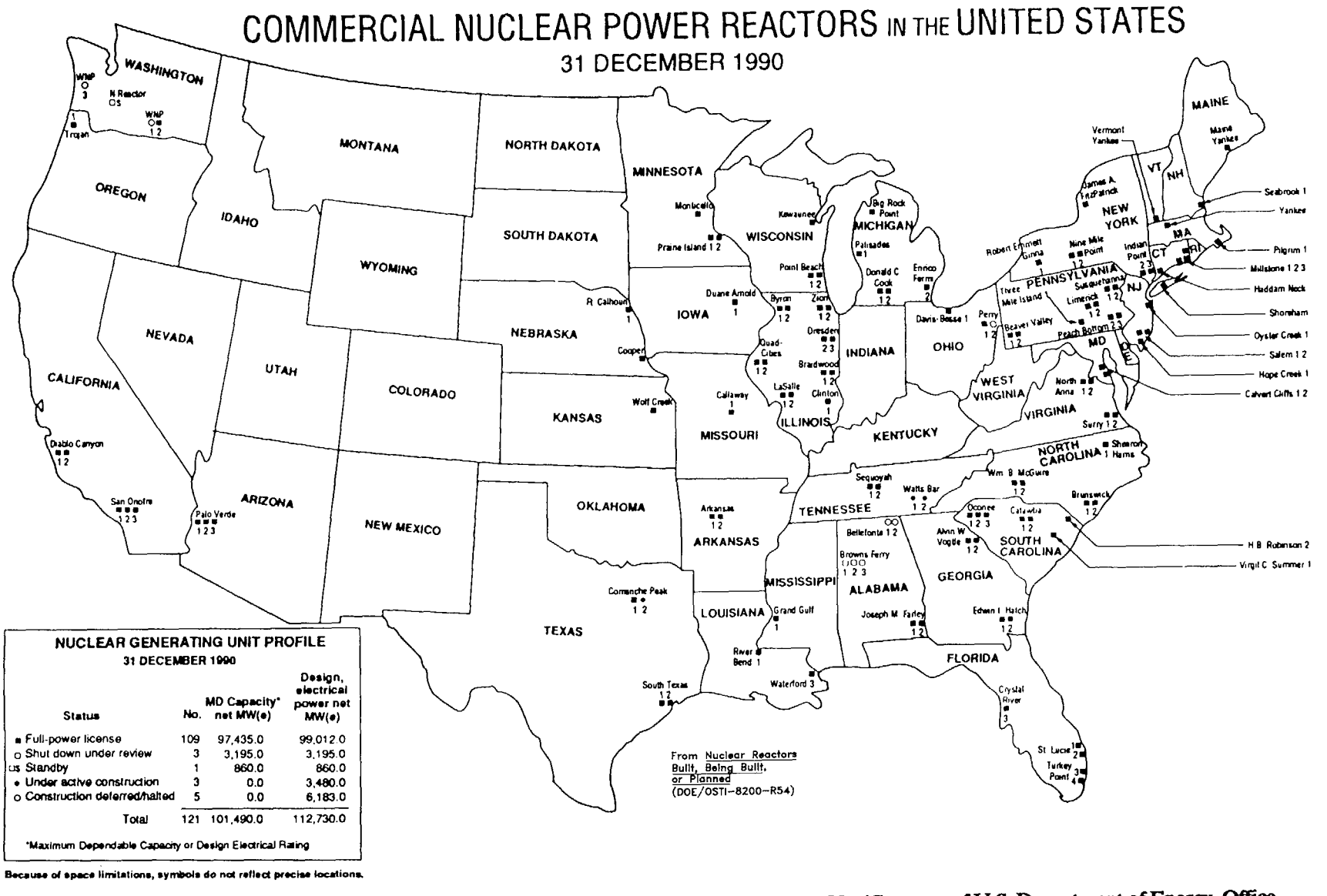


Fig. 1.1. Locations of existing and planned commercial reactors as of December 31, 1990. (Courtesy of U.S. Department of Energy, Office of Scientific and Technical Information, Oak Ridge, Tennessee.)

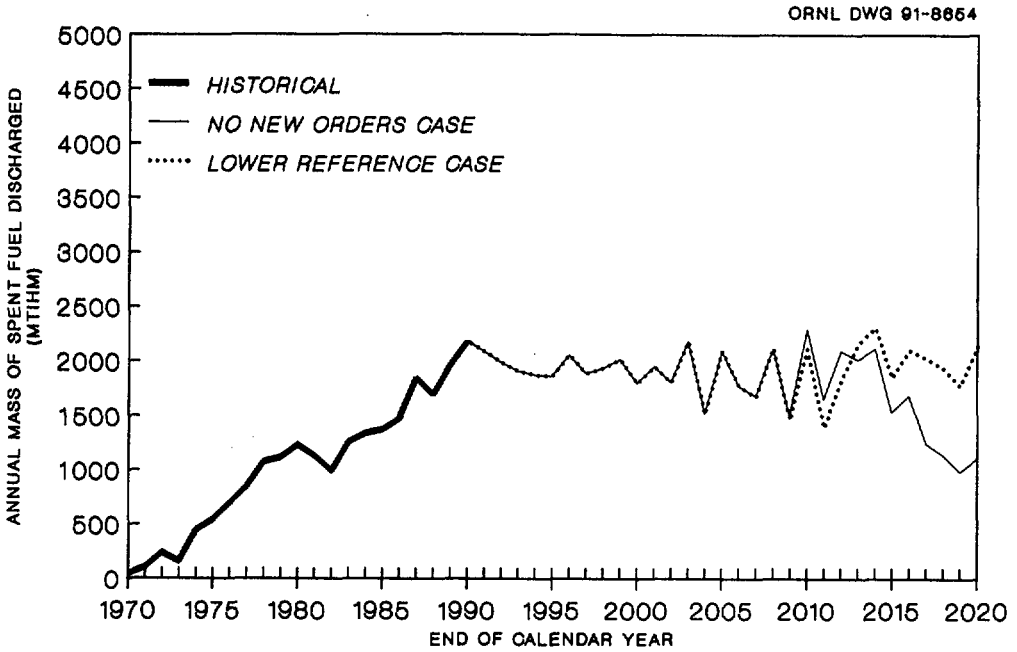


Fig. 1.2. Projected mass (MTIHM) of annual commercial spent fuel discharges for the DOE/EIA No New Orders and Lower Reference cases.

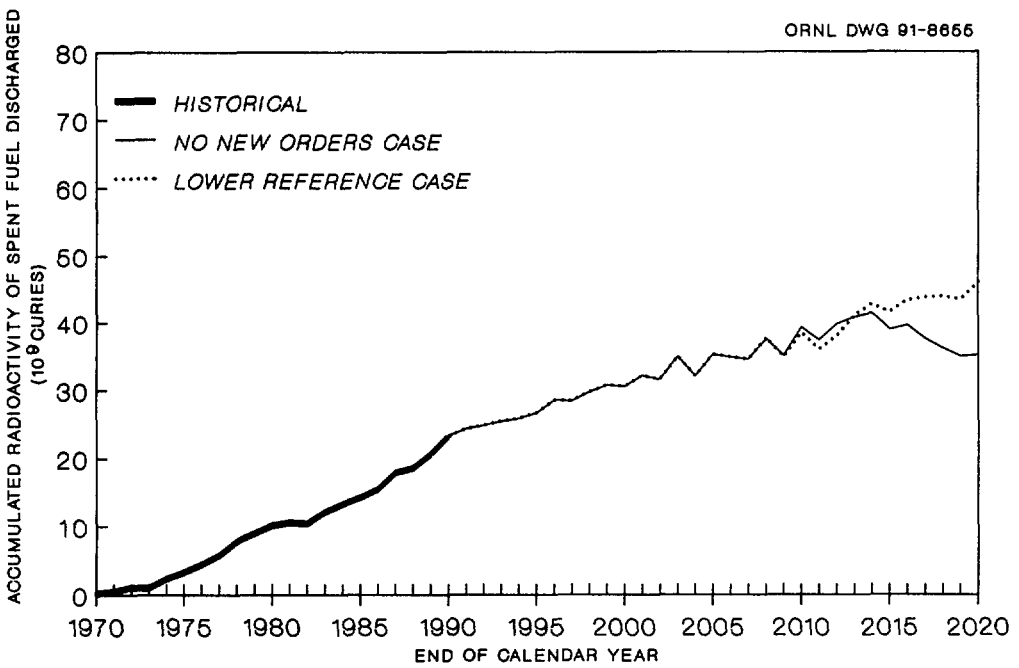


Fig. 1.3. Projected accumulated radioactivity of commercial spent fuel discharges for the DOE/EIA No New Orders and Lower Reference cases.

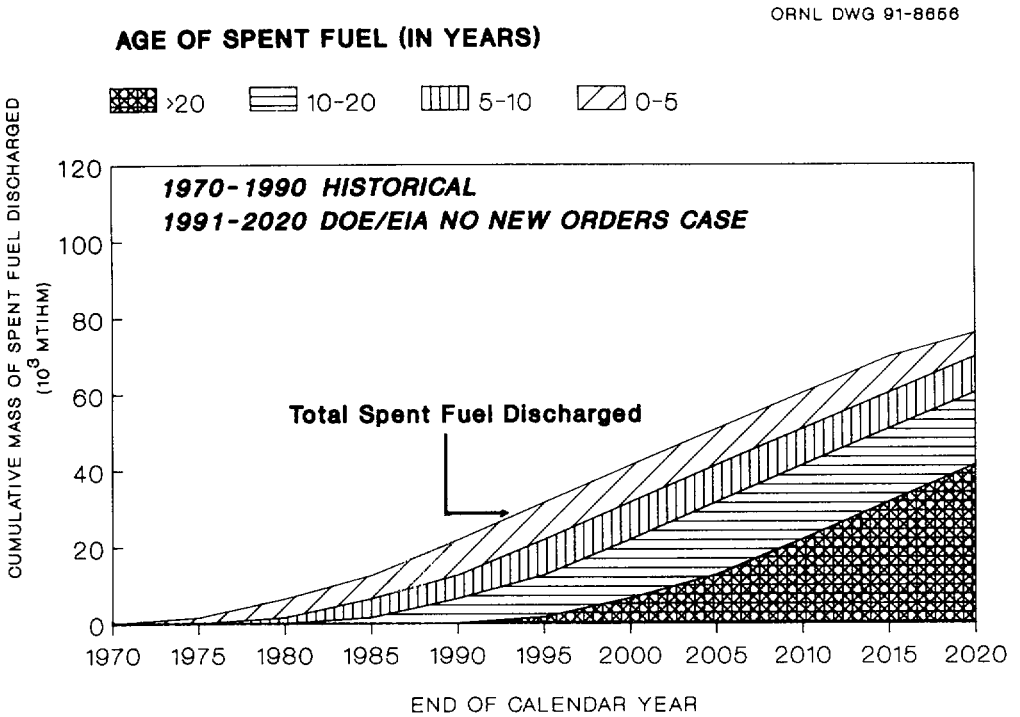


Fig. 1.4. Projected cumulative mass (MTIHM) of commercial spent fuel discharges for the DOE/EIA No New Orders Case.

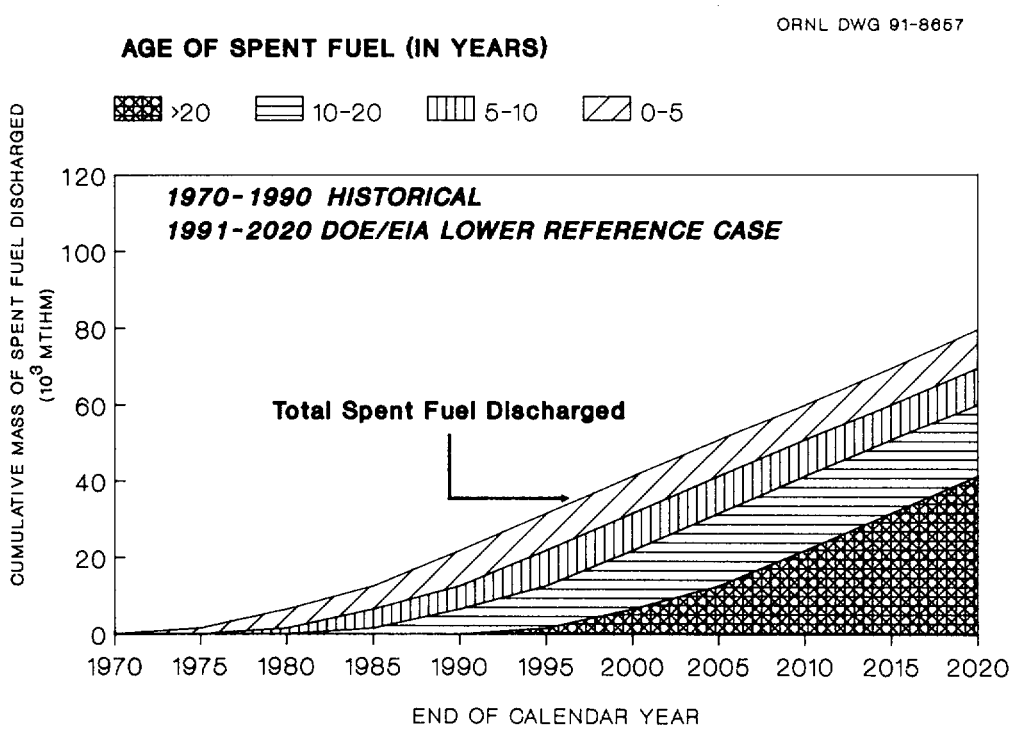


Fig. 1.5. Projected cumulative mass (MTIHM) of commercial spent fuel discharges for the DOE/EIA Lower Reference Case.

ORNL DWG 86-332

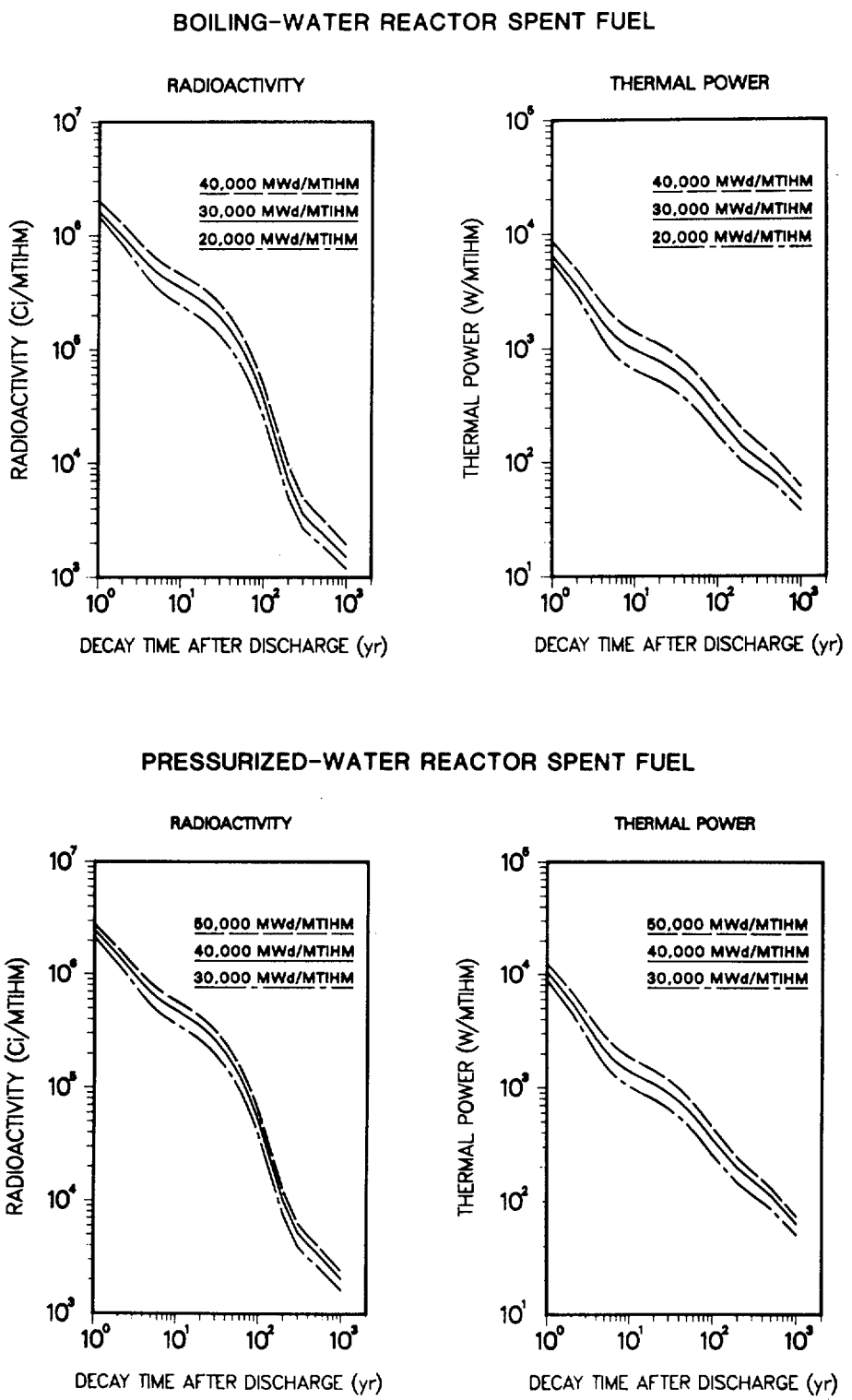


Fig. 1.6. Radioactivity and thermal power of 1 metric ton of heavy metal of BWR and PWR spent fuel as a function of burnup and time from reactor discharge.

Table 1.1. Historical and projected installed LWR electric power generating capacity for the DOE/EIA No New Orders and Lower Reference cases

End of calendar year	Historical capacity[a] [GW(e)]			End of calendar year	No New Orders Case projected capacity[b] [GW(e)]			Lower Reference Case projected capacity[c] [GW(e)]		
	BWR	PWR	Total		BWR	PWR	Total	BWR	PWR	Total
1960	0.1	0.2	0.3	1991	32.0	67.6	99.6	32.0	67.6	99.6
1961	0.1	0.2	0.3	1992	32.0	68.8	100.8	32.0	68.8	100.8
1962	0.1	0.2	0.4	1993	32.0	69.9	101.9	32.0	69.9	101.9
1963	0.1	0.2	0.4	1994	32.0	69.9	101.9	32.0	69.9	101.9
1964	0.1	0.2	0.4	1995	32.0	71.1	103.1	32.0	71.1	103.1
1965	0.1	0.2	0.4	1996	32.0	71.1	103.1	32.0	71.1	103.1
1966	0.1	0.2	0.4	1997	32.0	71.1	103.1	32.0	71.1	103.1
1967	0.1	1.3	1.4	1998	32.0	72.3	104.3	32.0	72.3	104.3
1968	0.2	1.2	1.4	1999	32.0	72.3	104.3	32.0	72.3	104.3
1969	0.8	1.7	2.6	2000	32.0	73.4	105.4	32.0	73.4	105.4
1970	2.9	2.9	5.8	2001	32.0	73.4	105.4	32.0	73.4	105.4
1971	4.3	3.7	8.0	2002	32.0	73.4	105.4	32.0	73.4	105.4
1972	7.0	6.5	13.5	2003	31.9	74.6	106.5	31.9	74.6	106.5
1973	8.1	14.1	22.1	2004	31.9	74.6	106.5	31.9	74.6	106.5
1974	13.3	19.4	32.7	2005	31.9	74.6	106.5	31.9	74.6	106.5
1975	15.0	23.3	38.3	2006	31.9	74.6	106.5	31.9	74.6	106.5
1976	16.8	27.9	44.7	2007	31.9	73.6	105.5	32.0	74.1	106.1
1977	16.8	30.4	47.2	2008	31.9	73.6	105.5	32.0	74.1	106.1
1978	17.6	32.2	49.8	2009	30.7	73.1	103.8	30.7	74.2	104.9
1979	17.6	32.2	49.8	2010	29.3	71.9	101.2	30.7	73.5	104.2
1980	17.6	34.3	51.9	2011	28.0	71.2	99.2	30.7	80.0	110.7
1981	17.6	38.6	56.2	2012	25.3	68.4	93.7	30.1	84.4	114.5
1982	18.7	40.5	59.2	2013	24.2	61.3	85.6	29.0	85.8	114.8
1983	19.7	43.6	63.3	2014	19.0	57.8	76.8	25.1	89.4	114.5
1984	24.2	45.8	70.0	2015	17.4	54.0	71.4	24.3	89.9	114.2
1985	26.8	51.7	78.5	2016	15.6	49.4	65.0	24.3	90.2	114.5
1986	28.9	55.2	84.1	2017	15.6	47.0	62.5	23.2	91.7	114.9
1987	31.8	60.8	92.6	2018	14.8	44.1	58.9	23.2	92.2	115.4
1988	31.8	63.1	94.9	2019	14.8	44.1	58.9	23.2	96.9	120.1
1989	33.8	64.1	97.9	2020	14.8	42.0	56.8	23.2	99.4	122.6
1990	32.9	66.7	99.6							

[a]Based on ref. 1.

[b]Data from ref. 3. Assumes (1) that no new reactors will be ordered and (2) that a few units currently under construction will be canceled.

[c]Data from ref. 3. Assumes basically the same criteria as given in footnote "b" except the case further assumes that any generating capacity lost due to reactor shutdown will be replaced.

Table 1.2. Projected cumulative mass of commercial spent fuel discharges for alternative DOE/EIA scenarios

End of calendar year	Cumulative spent fuel discharged, 10^3 MTIHM	
	No New Orders Case	Lower Reference Case
1990[a]	21.9	21.9
1991[b]	24.0	24.0
1992	25.9	25.9
1993	27.9	27.9
1994	29.7	29.7
1995	31.6	31.6
1996	33.7	33.7
1997	35.6	35.6
1998	37.5	37.5
1999	39.5	39.5
2000	41.3	41.3
2001	43.3	43.3
2002	45.1	45.1
2003	47.3	47.3
2004	48.8	48.8
2005	50.9	50.9
2006	52.7	52.7
2007	54.3	54.3
2008	56.5	56.5
2009	58.0	57.9
2010	60.3	60.1
2011	61.9	61.5
2012	64.0	63.3
2013	66.0	65.4
2014	68.2	67.8
2015	69.7	69.6
2016	71.4	71.7
2017	72.6	73.7
2018	73.8	75.7
2019	74.8	77.5
2020	75.9	79.6

[a]Reported historical data from ref. 1.
[b]Data for years 1991-2020 from ref. 4.

Table 1.3. Historical and projected mass, radioactivity, and thermal power of permanently discharged spent fuel by reactor type for the DOE/EIA No New Orders Case

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Boiling-water reactor			
1968	1	1	1	1	0.0	0.0
1969	10	10	39	39	0.2	0.2
1970	6	16	1	11	0.0	0.0
1971	64	80	190	197	0.7	0.8
1972	142	222	431	466	1.7	1.8
1973	95	317	350	442	1.4	1.7
1974	245	561	908	1,043	3.6	4.0
1975	226	787	921	1,218	3.7	4.7
1976	297	1,084	1,150	1,580	4.5	6.1
1977	383	1,467	1,566	2,129	6.2	8.2
1978	383	1,850	1,618	2,412	6.5	9.3
1979	400	2,250	1,734	2,728	7.1	10.5
1980	620	2,870	2,685	3,888	10.9	15.1
1981	459	3,329	2,014	3,664	8.2	14.0
1982	357	3,686	1,582	3,362	6.5	12.6
1983	491	4,177	2,218	4,015	9.1	15.1
1984	498	4,675	2,211	4,283	9.0	16.0
1985	510	5,185	2,225	4,497	9.1	16.7
1986	458	5,643	1,963	4,397	8.0	16.0
1987	699	6,343	2,919	5,407	11.7	19.8
1988	536	6,879	2,364	5,175	9.7	18.8
1989	715	7,593	3,090	6,036	12.6	22.1
1990	633	8,226	2,821	6,099	11.6	22.3
1991	700	8,900	3,000	6,500	12.5	23.9
1992	700	9,500	3,000	6,800	12.4	24.9
1993	600	10,100	2,800	6,800	11.6	24.8
1994	700	10,800	3,200	7,400	13.4	27.2
1995	600	11,400	2,800	7,400	11.8	26.8
1996	700	12,100	3,200	7,900	13.6	29.1
1997	700	12,800	3,500	8,600	14.9	31.6
1998	500	13,400	2,600	8,000	11.0	29.0
1999	800	14,200	3,800	9,200	16.1	33.9
2000	600	14,700	2,800	8,700	11.6	31.4
2001	500	15,200	2,400	8,300	10.2	29.8
2002	800	16,000	3,900	9,900	16.7	36.2
2003	500	16,600	2,600	9,100	11.2	33.0
2004	600	17,100	2,700	9,200	11.5	33.0
2005	800	17,900	3,800	10,400	16.1	37.9
2006	500	18,400	2,500	9,600	10.8	34.6
2007	600	19,000	2,900	9,900	12.5	35.8
2008	800	19,800	3,800	11,000	16.2	40.2
2009	500	20,300	2,600	10,200	10.7	36.6
2010	1,000	21,300	4,800	12,300	20.2	45.3
2011	500	21,800	2,500	10,800	10.5	38.7
2012	800	22,700	4,000	12,100	16.7	43.6
2013	400	23,100	2,000	10,500	8.5	37.0
2014	800	23,900	3,800	11,900	15.5	42.5
2015	500	24,400	2,300	10,800	9.4	37.8
2016	500	24,900	2,600	10,900	11.0	38.5
2017	200	25,200	1,200	9,500	5.1	32.9
2018	400	25,600	2,000	9,900	8.4	34.6
2019	200	25,800	1,200	9,200	5.1	31.7
2020	400	26,200	1,800	9,600	7.8	33.5

Table 1.3 (continued)

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^9 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Pressurized-water reactor			
1968	0	0	0	0	0.0	0.0
1969	0	0	0	0	0.0	0.0
1970	39	39	204	204	0.8	0.8
1971	44	83	247	296	1.0	1.2
1972	100	183	545	638	2.2	2.5
1973	67	250	374	571	1.5	2.2
1974	208	458	1,098	1,320	4.4	5.2
1975	322	780	1,683	2,098	6.7	8.2
1976	401	1,181	2,222	2,894	8.9	11.3
1977	467	1,648	2,660	3,677	10.8	14.5
1978	699	2,347	4,030	5,428	16.4	21.5
1979	722	3,069	4,190	6,258	17.1	24.7
1980	618	3,687	3,667	6,249	15.0	24.5
1981	676	4,363	4,025	6,888	16.5	26.9
1982	641	5,004	3,802	7,043	15.6	27.2
1983	773	5,777	4,595	8,084	18.9	31.2
1984	848	6,625	5,010	8,978	20.5	34.5
1985	870	7,495	5,247	9,703	21.6	37.3
1986	1,022	8,517	6,095	11,057	25.0	42.4
1987	1,153	9,671	6,911	12,514	28.4	48.0
1988	1,162	10,833	7,074	13,434	29.2	51.5
1989	1,256	12,089	7,585	14,629	31.2	55.9
1990	1,552	13,641	9,508	17,251	39.3	66.3
1991	1,400	15,100	9,000	17,900	37.2	68.6
1992	1,300	16,400	8,400	18,100	35.0	69.1
1993	1,300	17,700	8,400	18,700	35.3	71.0
1994	1,200	18,900	7,700	18,500	32.0	69.7
1995	1,300	20,200	8,200	19,400	34.5	73.0
1996	1,400	21,600	9,000	20,700	37.6	78.1
1997	1,200	22,700	7,400	20,000	31.2	74.6
1998	1,400	24,100	9,100	21,800	38.4	82.0
1999	1,200	25,400	8,000	21,500	33.6	80.4
2000	1,200	26,600	8,000	21,900	33.7	81.5
2001	1,500	28,100	9,600	23,900	40.5	89.6
2002	1,000	29,100	6,500	21,800	27.5	80.2
2003	1,700	30,700	10,900	25,900	46.0	97.3
2004	1,000	31,700	6,400	22,900	27.4	84.6
2005	1,300	33,000	8,900	24,900	37.7	93.0
2006	1,300	34,300	8,400	25,300	35.9	94.3
2007	1,100	35,400	7,300	24,600	31.1	91.4
2008	1,300	36,700	9,100	26,600	39.0	99.5
2009	1,000	37,700	6,500	24,900	28.0	92.1
2010	1,300	39,000	8,800	27,000	37.8	101.0
2011	1,100	40,100	7,600	26,600	32.6	99.2
2012	1,300	41,300	8,500	27,700	36.2	103.5
2013	1,600	42,900	10,500	30,300	44.4	113.9
2014	1,300	44,200	8,700	29,500	36.9	110.4
2015	1,100	45,300	7,200	28,300	30.5	104.8
2016	1,100	46,400	7,700	28,600	32.7	106.1
2017	1,000	47,500	6,900	28,100	29.4	103.6
2018	700	48,200	5,000	26,200	21.4	95.6
2019	800	49,000	5,100	25,800	22.0	93.9
2020	800	49,700	5,100	25,600	21.9	93.2

Table 1.3 (continued)

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Total			
1968	1	1	1	1	0.0	0.0
1969	10	10	39	39	0.2	0.2
1970	45	55	205	215	0.8	0.8
1971	108	163	438	492	1.7	1.9
1972	241	405	976	1,104	3.9	4.3
1973	162	567	724	1,013	2.9	3.9
1974	452	1,020	2,006	2,363	7.9	9.2
1975	547	1,567	2,603	3,316	10.3	12.9
1976	698	2,265	3,372	4,474	13.4	17.4
1977	850	3,115	4,225	5,805	17.0	22.6
1978	1,082	4,197	5,648	7,840	22.9	30.8
1979	1,122	5,319	5,924	8,987	24.1	35.2
1980	1,238	6,557	6,351	10,137	26.0	39.6
1981	1,135	7,692	6,039	10,552	24.7	40.9
1982	998	8,690	5,384	10,405	22.1	39.8
1983	1,264	9,954	6,813	12,099	28.0	46.3
1984	1,346	11,300	7,221	13,261	29.6	50.5
1985	1,380	12,680	7,472	14,200	30.7	53.9
1986	1,481	14,161	8,058	15,454	33.0	58.4
1987	1,853	16,013	9,830	17,921	40.1	67.9
1988	1,698	17,711	9,438	18,609	38.8	70.3
1989	1,971	19,683	10,675	20,665	43.8	78.0
1990	2,185	21,868	12,329	23,351	50.8	88.6
1991	2,100	24,000	12,000	24,400	49.7	92.5
1992	2,000	25,900	11,400	24,900	47.5	94.0
1993	1,900	27,900	11,200	25,500	46.9	95.9
1994	1,900	29,700	10,900	25,900	45.4	96.9
1995	1,900	31,600	11,100	26,700	46.3	99.8
1996	2,100	33,700	12,200	28,600	51.2	107.2
1997	1,900	35,600	11,000	28,500	46.1	106.1
1998	1,900	37,500	11,700	29,800	49.3	111.0
1999	2,000	39,500	11,800	30,800	49.6	114.3
2000	1,800	41,300	10,800	30,600	45.4	112.9
2001	2,000	43,300	12,000	32,200	50.7	119.5
2002	1,800	45,100	10,500	31,600	44.2	116.4
2003	2,200	47,300	13,500	35,000	57.2	130.2
2004	1,500	48,800	9,200	32,100	38.8	117.6
2005	2,100	50,900	12,600	35,300	53.8	130.9
2006	1,800	52,700	11,000	34,900	46.7	128.8
2007	1,700	54,300	10,200	34,600	43.5	127.2
2008	2,100	56,500	12,900	37,600	55.2	139.7
2009	1,500	58,000	9,100	35,100	38.7	128.7
2010	2,300	60,300	13,600	39,300	58.0	146.3
2011	1,700	61,900	10,100	37,400	43.2	137.9
2012	2,100	64,000	12,500	39,800	52.9	147.2
2013	2,000	66,000	12,500	40,800	52.8	150.9
2014	2,100	68,200	12,500	41,400	52.4	152.9
2015	1,500	69,700	9,400	39,000	39.9	142.5
2016	1,700	71,400	10,300	39,600	43.7	144.6
2017	1,200	72,600	8,000	37,600	34.5	136.5
2018	1,100	73,800	7,000	36,200	29.7	130.2
2019	1,000	74,800	6,300	35,000	27.2	125.6
2020	1,100	75,900	6,900	35,200	29.6	126.7

[a]Ref. 1 (1968-1990).
[b]Ref. 4 (1991-2020). Assumes no future reprocessing.

Table 1.4. Historical and projected mass, radioactivity, and thermal power of permanently discharged spent fuel by reactor type for the DOE/EIA Lower Reference Case

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Boiling-water reactor			
1968	1	1	1	1	0.0	0.0
1969	10	10	39	39	0.2	0.2
1970	6	16	1	11	0.0	0.0
1971	64	80	190	197	0.7	0.8
1972	142	222	431	466	1.7	1.8
1973	95	317	350	442	1.4	1.7
1974	245	561	908	1,043	3.6	4.0
1975	226	787	921	1,218	3.7	4.7
1976	297	1,084	1,150	1,580	4.5	6.1
1977	383	1,467	1,566	2,129	6.2	8.2
1978	383	1,850	1,618	2,412	6.5	9.3
1979	400	2,250	1,734	2,728	7.1	10.5
1980	620	2,870	2,685	3,888	10.9	15.1
1981	459	3,329	2,014	3,664	8.2	14.0
1982	357	3,686	1,582	3,362	6.5	12.6
1983	491	4,177	2,218	4,015	9.1	15.1
1984	498	4,675	2,211	4,283	9.0	16.0
1985	510	5,185	2,225	4,497	9.1	16.7
1986	458	5,643	1,963	4,397	8.0	16.0
1987	699	6,343	2,919	5,407	11.7	19.8
1988	536	6,879	2,364	5,175	9.7	18.8
1989	715	7,593	3,090	6,036	12.6	22.1
1990	633	8,226	2,821	6,099	11.6	22.3
1991	700	8,900	3,000	6,500	12.5	23.9
1992	700	9,500	3,000	6,800	12.4	24.9
1993	600	10,100	2,800	6,800	11.6	24.8
1994	700	10,800	3,200	7,400	13.4	27.2
1995	600	11,400	2,800	7,400	11.8	26.8
1996	700	12,100	3,200	7,900	13.6	29.1
1997	700	12,800	3,500	8,600	14.9	31.6
1998	500	13,400	2,600	8,000	11.0	29.0
1999	800	14,200	3,800	9,200	16.1	33.9
2000	600	14,700	2,800	8,700	11.6	31.4
2001	500	15,200	2,400	8,300	10.2	29.8
2002	800	16,000	3,900	9,900	16.7	36.2
2003	500	16,600	2,600	9,100	11.2	33.0
2004	600	17,100	2,700	9,200	11.5	33.0
2005	800	17,900	3,800	10,400	16.1	37.9
2006	500	18,400	2,500	9,600	10.8	34.6
2007	600	19,000	2,900	9,900	12.4	35.8
2008	800	19,800	3,800	11,000	16.1	40.1
2009	500	20,300	2,600	10,200	10.7	36.5
2010	800	21,100	4,100	11,600	17.4	42.6
2011	300	21,400	1,500	9,600	6.5	33.9
2012	600	22,100	3,100	10,700	12.9	38.3
2013	500	22,600	2,500	10,400	10.3	36.8
2014	800	23,300	3,600	11,500	15.1	41.5
2015	400	23,800	2,100	10,400	8.9	36.8
2016	500	24,300	2,500	10,600	10.6	37.6
2017	500	24,800	2,500	10,700	10.6	38.0
2018	500	25,200	2,300	10,500	9.9	37.6
2019	400	25,600	2,100	10,400	9.0	36.9
2020	500	26,200	2,600	10,900	11.3	39.2

Table 1.4 (continued)

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Pressurized-water reactor			
1968	0	0	0	0	0.0	0.0
1969	0	0	0	0	0.0	0.0
1970	39	39	204	204	0.8	0.8
1971	44	83	247	296	1.0	1.2
1972	100	183	545	638	2.2	2.5
1973	67	250	374	571	1.5	2.2
1974	208	458	1,098	1,320	4.4	5.2
1975	322	780	1,683	2,098	6.7	8.2
1976	401	1,181	2,222	2,894	8.9	11.3
1977	467	1,648	2,660	3,677	10.8	14.5
1978	699	2,347	4,030	5,428	16.4	21.5
1979	722	3,069	4,190	6,258	17.1	24.7
1980	618	3,687	3,667	6,249	15.0	24.5
1981	676	4,363	4,025	6,888	16.5	26.9
1982	641	5,004	3,802	7,043	15.6	27.2
1983	773	5,777	4,595	8,084	18.9	31.2
1984	848	6,625	5,010	8,978	20.5	34.5
1985	870	7,495	5,247	9,703	21.6	37.3
1986	1,022	8,517	6,095	11,057	25.0	42.4
1987	1,153	9,671	6,911	12,514	28.4	48.0
1988	1,162	10,833	7,074	13,434	29.2	51.5
1989	1,256	12,089	7,585	14,629	31.2	55.9
1990	1,552	13,641	9,508	17,251	39.3	66.3
1991	1,400	15,100	9,000	17,900	37.2	68.6
1992	1,300	16,400	8,400	18,100	35.0	69.1
1993	1,300	17,700	8,400	18,700	35.3	71.0
1994	1,200	18,900	7,700	18,500	32.0	69.7
1995	1,300	20,200	8,200	19,400	34.5	73.0
1996	1,400	21,600	9,000	20,700	37.6	78.1
1997	1,200	22,700	7,400	20,000	31.2	74.6
1998	1,400	24,100	9,100	21,800	38.4	82.0
1999	1,200	25,400	8,000	21,500	33.6	80.4
2000	1,200	26,600	8,000	21,900	33.7	81.5
2001	1,500	28,100	9,600	23,900	40.5	89.6
2002	1,000	29,100	6,500	21,800	27.5	80.2
2003	1,700	30,700	10,900	25,900	46.0	97.3
2004	1,000	31,700	6,400	22,900	27.4	84.6
2005	1,300	33,000	8,900	24,900	37.7	93.0
2006	1,300	34,300	8,400	25,300	35.9	94.3
2007	1,100	35,300	7,300	24,600	31.1	91.4
2008	1,400	36,700	9,200	26,700	39.5	100.1
2009	900	37,600	6,300	24,700	27.1	91.5
2010	1,300	38,900	8,800	26,900	37.6	100.7
2011	1,100	40,000	7,400	26,400	31.6	98.2
2012	1,200	41,200	8,100	27,300	35.1	102.1
2013	1,700	42,900	10,900	30,600	46.1	115.4
2014	1,500	44,400	10,200	31,100	43.2	117.3
2015	1,400	45,800	9,400	31,000	40.1	116.6
2016	1,600	47,400	10,800	32,700	46.0	123.6
2017	1,500	49,000	10,300	33,100	44.0	125.1
2018	1,500	50,400	10,000	33,400	42.7	126.0
2019	1,400	51,800	9,200	33,100	39.5	124.4
2020	1,600	53,400	11,000	35,000	47.0	132.7

Table 1.4 (continued)

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Total			
1968	1	1	1	1	0.0	0.0
1969	10	10	39	39	0.2	0.2
1970	45	55	205	215	0.8	0.8
1971	108	163	438	492	1.7	1.9
1972	241	405	976	1,104	3.9	4.3
1973	162	567	724	1,013	2.9	3.9
1974	452	1,020	2,006	2,363	7.9	9.2
1975	547	1,567	2,603	3,316	10.3	12.9
1976	698	2,265	3,372	4,474	13.4	17.4
1977	850	3,115	4,225	5,805	17.0	22.6
1978	1,082	4,197	5,648	7,840	22.9	30.8
1979	1,122	5,319	5,924	8,987	24.1	35.2
1980	1,238	6,557	6,351	10,137	26.0	39.6
1981	1,135	7,692	6,039	10,552	24.7	40.9
1982	998	8,690	5,384	10,405	22.1	39.8
1983	1,264	9,954	6,813	12,099	28.0	46.3
1984	1,346	11,300	7,221	13,261	29.6	50.5
1985	1,380	12,680	7,472	14,200	30.7	53.9
1986	1,481	14,161	8,058	15,454	33.0	58.4
1987	1,853	16,013	9,830	17,921	40.1	67.9
1988	1,698	17,711	9,438	18,609	38.8	70.3
1989	1,971	19,683	10,675	20,665	43.8	78.0
1990	2,185	21,868	12,329	23,351	50.8	88.6
1991	2,100	24,000	12,000	24,400	49.7	92.5
1992	2,000	25,900	11,400	24,900	47.5	94.0
1993	1,900	27,900	11,200	25,500	46.9	95.9
1994	1,900	29,700	10,900	25,900	45.4	96.9
1995	1,900	31,600	11,100	26,700	46.3	99.8
1996	2,100	33,700	12,200	28,600	51.2	107.2
1997	1,900	35,600	11,000	28,500	46.1	106.1
1998	1,900	37,500	11,700	29,800	49.3	111.0
1999	2,000	39,500	11,800	30,800	49.6	114.3
2000	1,800	41,300	10,800	30,600	45.4	112.9
2001	2,000	43,300	12,000	32,200	50.7	119.5
2002	1,800	45,100	10,500	31,600	44.2	116.4
2003	2,200	47,300	13,500	35,000	57.2	130.2
2004	1,500	48,800	9,200	32,100	38.8	117.6
2005	2,100	50,900	12,600	35,300	53.8	130.9
2006	1,800	52,700	11,000	34,900	46.7	128.9
2007	1,700	54,300	10,200	34,600	43.6	127.3
2008	2,100	56,500	13,000	37,700	55.6	140.2
2009	1,500	57,900	8,900	34,900	37.8	128.0
2010	2,100	60,100	12,800	38,500	55.0	143.3
2011	1,400	61,500	8,900	36,000	38.1	132.1
2012	1,800	63,300	11,200	38,000	48.0	140.4
2013	2,200	65,400	13,400	41,000	56.4	152.3
2014	2,300	67,800	13,800	42,700	58.3	158.8
2015	1,900	69,600	11,600	41,500	49.0	153.4
2016	2,100	71,700	13,300	43,300	56.5	161.2
2017	2,000	73,700	12,800	43,700	54.5	163.0
2018	1,900	75,700	12,300	43,900	52.6	163.6
2019	1,800	77,500	11,300	43,400	48.5	161.4
2020	2,100	79,600	13,600	45,900	58.3	171.9

[a]Ref. 1 (1968-1990).
[b]Ref. 4 (1991-2020). Assumes no future reprocessing.

Table 1.5. Projected number of permanently discharged LWR spent fuel assemblies for the DOE/EIA No New Orders Case

End of calendar year	BWR		PWR		Total	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1990[a]	3,486	45,290	3,594	31,966	7,080	77,256
1991[b]	3,700	49,000	3,300	35,300	7,000	84,200
1992	3,700	52,600	3,100	38,400	6,800	91,000
1993	3,300	55,900	3,100	41,500	6,400	97,400
1994	3,800	59,800	2,800	44,300	6,600	104,000
1995	3,300	63,100	3,000	47,200	6,300	110,300
1996	3,800	67,000	3,200	50,400	7,100	117,400
1997	4,200	71,100	2,700	53,100	6,900	124,300
1998	3,000	74,100	3,300	56,400	6,300	130,500
1999	4,500	78,600	2,900	59,300	7,300	137,900
2000	3,200	81,800	2,900	62,200	6,200	144,000
2001	2,800	84,600	3,400	65,600	6,200	150,200
2002	4,500	89,100	2,300	67,900	6,900	157,000
2003	3,000	92,100	3,800	71,700	6,800	163,900
2004	3,100	95,200	2,300	74,000	5,300	169,200
2005	4,300	99,600	3,100	77,100	7,400	176,600
2006	2,900	102,400	2,900	80,000	5,800	182,400
2007	3,400	105,800	2,500	82,500	5,900	188,300
2008	4,300	110,100	3,100	85,700	7,500	195,800
2009	3,100	113,200	2,200	87,900	5,300	201,100
2010	5,600	118,800	3,000	90,900	8,600	209,700
2011	3,000	121,800	2,600	93,500	5,600	215,300
2012	4,700	126,600	2,900	96,400	7,600	223,000
2013	2,300	128,900	3,600	100,100	6,000	228,900
2014	4,600	133,500	3,000	103,000	7,600	236,500
2015	2,600	136,100	2,500	105,500	5,100	241,600
2016	3,000	139,100	2,600	108,200	5,600	247,200
2017	1,300	140,400	2,300	110,500	3,600	250,800
2018	2,200	142,600	1,700	112,200	3,900	254,800
2019	1,300	143,900	1,700	113,900	3,000	257,800
2020	2,000	145,900	1,700	115,600	3,700	261,500

[a]Reported historical data (ref. 1).

[b]Data for years 1991-2020 are based on 105.4 GW(e) installed in the year 2000 and 56.8 GW(e) installed in the year 2020 (ref. 3). Number of projected fuel assemblies reported has been rounded to the nearest 100 (ref. 4).

Table 1.6. Projected number of permanently discharged LWR spent fuel assemblies for the DOE/EIA Lower Reference Case

End of calendar year	BWR		PWR		Total	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1990[a]	3,486	45,290	3,594	31,966	7,080	77,256
1991[b]	3,700	49,000	3,300	35,300	7,000	84,200
1992	3,700	52,600	3,100	38,400	6,800	91,000
1993	3,300	55,900	3,100	41,500	6,400	97,400
1994	3,800	59,800	2,800	44,300	6,600	104,000
1995	3,300	63,100	3,000	47,200	6,300	110,300
1996	3,800	67,000	3,200	50,400	7,100	117,400
1997	4,200	71,100	2,700	53,100	6,900	124,300
1998	3,000	74,100	3,300	56,400	6,300	130,500
1999	4,500	78,600	2,900	59,300	7,300	137,900
2000	3,200	81,800	2,900	62,200	6,200	144,000
2001	2,800	84,600	3,400	65,600	6,200	150,200
2002	4,500	89,100	2,300	67,900	6,900	157,000
2003	3,000	92,100	3,800	71,700	6,800	163,900
2004	3,100	95,200	2,300	74,000	5,300	169,200
2005	4,300	99,600	3,100	77,100	7,400	176,600
2006	2,900	102,400	2,900	80,000	5,800	182,400
2007	3,400	105,800	2,500	82,500	5,800	188,300
2008	4,300	110,100	3,200	85,700	7,500	195,800
2009	3,100	113,100	2,100	87,800	5,200	200,900
2010	4,600	117,700	3,000	90,800	7,600	208,500
2011	1,700	119,500	2,500	93,300	4,300	212,800
2012	3,500	123,000	2,700	96,100	6,300	219,000
2013	2,800	125,800	3,800	99,800	6,600	225,700
2014	4,300	130,200	3,500	103,300	7,900	233,500
2015	2,400	132,600	3,300	106,600	5,700	239,200
2016	2,700	135,300	3,700	110,300	6,500	245,600
2017	2,900	138,200	3,500	113,800	6,400	252,000
2018	2,600	140,800	3,500	117,300	6,000	258,000
2019	2,300	143,100	3,200	120,400	5,500	263,500
2020	2,900	146,100	3,700	124,100	6,600	270,200

[a]Reported historical data (ref. 1).

[b]Data for years 1991-2020 are based on 105.4 GW(e) installed in the year 2000 and 122.6 GW(e) installed in the year 2020 (ref. 3). Number of projected fuel assemblies reported has been rounded to the nearest 100 (ref. 4).

Table 1.7. Historical and projected spent fuel discharged from the Fort St. Vrain HTGR[a]

End of calendar year	Number of fuel assemblies discharged		Mass of fuel discharged (MTIHM)	
	Annual	Cumulative	Annual	Cumulative
1979	246[b]	246	2.80	2.80
1980	0	246	0.00	2.80
1981	240	486	2.77	5.57
1982	0	486	0.00	5.57
1983	0	486	0.00	5.57
1984	240	726	2.85	8.42
1985	0	726	0.00	8.42
1986	0	726	0.00	8.42
1987	0	726	0.00	8.42
1988	0	726[c]	0.00	8.42
1989	126[d]	852	1.32	9.74
1990	332[d]	1,184	3.49	13.23
1991	1,024	2,208	10.77	24.00

[a]Based on ref. 8.

[b]This refueling replaced 246 spent fuel elements made up of 240 standard fuel elements and 6 fuel test elements.

[c]All spent fuel discharged prior to December 31, 1988, is located at the ICPP (see Table C.6 of Appendix C).

[d]Fuel removed from the core in 1989 and 1990 remains on-site in temporary storage wells until shipment to the ICPP can be accomplished or an independent spent fuel storage installation is built for extended on-site storage.

Table 1.8. IDB reference characteristics of LWR fuel assemblies

Characteristics	BWR[a]	PWR[b]
Overall assembly length, m	4.470	4.059
Cross section, cm	13.9 x 13.9	21.4 x 21.4
Fuel rod length, m	4.064	3.851
Active fuel height, m	3.759	3.658
Fuel rod outer diameter, cm	1.252	0.950
Fuel rod array	8 x 8	17 x 17
Fuel rods per assembly	63	264
Assembly total weight, kg	319.9	657.9
Uranium/assembly, kg	183.3	461.4
UO_2/assembly, kg	208.0	523.4
Zircaloy/assembly, kg	103.3[c]	108.4[d]
Hardware/assembly, kg	8.6[e]	26.1[f]
Total metal/assembly, kg	111.9	134.5
Nominal volume/assembly, m^3	0.0864[g]	0.186[g]

[a]Ref. 9.

[b]Ref. 10.

[c]Includes Zircaloy fuel-rod spacers and fuel channel.

[d]Includes Zircaloy control-rod guide thimbles.

[e]Includes stainless steel tie-plates, Inconel springs, and plenum springs.

[f]Includes stainless steel nozzles and Inconel-718 grids.

[g]Based on overall outside dimension. Includes spacing between the stacked fuel rods of an assembly.

Table 1.9. Historical mass of commercial BWR spent fuel discharged at various ranges of burnup[a,b]

End of calendar year	Annual mass of discharged spent fuel for various burnup ranges, MTIHM									Total annual mass over all burnup ranges (MTIHM)
	0-5,000[c]	5,001-10,000	10,001-15,000	15,001-20,000	20,001-25,000	25,001-30,000	30,001-35,000	35,001-40,000	40,001-45,000	
1968	0.6									0.6
1969		1.2	1.0	7.3	0.2	0.1				9.8
1970	5.6									5.6
1971	41.5	8.1	2.8	10.0	1.6					64.0
1972	97.9	12.1	27.6	4.0						141.5
1973	9.5	16.7	31.0	36.4	1.5	0.1				95.2
1974		78.4	117.7	44.7	3.8					244.6
1975	0.3	1.7	62.0	136.5	25.3					225.7
1976	0.9	67.1	110.0	116.9	2.3					297.1
1977		48.0	40.3	235.0	58.9	0.7				382.9
1978	6.3	32.4	13.1	84.2	232.0	15.2				383.2
1979			18.6	108.7	149.2	123.1	0.3			399.8
1980	14.0	0.4	0.6	93.3	413.3	87.6	10.7			619.9
1981		0.2	0.2	58.1	265.4	133.3	0.7	0.7		458.7
1982		0.2	4.6	25.6	138.5	173.6	13.8	0.6	0.4	357.2
1983			0.9	2.9	113.5	337.8	35.7	0.4		491.3
1984		7.9	43.0	0.3	136.2	239.5	70.8		0.4	498.0
1985	16.9	42.5	18.3	35.8	101.4	284.6	10.2		0.2	510.1
1986	50.8	32.4	42.5	72.5	63.0	159.4	37.3	0.4		458.2
1987	136.1	33.4	68.8	40.8	132.1	279.8	8.0		0.4	699.4
1988	17.0	24.6	1.7	43.9	176.1	237.4	35.0			535.8
1989	47.8	20.6	64.7	72.0	220.4	214.3	74.4	0.7		714.9
1990	17.0		62.0	106.1	40.1	287.1	119.1	1.6		633.0

[a]Based on ref. 1.
[b]Does not include commercial spent fuel reprocessed at WVDP.
[c]Burnup range is given in units of MWd/MTIHM.

Table 1.10. Historical mass of commercial PWR spent fuel discharged at various ranges of burnup[a,b]

End of calendar year	Annual mass of discharged spent fuel for various burnup ranges, MTIHM												Total annual mass over all burnup ranges (MTIHM)
	0-5,000[c]	5,001-10,000	10,001-15,000	15,001-20,000	20,001-25,000	25,001-30,000	30,001-35,000	35,001-40,000	40,001-45,000	45,001-50,000	50,001-55,000	55,001-60,000	
1970			1.7	37.3									39.0
1971		4.6			6.2	33.7							44.5
1972			11.9	29.3	27.8	8.9	22.1						99.9
1973				26.2		33.3	7.6						67.1
1974	7.4	1.5	86.4	13.6	40.5	57.2	1.1						207.7
1975	2.7	42.6	95.0	48.2	84.8	25.3	23.1						321.8
1976			5.6	194.2	82.4	63.3	55.4						401.0
1977			2.8	108.3	117.7	135.6	87.1	15.4					466.9
1978		1.4	47.9	89.8	39.6	336.9	121.9	61.2	0.4				699.0
1979			31.0	109.4	64.0	232.3	234.7	50.1	0.5				722.1
1980			0.4		62.6	244.6	282.0	26.3	2.0				618.1
1981			17.2	1.9	25.8	228.5	353.0	48.2	1.3				675.9
1982			1.8	81.1	80.9	57.8	297.1	117.4	2.7	0.4	1.3	0.9	641.3
1983		5.5	4.5	80.6	44.2	176.4	321.6	134.6	5.4		0.5		773.1
1984			58.4	45.2	56.3	201.3	378.8	103.5	4.1				847.6
1985				49.4	13.6	224.4	342.9	215.0	24.2	0.4			870.0
1986		0.8	27.6	132.4	22.9	187.4	343.0	270.7	35.0	1.3	1.3		1,022.5
1987			27.2	133.6	82.3	133.8	423.5	328.2	24.4				1,153.1
1988				109.2	25.7	142.1	392.3	403.9	84.8	2.1	0.4	2.0	1,162.5
1989		25.9	50.7	126.4	23.5	156.2	342.7	428.0	90.6	11.8		0.4	1,256.2
1990			40.4	89.8	17.7	230.2	439.1	572.9	159.0	2.9	0.3		1,552.2

[a]Based on ref. 1.
[b]Does not include commercial spent fuel reprocessed at WVDP.
[c]Burnup range is given in units of MWd/MTIHM.

ORNL PHOTO 7966-91

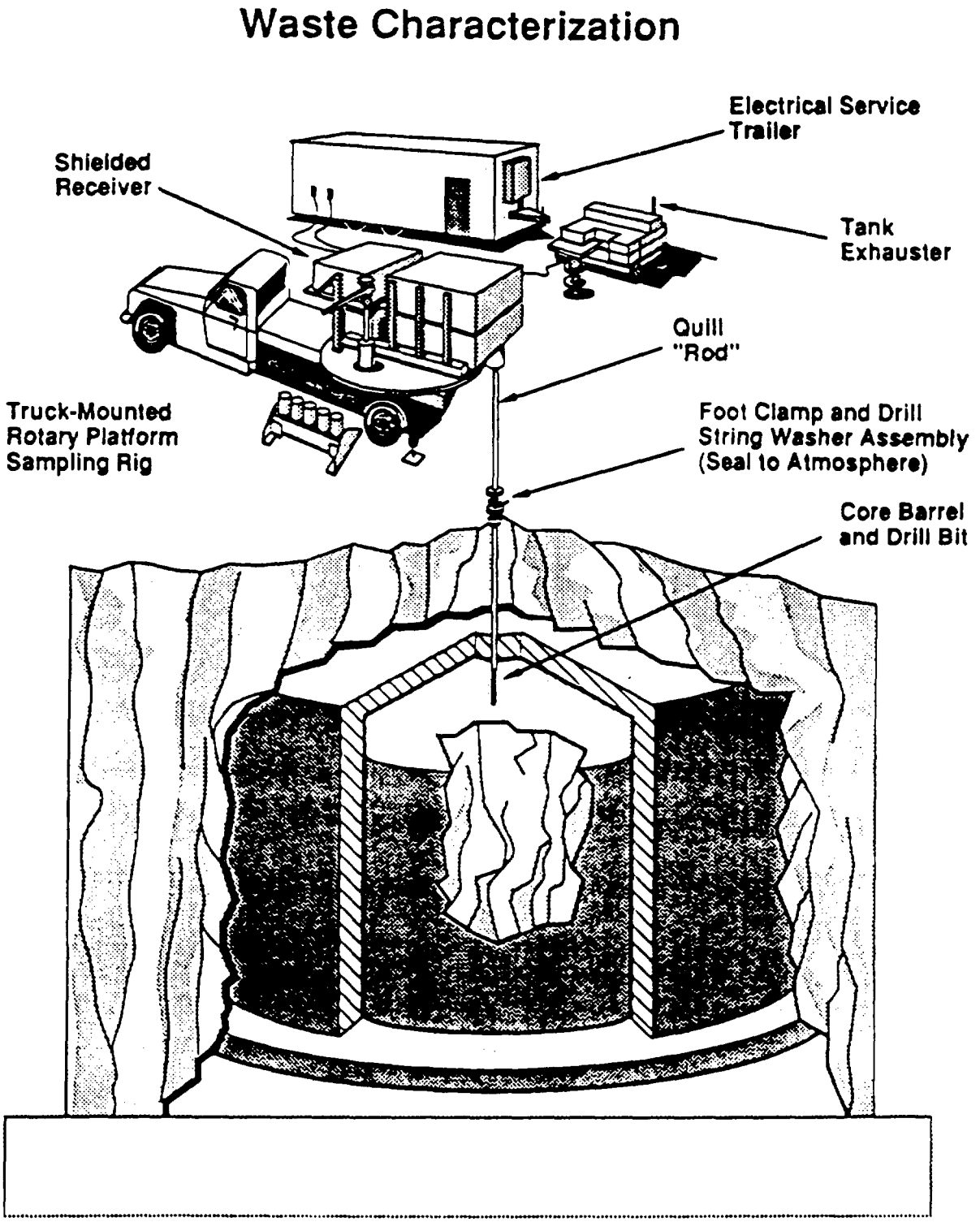


Photo 2.1. Methodology used at the Hanford Site for collecting a core sample from the solids layer in a typical single-shell or double-shell high-level waste tank. (Courtesy of the Westinghouse Hanford Company, Richland, Washington.)

2. HIGH-LEVEL WASTE

2.1 INTRODUCTION

High-level waste (HLW), which is generated by the reprocessing of spent reactor fuel and irradiated targets, generally contains more than 99% of the nonvolatile fission products produced in the fuel or targets during reactor operation. The HLW from a facility that recovers uranium and plutonium contains approximately 0.5% of these elements, while the HLW from a facility that recovers only uranium contains approximately 0.5% of the uranium and essentially all of the plutonium. Most of the present U.S. inventory of HLW is the result of DOE activities and is stored at the Savannah River Site (SRS), Idaho National Engineering Laboratory (INEL) [at the Idaho Chemical Processing Plant (ICPP)], and Hanford Site (HANF). A small amount of commercial HLW was generated at the Nuclear Fuel Services (NFS) Plant near West Valley, New York, during 1966–1972. That facility (located on land leased from the state of New York) is now referred to as the West Valley Demonstration Project (WVDP) and is the responsibility of the DOE Field Office, Idaho, West Valley Demonstration Project Office. West Valley Nuclear Services, Inc. (a subsidiary of Westinghouse Electric Corporation), is the prime contractor and site operator. The prime contractor and site operator for HLW at SRS is Westinghouse Savannah River Company; for INEL (the ICPP) is Westinghouse Idaho Nuclear Company, Inc.; and for HANF is Westinghouse Hanford Company (all subsidiaries of Westinghouse Electric Corporation). The historical/projected HLW inventories presented here (except for HLW solidified in glass or ceramic forms) are for wastes in interim storage. These wastes have already undergone one or more treatment steps (e.g., neutralization, precipitation, decantation, or evaporation) and are not as generated. Their volumes depend strongly on the steps to which they are subjected. Most of these wastes will require incorporation into a stable, solid medium (e.g., glass) for final disposal. Data on the volume, radioactivity, distribution, and location of HLW (through 1990) are shown in Figs. 2.1–2.4. Present (and projected) HLW operations at these sites are depicted in Figs. 2.5–2.8.

The DOE HLW at INEL (Fig. 2.6), which is stored at the ICPP, results from the reprocessing of nuclear fuels from naval propulsion reactors and special research and test reactors. The acidic liquid portion of this waste is stored in tanks, although the bulk of this material has been converted to a stable, granular solid (calcine).

At SRS (Fig. 2.5) and HANF (Fig. 2.7), the acidic liquid waste from reprocessing production reactor fuel has been made alkaline with caustic soda and stored in tanks. During storage, these alkaline wastes separate into two phases: liquid and sludge. When the liquid phase is volume reduced by evaporation, a third phase called salt cake is formed in those tanks holding evaporator concentrates (see Fig. 2.5). The relative proportions of liquid and salt cake depend upon how much water is removed by waste evaporators during interim waste management operations. The condensed water at HANF is sent to a double-lined surface impoundment. At SRS (Fig. 2.5), the condensate is sent to the Effluent Treatment Facility where it is treated and discharged to the environment. Also at SRS (Fig. A.10 in Appendix A), the processing of salt cake for future glassmaking generates a waste called precipitate. At HANF, all the wastes contained in double-shell tanks consist of mixtures of HLW, TRU waste, and several LLWs (Fig. 2.7), which have unique rheological properties and are referred to as slurry. In HANF storage practice, the double-shell tanks are managed as if they contain HLW. Thus, their contents are included in the HLW inventory.

The commercial HLW at WVDP consists of both alkaline and acidic wastes (Fig. 2.8); the alkaline waste was generated by reprocessing of commercial power reactor fuels and Hanford N-Reactor fuels, while the acidic waste was generated by reprocessing a small amount of commercial fuel containing thorium. Also at WVDP, the processing of liquid waste for future glassmaking generates a granular solid waste which is a zeolite loaded with radioactive cesium (Fig. 2.8).

The historical and projected inventories of HLW that is stored in tanks, bins, and capsules are presented in Table 2.1. Projected inventories of HLW that is incorporated into glass are given in Table 2.2. A year-by-year estimate of the number of HLW canisters, by source, is presented in Table 2.3. The 1988 estimate of DOE HLW canister totals, as required for repository disposal costs, is presented in Table 2.4. The volume and radioactivity of HLW in storage at the end of 1990 are given in Tables 2.5 and Table 2.6, respectively. Historical and projected volume,

radioactivity, and thermal power data for DOE and commercial HLW are given in Tables 2.7–2.9. The data for DOE sites represent a summary of information obtained from each of the sites.[1-3] The information on commercial HLW at WVDP was taken from data given in ref. 4.

2.2 INVENTORIES

Inventories of HLW at the various DOE sites and the WVDP through 1990 are presented in this section. Significant changes affecting HLW inventories are shown in Table 2.10.

2.2.1 HLW Inventories at SRS (DOE)

Approximately 131,700 m^3 of alkaline HLW that has accumulated at the SRS during the past three to four decades is being stored in underground, high-integrity, double-walled, carbon-steel tanks. The current inventories (Tables 2.5 and 2.6) include alkaline liquid (61,300 m^3), sludge (14,800 m^3), salt cake (55,500 m^3), and precipitate (125 m^3) that were generated primarily by the PUREX reprocessing of nuclear fuels and targets from production reactors. Most of the waste, as generated, is acidic liquid, and the sludge is formed during subsequent treatment with caustic and during aging. Salt cake results when the supernatant liquor is concentrated in evaporators. Precipitate results when salt cake is treated by the in-tank precipitation process.

2.2.2 HLW Inventories at INEL (DOE)

The 12,000 m^3 of HLW stored at INEL (at the ICPP) consists of 8,500 m^3 of liquid waste and 3,500 m^3 of calcine (Tables 2.5 and 2.6). Liquid HLW is generated at ICPP primarily by the reprocessing of spent fuel from naval propulsion nuclear reactors and reactor testing programs; a small amount is generated by reprocessing fuel from research reactors. This acidic liquid waste is stored in underground stainless steel tanks that are housed in concrete vaults. The waste is then converted to a calcine and stored retrievably in stainless steel bins that are housed in reinforced concrete vaults.

2.2.3 HLW Inventories at HANF (DOE)

The 253,600 m^3 of alkaline HLW stored at HANF is categorized as liquid (26,400 m^3), sludge (46,000 m^3), and salt cake (93,000 m^3) that are stored in single-shell tanks and as slurry (88,200 m^3) that is stored in double-shell tanks. This waste, which has been accumulating since 1944, was generated by the reprocessing of production reactor fuel for the recovery of plutonium, uranium, and neptunium for defense and other national programs. This reprocessing was suspended from 1972 until November 1983. Most of the high-heat-emitting isotopes (^{90}Sr and ^{137}Cs, plus their daughters) were removed from the old waste, converted to solids (strontium fluoride and cesium chloride), placed in double-walled capsules, and stored in a water basin. At present, 1,345 cesium capsules (2.48 m^3) and 597 strontium capsules (1.06 m^3) are stored in the basin. The liquid, sludge, salt-cake, and slurry wastes are stored in underground concrete tanks with carbon-steel liners. Current inventories of these wastes at HANF are listed in Tables 2.5 and 2.6.

2.2.4 HLW Inventories at WVDP (Commercial)

Reprocessing at the NFS plant was terminated in 1972, and no additional HLW has been generated since that time. As of December 31, 1990, the 1,231 m^3 of HLW stored at WVDP consists of 1,136 m^3 of alkaline waste (1,090 m^3 of liquid plus 46 m^3 of sludge), 50 m^3 of acidic waste, and 45 m^3 of an inorganic ion-exchange material (a zeolite) loaded with radioactive cesium (^{134}Cs, ^{135}Cs, and ^{137}Cs). The alkaline waste was generated by reprocessing commercial and Hanford N-Reactor spent fuels. As generated, the waste was acidic; treatment with excess sodium hydroxide resulted in the formation of an alkaline sludge. The small amount of acidic waste now in storage was generated by reprocessing a batch of thorium-uranium fuel from the Indian Point-1 Reactor. Storage for the alkaline waste is in an underground carbon-steel tank, while the acidic waste is stored in an underground stainless-steel tank.

In May 1988, the processing of high-level alkaline liquid waste started at the WVDP. This liquid is being decontaminated to LLW in the WVDP Supernatant Treatment System (STS) in preparation for the incorporation of all HLW at the WVDP into a glass. In the STS, a batch process that utilizes ion exchange is employed to remove cesium from alkaline liquid waste, as depicted in Fig. 2.8. The ion-exchange columns are located in the underground carbon-steel tank originally installed as a backup tank for alkaline HLW. When the liquid has been processed, the sludge in the bottom of the tank will be washed. The washed sludge, acidic waste, and loaded zeolite will be combined and incorporated into a glass. The current inventories of HLW at WVDP are presented in Tables 2.5 and 2.6.

2.3 WASTE CHARACTERIZATION

A generic characterization of HLW at any site is difficult, since over the years several different flowsheets have been used for the processes that generated the wastes and several methods have been employed to prepare the wastes for storage (e.g., evaporation and precipitation). In some instances, various types of wastes have been blended. However, representative data on chemical and radionuclide compositions are given in Tables 2.11–2.21 for current and

projected HLW at SRS, ICPP, HANF, and WVDP. The information used to construct these tables was taken from refs. 1-4, as well as from the references cited in the footnotes to the tables.

2.4 PROJECTIONS

Projected inventories (volume, radioactivity, and thermal power) for HLW are presented in Tables 2.7-2.9. These projections were generated by each site and are based on the assumptions given by each site. Due to the uncertainties in programmatic funding and future decisions, these projections should be considered only as best estimates based on current information. An estimate by each site[1-4] of a potential number of canisters of solidified HLW is shown in Table 2.3.

The HLW projections for SRS are based on the assumption that (1) three reactors will be restarted during 1991 and will be operating through September of 2004; (2) these three reactors will be replaced by a single new production reactor which will begin operation in late 2000; and (3) the Defense Waste Processing Facility (DWPF) will begin to produce a glass waste form (see flowsheet in Fig. A.10 of Appendix A) in February 1993, following the schedule shown in Table 2.3. The HLW glass will be stored on-site until a national repository[5-7] becomes available. Current plans call for the DWPF to produce 5,282 canisters of glass between 1993 and the end of 2020. A recent announcement by DOE indicated that only one reactor is to be restarted at SRS. Detailed information on this situation is not yet available. Thus, projections of HLW at SRS are based on the earlier fuel reprocessing schedule for the restart of three reactors.

The HLW projections for ICPP are based on predictions of fuel delivery and estimates of continued operation of fuel reprocessing and waste management through 2020. A facility to immobilize newly generated HLW at ICPP is planned for operation by the early part of the next century.[8] It will also be able to process the stored calcine. Evaluations of waste immobilization processes are continuing at ICPP, with the identification of a reference waste form (glass, ceramic, etc.) and process scheduled for completion in the 1990s. The projections of HLW presented in Tables 2.7-2.9 for ICPP are based on the waste composition prior to immobilization.

The HLW projections for HANF are based on resumed operation of the fuel reprocessing plant in 1998. A Hanford Waste Vitrification Plant (HWVP) is to begin operation in 1999.[8-9] The planned operations for the HWVP are discussed in the Hanford Defense Waste Environmental Impact Statement.[10] Estimates of the number of canisters of HLW incorporated in borosilicate glass that might be generated annually by the HWVP are given in Table 2.3. The projections of HLW given in Tables 2.7-2.9 for HANF do not include vitrification, since material balances for such processes are not yet available.

The cost for the disposal of DOE HLW in a national repository will be paid by DOE into the Nuclear Waste Fund. Reference 11 states that the number of canisters used in the annual estimate of this cost will be published in the IDB. Consequently, projections of the potential total number of DOE HLW canisters from SRS, ICPP, and HANF are presented in Table 2.4. Table 2.3 includes potential production schedules for canisters, which are not used in the disposal cost estimate. Table 2.4 shows the possible number of canisters, which could be produced from various waste streams, separated into four categories. The projections, totaling 6,100 canisters, in the committed category are based on National Environmental Policy Act (NEPA)-supported commitments to geological disposal by DOE. The projections in the other three categories are not based on NEPA decisions and reflect differing levels of uncertainty in the information used to determine the values for the number of canisters.

The DOE has recently proposed a plan for two new production reactors (NPRs) to provide defense material into the next century. Several reactor concepts and sites were considered. Projections, based on current technology, have been made of the possible volume of HLW. A range of the possible number of canisters estimated for solidified NPR-HLW is shown in Table 2.4.

At the WVDP, vitrification of the HLW (Fig. 2.8) is scheduled to begin in late 1996 and to be completed in 1998.

2.5 REFERENCES

1. R. G. Garvin, Westinghouse Savannah River Company, Savannah River Site, Aiken, South Carolina, letter to A. L. Watkins, DOE Field Office, Savannah River, Aiken, South Carolina, "Data for Integrated Data Base," NMP-WMT-910376, dated Apr. 24, 1991.

2. D. A. Knecht, Westinghouse Idaho Nuclear Company, Inc., Idaho National Engineering Laboratory, Idaho Falls, Idaho, letter to M. J. Bonkoski, DOE Field Office, Idaho, Idaho Falls, Idaho, "CY-90 Integrated Data Base Information," DAK-25-91, dated Apr. 11, 1991.

3. H. D. Harmon, Westinghouse Hanford Company, Hanford Site, Richland, Washington, letter to K. W. Bracken, DOE Field Office, Richland, Richland, Washington, "Update of Department of Energy High-Level Waste Data Needed for the 1991 Integrated Data Base Report," 9153158, dated Apr. 25, 1991.

4. T. J. Rowland, U.S. Department of Energy, West Valley Demonstration Project Office, West Valley, New York, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update to the DOE 1991 Integrated Data Base Report," dated Apr. 15, 1991.

5. U.S. Congress, The Nuclear Waste Policy Act of 1982, Pub. L. 97-425, Sect. 8, Jan. 7, 1983, as amended.

6. Ronald Reagan, President of the United States, Washington, D.C., letter to John S. Herrington, Secretary of Energy, "Disposal of Defense Waste in a Commercial Repository," dated Apr. 30, 1985.

7. U.S. Congress, The Nuclear Waste Policy Amendments Act of 1987, Pub. L. 100-203, Title V, Subtitle A, Dec. 22, 1987.

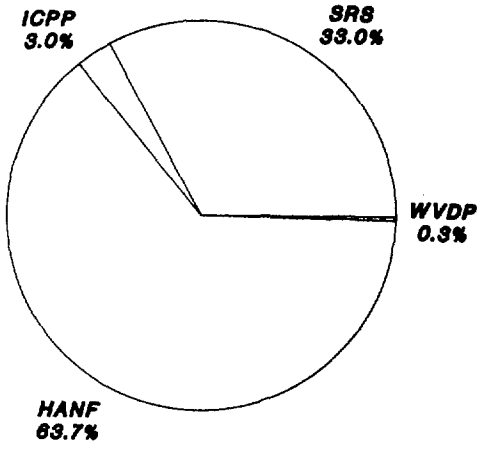
8. U.S. Department of Energy, Office of Defense Waste and Transportation Management, Defense Waste and Transportation Management Program Implementation Plan, DOE/DP-0059, Washington, D.C. (August 1988).

9. Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Hanford Federal Facility Agreement and Consent Order, EPA Docket Number 1089-03-040120, Ecology Docket Number 89-54, Richland, Washington (May 1989).

10. U.S. Department of Energy, Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic, and Tank Waste, Hanford Site, Richland, Washington, DOE/EIS-0113, DOE Field Office, Richland, Richland, Washington (December 1987).

11. U.S. Department of Energy, "Civilian Radioactive Waste Management: Calculating Nuclear Waste Fund Disposal Fees for Department of Energy Defense Program Waste; Notice," Fed. Regist. 56(161), 31508 (Aug. 20, 1987).

ORNL DWG 91-8658



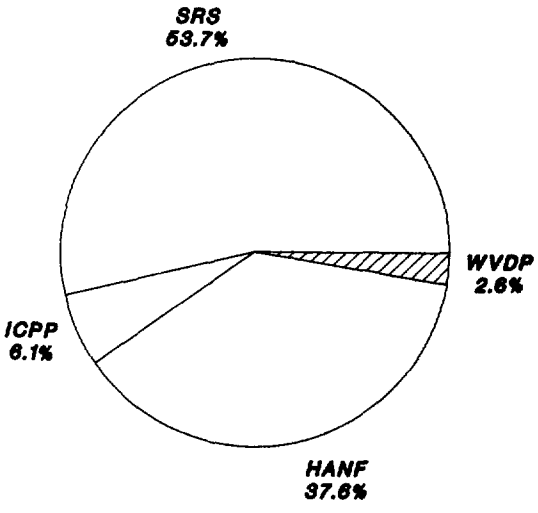
SITE	CUBIC METERS
SRS	1.32E+05
ICPP	1.20E+04
HANF	2.54E+05
WVDP	1.23E+03
TOTAL	3.99E+05

COMMERCIAL

DOE

Fig. 2.1. Total volume of HLW through 1990.

ORNL DWG 91-8659



SITE	CURIES
SRS	5.62E+08
ICPP	6.35E+07
HANF	3.93E+08
WVDP	2.73E+07
TOTAL	1.05E+09

COMMERCIAL

DOE

Fig. 2.2. Total radioactivity of HLW through 1990.

ORNL DWG 91-8660

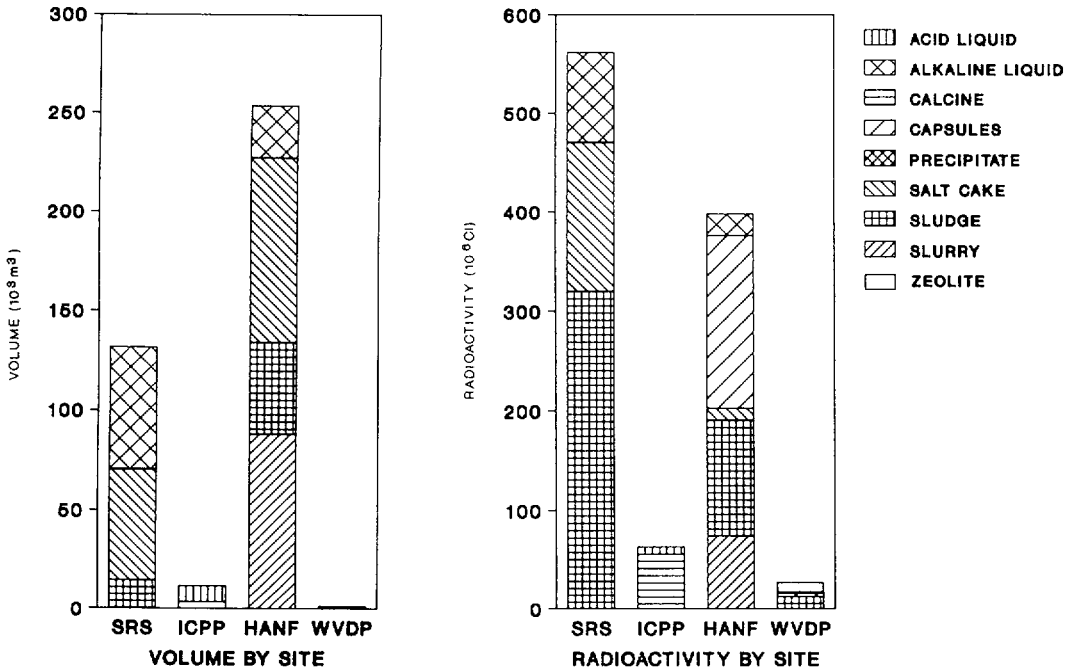


Fig. 2.3. Distribution of total accumulative volume and radioactivity of HLW by site and type through 1990.

ORNL DWG 91-8661

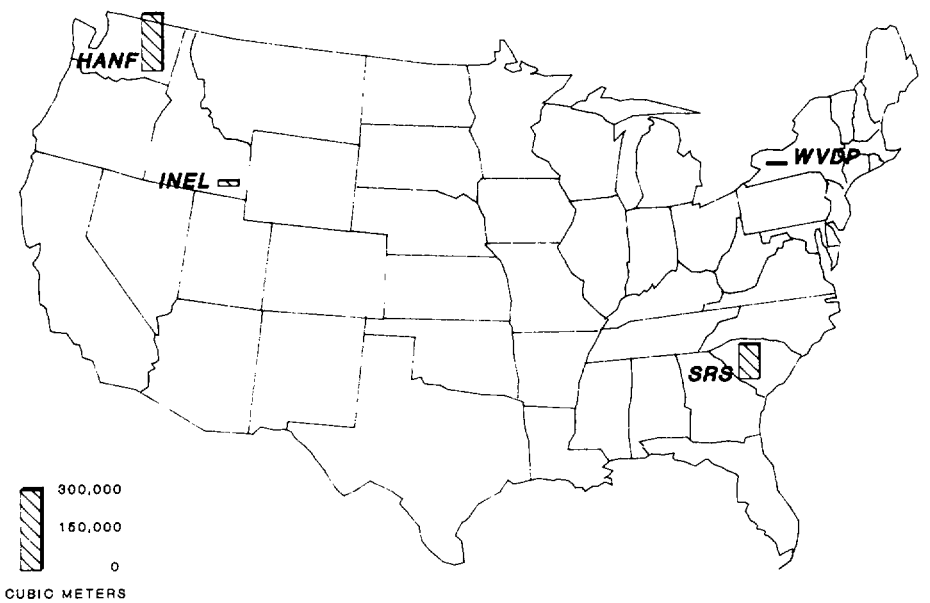


Fig. 2.4. Locations and total volumes of HLW through 1990.

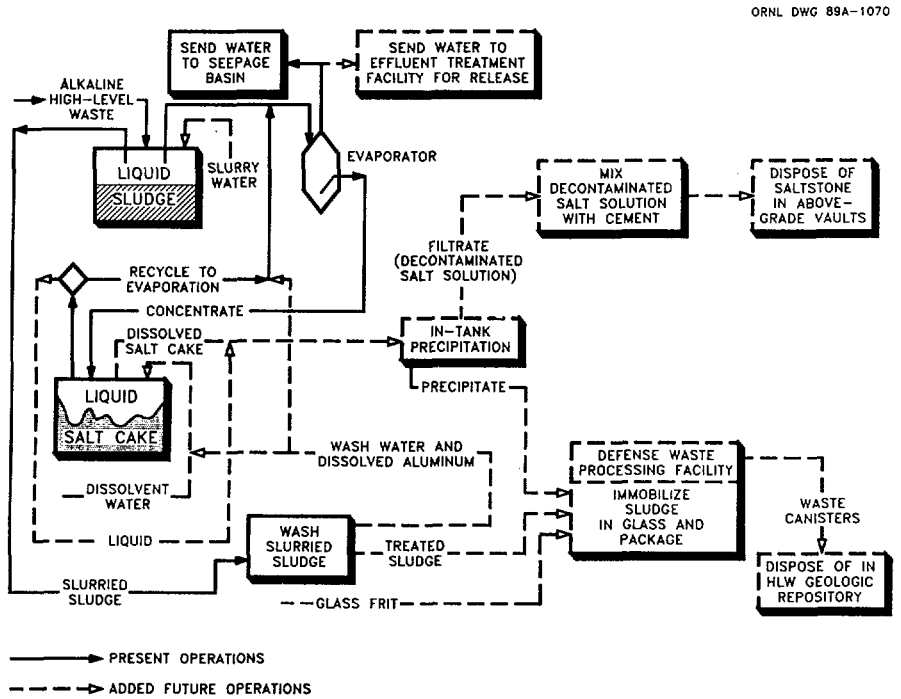


Fig. 2.5. Treatment methods for HLW in tanks and canisters at SRS.

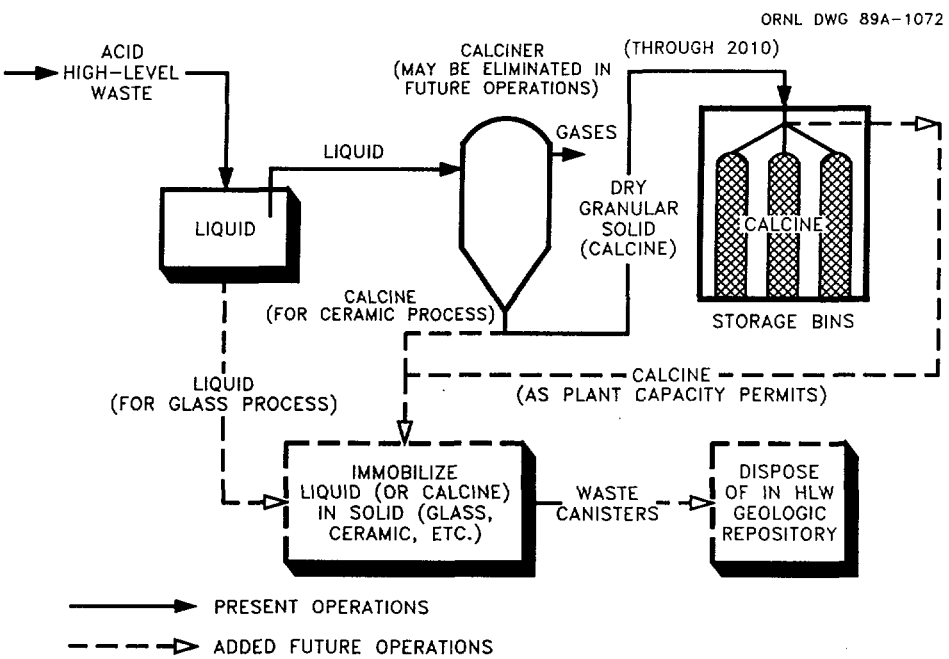


Fig. 2.6. Treatment methods for HLW in tanks, bins, and canisters at INEL.

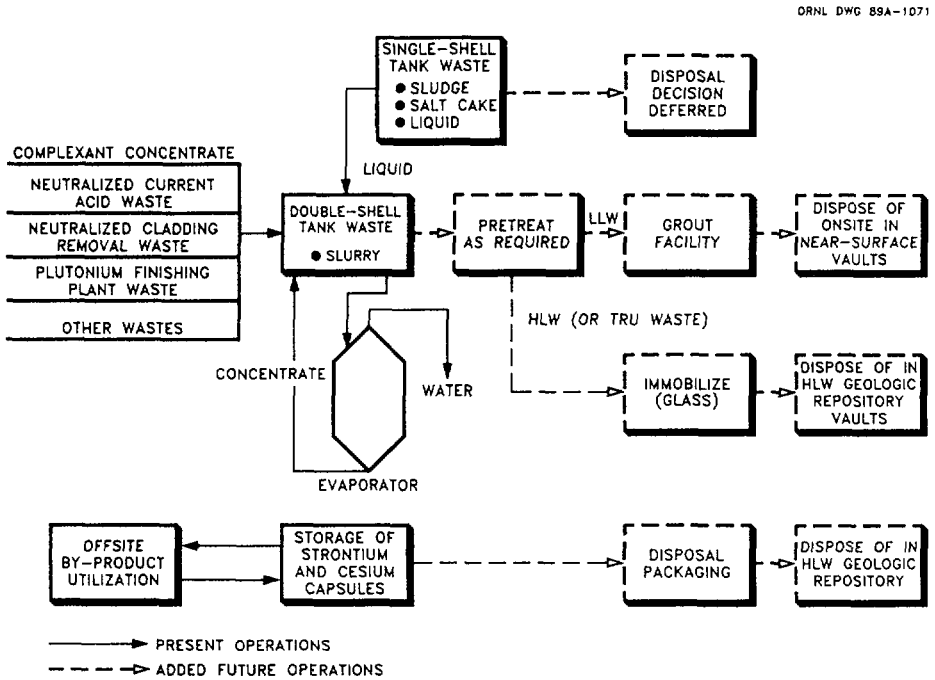


Fig. 2.7. Treatment methods for HLW in tanks, capsules, and canisters at HANF.

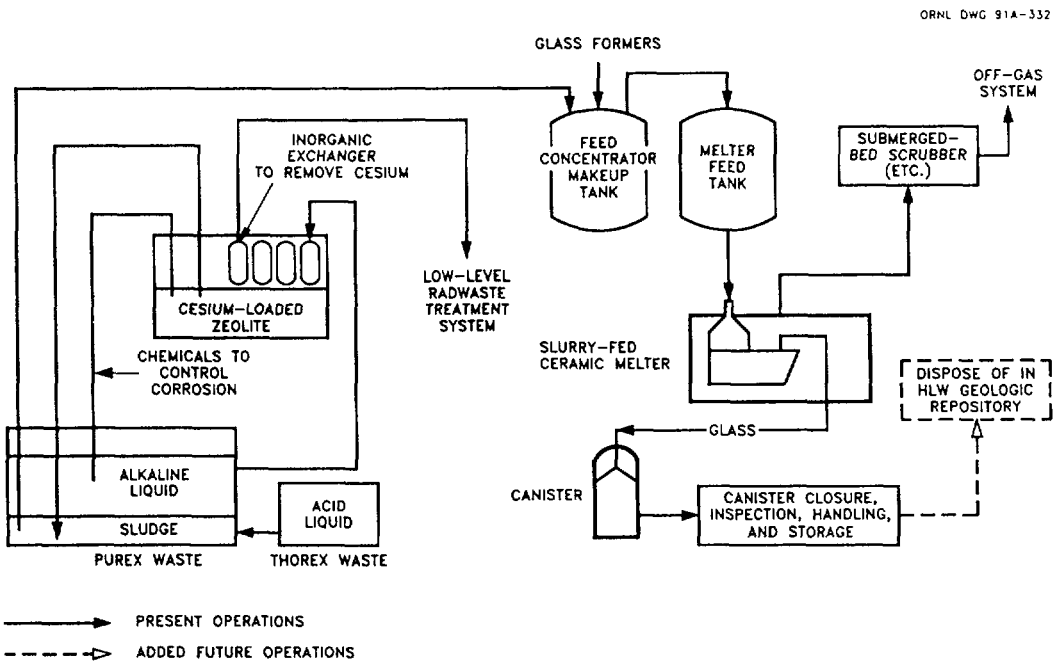


Fig. 2.8. Treatment methods for HLW in tanks and canisters at WVDP.

Table 2.1. Historical and projected total accumulative volume, radioactivity, and thermal power of HLW stored in tanks, bins, and capsules by source[a,b,c]

End of calendar year	Accumulation		
	Volume (10^3 m^3)	Radioactivity (10^6 Ci)	Thermal power (10^3 W)
	DOE (SRS, ICPP, and HANF)		
1980	295	1,310	3,298
1981	305	1,577	4,748
1982	340	1,316	3,919
1983	351	1,248	3,653
1984	361	1,397	4,227
1985	355	1,465	4,466
1986	364	1,417	4,475
1987	379	1,277	3,750
1988	383	1,177	3,388
1989	379	1,084	3,080
1990	397	1,018	2,884
1991	386	977	2,780
1992	369	998	2,836
1993	364	1,025	2,964
1994	361	1,002	2,892
1995	352	1,005	2,927
1996	348	972	2,823
1997	342	971	2,844
1998	341	957	2,800
1999	334	1,037	3,171
2000	332	987	2,996
2001	329	962	2,919
2002	323	1,022	3,172
2003	324	1,037	3,229
2004	325	1,033	3,220
2005	318	1,028	3,205
2006	316	1,024	3,193
2007	315	862	2,571
2008	318	784	2,313
2009	321	756	2,227
2010	325	746	2,200
2011	327	751	2,226
2012	329	751	2,233
2013	330	754	2,249
2014	329	765	2,295
2015	331	770	2,316
2016	330	776	2,288
2017	332	788	2,387
2018	332	780	2,361
2019	333	765	2,303
2020	333	768	2,322
	Commercial (WVDP)		
1980	2.2	34.2	102.0
1981	2.2	33.4	99.6
1982	2.2	32.7	97.2
1983	2.2	31.9	95.0
1984	2.2	31.2	92.8
1985	2.2	30.4	90.5
1986	2.2	29.7	88.4
1987	2.2	29.2	85.5
1988	2.1	28.7	85.0
1989	2.4	27.9	83.2
1990	1.2	27.3	81.2
1991	1.2	26.8	79.3
1992	1.2	26.2	77.5

Table 2.1 (continued)

End of calendar year	Accumulation		
	Volume (10^3 m^3)	Radioactivity (10^6 Ci)	Thermal power (10^3 W)
1993	1.1	25.6	75.7
1994	1.0	25.1	73.9
1995	1.0	24.5	72.4
1996	0.7	15.9	46.9
1997	0.4	8.0	22.8
		Total	
1980	297	1,344	3,400
1981	307	1,610	4,848
1982	342	1,349	4,016
1983	353	1,280	3,748
1984	363	1,428	4,319
1985	357	1,495	4,557
1986	366	1,446	4,564
1987	381	1,306	3,835
1988	385	1,206	3,473
1989	381	1,112	3,163
1990	398	1,045	2,965
1991	387	1,004	2,859
1992	370	1,025	2,913
1993	365	1,051	3,039
1994	362	1,027	2,966
1995	353	1,030	3,000
1996	349	988	2,870
1997	343	979	2,867
1998	341	957	2,800
1999	334	1,037	3,171
2000	332	987	2,996
2001	329	962	2,919
2002	323	1,022	3,172
2003	324	1,037	3,229
2004	325	1,033	3,220
2005	318	1,028	3,205
2006	316	1,024	3,193
2007	315	862	2,571
2008	318	784	2,313
2009	321	756	2,227
2010	325	746	2,200
2011	327	751	2,226
2012	329	751	2,233
2013	330	754	2,249
2014	329	765	2,295
2015	331	770	2,316
2016	330	776	2,288
2017	332	788	2,387
2018	332	780	2,361
2019	333	765	2,303
2020	333	768	2,322

[a]Historical inventories for HLW are taken from the previous edition of this report [i.e., DOE/RW-0006, Rev. 6 (October 1990)]. The inventories for 1990 and the projections through 2020 are taken from refs. 1-4.

[b]Annual rates for volume are not given since they can fluctuate widely depending upon waste generation (or nongeneration) coupled with waste management operations such as evaporation and/or calcination. Annual rates for radioactivity and thermal power are not given for the same reasons plus the fact that radioactive decay, especially for short-lived activity, causes apparent perturbations.

[c]Radioactive decay is taken into account by each site through isotope generation/depletion codes.

Table 2.2. Projected volume, radioactivity, and thermal power of HLW glass stored in canisters by source[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^6 Ci)		Thermal power (10^3 W)	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			DOE (SRS)[b]			
1993	0.09	0.09	23	23	57	57
1994	0.19	0.28	30	52	78	133
1995	0.23	0.51	37	88	95	223
1996	0.26	0.77	65	150	203	413
1997	0.26	1.03	65	211	209	603
1998	0.23	1.26	58	264	180	763
1999	0.24	1.50	54	311	169	908
2000	0.23	1.73	42	346	136	1,019
2001	0.21	1.94	35	372	112	1,104
2002	0.21	2.15	30	393	96	1,171
2003	0.22	2.37	27	411	86	1,227
2004	0.21	2.58	25	426	79	1,276
2005	0.19	2.77	23	438	74	1,318
2006	0.17	2.94	21	449	69	1,355
2007	0.17	3.11	20	459	65	1,387
2008	0.17	3.28	20	467	62	1,416
2009	0.02	3.30	4	460	12	1,397
2010		3.30		450		1,368
2011		3.30		440		1,340
2012		3.30		429		1,310
2013		3.30		419		1,282
2014		3.30		410		1,253
2015		3.30		400		1,226
2016		3.30		391		1,199
2017		3.30		382		1,172
2018		3.30		373		1,147
2019		3.30		365		1,122
2020		3.30		356		1,098
			Commercial (WVDP)[c]			
1996	0.07	0.07	7.9	7.9	23.5	23.5
1997	0.07	0.14	7.6	15.3	22.9	45.9
1998	0.07	0.21	7.8	22.8	22.4	67.3
1999		0.21		22.4		65.6
2000		0.21		22.0		64.2
2001		0.21		21.6		62.7
2002		0.21		21.2		61.2
2003		0.21		20.8		59.9
2004		0.21		20.4		58.6
2005		0.21		20.0		57.2
2006		0.21		19.4		55.9
2007		0.21		18.9		54.6
2008		0.21		18.3		53.5
2009		0.21		17.8		52.2
2010		0.21		17.4		51.0
2011		0.21		17.0		49.9
2012		0.21		16.6		48.8
2013		0.21		16.2		47.6
2014		0.21		15.8		46.6
2015		0.21		15.5		45.5
2016		0.21		15.1		44.4
2017		0.21		14.8		43.6
2018		0.21		14.4		42.6
2019		0.21		14.1		41.6
2020		0.21		13.8		40.6

Table 2.2 (continued)

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^6 Ci)		Thermal power (10^3 W)	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Total			
1993	0.09	0.09	23	23	57	57
1994	0.19	0.28	30	52	78	133
1995	0.23	0.51	37	88	95	223
1996	0.33	0.84	73	158	226	436
1997	0.33	1.17	73	226	232	649
1998	0.30	1.47	66	286	202	830
1999	0.24	1.71	54	333	169	974
2000	0.23	1.94	42	368	136	1,083
2001	0.21	2.15	35	394	112	1,167
2002	0.21	2.36	30	415	96	1,232
2003	0.22	2.58	27	432	86	1,287
2004	0.21	2.79	25	446	79	1,335
2005	0.19	2.98	23	458	74	1,375
2006	0.17	3.15	21	469	69	1,411
2007	0.17	3.32	20	478	65	1,442
2008	0.17	3.49	20	486	62	1,470
2009	0.02	3.51	4	478	12	1,449
2010		3.51		467		1,419
2011		3.51		457		1,390
2012		3.51		446		1,359
2013		3.51		436		1,330
2014		3.51		426		1,300
2015		3.51		416		1,272
2016		3.51		406		1,243
2017		3.51		397		1,216
2018		3.51		387		1,190
2019		3.51		379		1,164
2020		3.51		370		1,139

[a]Glass may be in storage at the site, in transit to a repository, or in a repository.

[b]Taken from or calculated with data given in ref. 1. The DWPF (see Fig. A.10 in Appendix A) canisters are 2 ft in diam x 10 ft long. Each is assumed to be filled with 0.637 m^3 of glass [i.e., 85% of the usable capacity (0.736 m^3)] made with HLW from the reprocessing of spent fuel at SRS. The glass incorporates 36 wt % oxides from waste (28 wt % from spent fuel and 8 wt % from processing chemicals) and 64 wt % oxides from nonradioactive glass frit. Volumes reported are for the glass waste form and not the canisters (see Table 2.3 for the number of canisters).

[c]Taken from data given in ref. 4. It is assumed that 300 canisters (2 ft in diam x 10 ft long) are filled with waste glass during 1996-1998 and that each canister contains 0.7 m^3 of glass at the filling temperature.

Table 2.3. Estimated potential number of HLW canisters by source[a]

	Number of canisters[b]							
	SRS[c]		ICPP[d]		HANF[e]		WVDP[f]	
Year	Annual	Accumulation	Annual	Accumulation	Annual	Accumulation	Annual	Accumulation
1993	136	136	-	-	-	-	-	-
1994	308	444	-	-	-	-	-	-
1995	376	820	-	-	-	-	-	-
1996	410	1,230	-	-	-	-	100	100
1997	410	1,640	-	-	-	-	100	200
1998	383	2,023	-	-	-	-	100	300
1999	369	2,392	-	-	-	-	-	300
2000	369	2,761	-	-	240	240	-	300
2001	342	3,103	-	-	370	610	-	300
2002	342	3,445	-	-	345	955	-	300
2003	342	3,787	-	-	185	1,140	-	300
2004	342	4,129	-	-	370	1,510	-	300
2005	302	4,431	-	-	370	1,880	-	300
2006	273	4,704	-	-	144	2,024	-	300
2007	273	4,977	-	-	64	2,088	-	300
2008	273	5,250	-	-	64	2,152	-	300
2009	32	5,282	-	-	64	2,216	-	300
2010	-	5,282	-	-	64	2,280	-	300
2011	-	5,282	-	-	-	2,280	-	300
2012	-	5,282	-	-	-	2,280	-	300
2013	-	5,282	-	-	-	2,280	-	300
2014	-	5,282	500	500	-	2,280	-	300
2015	-	5,282	600	1,100	-	2,280	-	300
2016	-	5,282	700	1,800	-	2,280	-	300
2017	-	5,282	1,000	2,800	-	2,280	-	300
2018	-	5,282	1,000	3,800	-	2,280	-	300
2019	-	5,282	1,000	4,800	-	2,280	-	300
2020	-	5,282	1,000	5,800	-	2,280	-	300

[a]Taken from refs. 1-4. The projected waste volumes, radioactivity, and thermal power values at SRS and WVDP are consistent with the number of canisters reported since these sites are further along in their solidification programs and have developed definitive and defensible material balances for their solidification facilities. The number of canisters at ICPP and HANF are estimates since the solidification facilities at these sites are still in the planning stage.

[b]Canisters are 2-ft diam x 10-ft length.

[c]Each canister is assumed to contain 0.637 m^3 of glass made with HLW from the reprocessing of spent fuel at SRS. The glass incorporates 36 wt % oxides from waste (28 wt % from spent fuel and 8 wt % from processing chemicals) and 64 wt % oxides from nonradioactive glass frit.

[d]Each canister is assumed to contain 0.57 m^3 of a ceramic waste form incorporating 70 wt % solids from waste.

[e]Each canister of vitrified waste is assumed to contain 0.62 m^3 of a borosilicate glass incorporating waste solids. The glass in 1,460 of these canisters includes solids from neutralized current acid waste and complexant concentrate. In addition to the canisters of glass, 320 canisters or overpacks (96 for Sr and 224 for Cs) containing strontium capsules and cesium capsules, as well as 500 canisters from neutralized cladding removal waste and plutonium finishing plant waste, are projected to be produced. The 500 latter canisters meet the definition of TRU waste and are candidates for disposal at the Waste Isolation Pilot Plant.

[f]Each canister is assumed to contain 0.7 m^3 of a borosilicate glass incorporating waste solids.

Table 2.4. The 1988 estimate of the number of DOE HLW canisters that could be produced from stored and projected HLW[a]

Interim waste form/ source and generation/ generation period	Estimated number of canisters (Values rounded to nearest 100)			
	Committed to disposal[b]	High potential for disposal[c]	Medium potential for disposal[d]	Not included[e]
		Savannah River Site[f]		
Tank waste (liquid, salt cake, and sludge)				
Start-1987	4,600			
1988-2000	1,000			
		Idaho Chemical Processing Plant[g]		
Calcined waste				
Start-1987		3,800		
1988-2020		16,300		
2021-2033			9,500	
		Hanford Site[h]		
Double-shell tanks				
Slurry				
NCAW[i]	500			
CC-1987[j]		200-600		
CC after 1987[k]			0-400	
PFP[l]				100
NCRW[m]				400
Cs and Sr capsules[n]		300		
Single-shell tanks[o] (liquid, salt cake, and sludge)			0-24,000	
		Undesignated site		
New production reactor[p] (2000-2040)		800-1,000		
Total	6,100	21,400-22,000	9,500-33,900	500

[a]Taken from ref. 3 in the previous edition of this report [i.e., DOE/RW-0006, Rev. 5 (November 1989)]. Data required for repository program planning.

[b]Committed values are well established (e.g., DWPF glass) and are based on National Environmental Policy Act (NEPA) decisions.

[c]High-potential values are not supported by a NEPA action and/or are less sharply known.

[d]Medium-potential values are not supported by a NEPA action and/or they are based on imprecise source estimates or undeveloped treatment technology.

[e]Projections are not included when values are very imprecisely known or the waste is non-HLW that has been associated with past canister estimates. Values are for reference only.

[f]Canisters from the DWPF contain glass made with existing HLW and HLW from the operation of existing reactors through 2000.

[g]Canisters contain a ceramic waste form made with HLW from the reprocessing of naval nuclear propulsion fuels. Estimated projections beyond 2020 are less precise. Projected values assume no on-site disposal of calcine and no removal of inerts from the original waste streams.

[h]Slurry refers to all waste in double-shell tanks regardless of when it was generated.

[i]Neutralized current acid waste (NCAW) is HLW from existing N-Reactor fuel.

[j]Complexant concentrate (CC) generated through 1987 will be vitrified, but the volume is not precisely known.

[k]Complexant concentrate (CC) source beyond 1987 is not clearly defined.

[l]Plutonium Finishing Plant (PFP) waste is not HLW by source definition.

[m]Neutralized coating removal waste (NCRW) is not HLW by source definition.

[n]Capsule waste will most likely go to a repository, but final form has not been determined.

[o]Single-shell tank waste has not been designated through NEPA to be sent to a repository. Final class and recommended treatment are still being studied.

[p]HLW from new production reactors will probably be sent to a repository, but no NEPA action has been initiated. The expected volume is relatively firm.

Table 2.5. Current volume of HLW in storage by site through 1990

Site[a]	Volume, 10^3 m^3									
								Capsules[d]		
	Liquid	Sludge	Salt cake	Slurry[b]	Calcine	Precipitate[c]	Zeolite	Sr	Cs	Total
DOE[e]										
SRS	61.3	14.8	55.5	f	f	0.125	f	f	f	131.7
ICPP	8.5	f	f	f	3.5	f	f	f	f	12.0
HANF[g]	26.4	46.0	93.0	88.2	f	f	f	0.00106	0.00248	253.6
Subtotal	96.2	60.8	148.5	88.2	3.5	0.125	f	0.00106	0.00248	397.3
Commercial[h]										
WVDP										
Acid waste	0.05	f	f	f	f	f	f	f	f	0.050
Alkaline waste[i]	1.09	0.046	f	f	f	f	f	f	f	1.136
Zeolite waste	f	f	f	f	f	f	0.045	f	f	0.045
Subtotal	1.14	0.046	f	f	f	f	0.045	f	f	1.231
Total	97.3	60.8	148.5	88.2	3.5	0.125	0.045	0.00106	0.00248	398.5

[a]SRS is Savannah River Site, ICPP is Idaho Chemical Processing Plant, HANF is Hanford Site, and WVDP is West Valley Demonstration Project.

[b]Slurry refers to all waste (regardless of when it was generated) contained in double-shell tanks.

[c]Precipitate (non-Newtonian fluid) from the in-tank precipitation process.

[d]Capsules contain either strontium (^{90}Sr-^{90}Y) fluoride or cesium (^{137}Cs-^{137m}Ba) chloride.

[e]Taken from refs. 1-3.

[f]Not applicable.

[g]Hanford single-shell tank wastes (i.e., liquid, sludge, and salt cake) and double-shell tank wastes (i.e., slurry) consist of HLW, TRU waste, and several LLWs. However, in storage practice, all tanks are managed as if they contain HLW. Thus, their contents are included in the HLW inventory.

[h]Taken from ref. 4.

[i]Includes small (~15 m^3) amount of alkaline liquid in the interstices of cesium-loaded zeolite (see Fig. 2.8).

Table 2.6. Current radioactivity of HLW in storage by site through 1990

Site[b]	Radioactivity,[a] 10^6 Ci										Thermal power (10^6 W)
								Capsules[e]			
	Liquid	Sludge	Salt cake	Slurry[c]	Calcine	Precipitate[d]	Zeolite	Sr	Cs	Total	
DOE[f]											
SRS	91.6	319.8	150.1	g	g	0.15	g	g	g	561.6	1.566
ICPP	7.5	g	g	g	56.0	g	g	g	g	63.5	0.184
HANF[h]	21.9	115.7	12.1	74.6	g	g	g	53.2	115.2	392.7	1.078
Subtotal	121.0	435.5	162.2	74.6	56.0	0.15	g	53.2	115.2	1,017.85	2.828
Commercial[i]											
WVDP											
Acid waste	1.7	g	g	g	g	g	g	g	g	1.7	0.005
Alkaline waste[j]	3.6	12.7	g	g	g	g	g	g	g	16.3	0.053
Zeolite waste	g	g	g	g	g	g	9.3	g	g	9.3	0.023
Subtotal	5.3	12.7	g	g	g	g	9.3	g	g	27.3	0.081
Total	126.3	448.2	162.2	74.6	56.0	0.15	9.3	53.2	115.2	1,045.15	2.909

[a]Calculated values allowing for radioactive decay.

[b]SRS is Savannah River Site, ICPP is Idaho Chemical Processing Plant, HANF is Hanford Site, and WVDP is West Valley Demonstration Project.

[c]Slurry refers to all waste (regardless of when it was generated) contained in double-shell tanks.

[d]Precipitate (non-Newtonian fluid) from the in-tank precipitation process.

[e]Capsules contain either strontium (^{90}Sr-^{90}Y) fluoride or cesium (^{137}Cs-^{137m}Ba) chloride. Radioactivity values are for the pair, that is, parent plus daughter radionuclide.

[f]Taken from refs. 1-3.

[g]Not applicable.

[h]Hanford single-shell tank wastes (i.e., liquid, sludge, and salt cake) and double-shell tank wastes (i.e., slurry) consist of HLW, TRU waste, and several LLWs. However, in storage practice, all tanks are managed as if they contain HLW. Thus, their contents are included in the HLW inventory.

[i]Taken from ref. 4.

[j]Includes the radioactivity (~1.0 x 10^6 Ci) associated with the alkaline liquid in the interstices of cesium-loaded zeolite (see Fig. 2.8 and Table 2.21).

Table 2.7. Historical and projected total accumulative volume of HLW in storage by site through 2020[a]

End of calendar year	Volume, 10^3 m^3									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Savannah River Site					
1980	59.8	10.5	26.4	-	-	-	-	-	-	97
1981	66.3	11.8	27.6	-	-	-	-	-	-	106
1982	72.9	12.3	29.8	-	-	-	-	-	-	115
1983	65.9	12.8	32.7	-	-	-	-	-	-	111
1984	77.8	13.8	34.0	-	-	-	-	-	-	126
1985	71.3	13.8	37.6	-	-	-	-	-	-	123
1986	72.8	13.8	41.2	-	-	-	-	-	-	128
1987	63.2	13.8	50.5	-	-	0.1	-	-	-	128
1988	64.2	14.1	50.0	-	-	0.1	-	-	-	128
1989	53.3	13.8	54.8	-	-	0.1	-	-	-	122
1990	61.3	14.8	55.5	-	-	0.1	-	-	-	132
1995	48.4	15.9	44.4	-	-	1.3	-	-	0.5	110
2000	43.4	11.2	27.4	-	-	1.4	-	-	1.7	85
2005	41.4	8.2	16.5	-	-	0.3	-	-	2.8	69
2010	42.9	8.9	18.1	-	-	-	-	-	3.3	73
2015	42.9	9.6	21.4	-	-	0.3	-	-	3.3	78
2020	42.2	10.3	21.4	-	-	0.9	-	-	3.3	78
					Idaho Chemical Processing Plant					
1980	9.3	-	-	-	2.1	-	-	-	-	11
1981	9.8	-	-	-	2.2	-	-	-	-	12
1982	9.1	-	-	-	2.4	-	-	-	-	12
1983	6.9	-	-	-	2.8	-	-	-	-	10
1984	7.1	-	-	-	3.0	-	-	-	-	10
1985	7.1	-	-	-	3.0	-	-	-	-	10
1986	6.5	-	-	-	3.0	-	-	-	-	10
1987	8.9	-	-	-	3.0	-	-	-	-	12
1988	7.6	-	-	-	3.4	-	-	-	-	11
1989	8.5	-	-	-	3.5	-	-	-	-	12
1990	8.5	-	-	-	3.5	-	-	-	-	12
1995	5.9	-	-	-	4.8	-	-	-	-	11
2000	5.9	-	-	-	5.7	-	-	-	-	12
2005	5.5	-	-	-	6.8	-	-	-	-	12
2010	5.3	-	-	-	8.0	-	-	-	-	13
2015	3.5	-	-	-	10.1	-	-	-	-	14
2020	2.2	-	-	-	11.8	-	-	-	-	14

Table 2.7 (continued)

End of calendar year	Volume, 10^3 m^3									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Hanford Site					
1980	39.0	49.0	95.0	4.0	-	-	-	0.002	-	187
1981	39.0	49.0	95.0	4.0	-	-	-	0.002	-	187
1982	33.5	46.8	96.6	36.4	-	-	-	0.004	-	213
1983	29.8	46.7	93.8	59.1	-	-	-	0.004	-	229
1984	29.4	46.0	93.0	57.2	-	-	-	0.004	-	226
1985	28.1	46.0	93.0	55.1	-	-	-	0.004	-	222
1986	27.9	46.0	93.0	59.5	-	-	-	0.004	-	226
1987	27.3	46.0	93.0	73.4	-	-	-	0.004	-	240
1988	26.8	46.0	93.0	77.7	-	-	-	0.004	-	243
1989	26.5	46.0	93.0	79.3	-	-	-	0.004	-	245
1990	26.4	46.0	93.0	88.2	-	-	-	0.004	-	254
1995	11.8	46.0	93.0	80.8	-	-	-	0.004	-	232
2000	11.6	46.0	93.0	86.1	-	-	-	0.004	-	237
2005	11.6	46.0	93.0	88.4	-	-	-	0.004	-	239
2010	11.6	46.0	93.0	91.2	-	-	-	0.004	-	242
2015	11.6	46.0	93.0	92.4	-	-	-	0.004	-	243
2020	11.6	46.0	93.0	93.5	-	-	-	0.004	-	244
					West Valley Demonstration Project					
1980	2.150	0.046	-	-	-	-	-	-	-	2.196
1981	2.150	0.046	-	-	-	-	-	-	-	2.196
1982	2.150	0.046	-	-	-	-	-	-	-	2.196
1983	2.150	0.046	-	-	-	-	-	-	-	2.196
1984	2.150	0.046	-	-	-	-	-	-	-	2.196
1985	2.150	0.046	-	-	-	-	-	-	-	2.196
1986	2.150	0.046	-	-	-	-	-	-	-	2.196
1987	2.150	0.046	-	-	-	-	-	-	-	2.196
1988	2.070	0.046	-	-	-	-	0.013	-	-	2.129
1989	2.310	0.046	-	-	-	-	0.031	-	-	2.387
1990	1.140	0.046	-	-	-	-	0.045	-	-	1.231
1995	0.888	0.046	-	-	-	-	0.072	-	-	1.006
2000	-	-	-	-	-	-	-	-	0.210	0.210
2005	-	-	-	-	-	-	-	-	0.210	0.210
2010	-	-	-	-	-	-	-	-	0.210	0.210
2015	-	-	-	-	-	-	-	-	0.210	0.210
2020	-	-	-	-	-	-	-	-	0.210	0.210

[a]Historical inventories for HLW are taken from the previous edition of this report [i.e., DOE/RW-0006, Rev. 6 (October 1990)]. The inventories for 1990 and the projections through 2020 are taken from refs. 1-4.

[b]Capsules contain either strontium (^{90}Sr-^{90}Y) fluoride or cesium (^{137}Cs-^{137m}Ba) chloride.

[c]Glass may be in storage at the site, in transit to a repository, or in a repository.

Table 2.8. Historical and projected total accumulative radioactivity of HLW in storage by site through 2020[a]

End of calendar year	Radioactivity, 10^6 Ci									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Savannah River Site					
1980	187.4	429.0	82.6	-	-	-	-	-	-	699
1981	165.6	722.0	94.4	-	-	-	-	-	-	982
1982	161.7	558.3	107.8	-	-	-	-	-	-	828
1983	85.9	509.2	181.1	-	-	-	-	-	-	776
1984	88.1	523.6	184.2	-	-	-	-	-	-	796
1985	93.3	561.3	186.8	-	-	-	-	-	-	841
1986	88.1	517.2	189.4	-	-	-	-	-	-	795
1987	105.2	460.4	168.2	-	-	0.2	-	-	-	734
1988	99.0	403.1	162.1	-	-	0.2	-	-	-	664
1989	94.6	351.2	152.8	-	-	0.3	-	-	-	599
1990	91.6	319.8	150.1	-	-	0.1	-	-	-	562
1995	68.1	385.9	118.4	-	-	23.5	-	-	87.7	684
2000	54.8	400.3	106.9	-	-	8.7	-	-	345.6	916
2005	44.7	467.2	88.1	-	-	6.2	-	-	438.3	1,045
2010	24.6	234.7	79.6	-	-	-	-	-	449.8	789
2015	18.0	240.1	74.3	-	-	2.2	-	-	400.2	735
2020	14.1	251.9	66.6	-	-	5.3	-	-	356.0	694
					Idaho Chemical Processing Plant					
1980	17.0	-	-	-	36.4	-	-	-	-	53
1981	26.4	-	-	-	37.2	-	-	-	-	64
1982	31.8	-	-	-	39.8	-	-	-	-	72
1983	16.2	-	-	-	48.6	-	-	-	-	65
1984	9.5	-	-	-	49.1	-	-	-	-	59
1985	21.7	-	-	-	47.7	-	-	-	-	69
1986	12.9	-	-	-	47.7	-	-	-	-	61
1987	14.3	-	-	-	48.2	-	-	-	-	63
1988	10.1	-	-	-	56.9	-	-	-	-	67
1989	11.5	-	-	-	56.9	-	-	-	-	68
1990	7.5	-	-	-	55.7	-	-	-	-	63
1995	8.7	-	-	-	65.5	-	-	-	-	74
2000	1.3	-	-	-	80.2	-	-	-	-	82
2005	1.6	-	-	-	116.6	-	-	-	-	118
2010	1.4	-	-	-	135.2	-	-	-	-	137
2015	1.4	-	-	-	193.4	-	-	-	-	195
2020	3.3	-	-	-	213.2	-	-	-	-	217

Table 2.8 (continued)

End of calendar year	Radioactivity, 10^6 Ci									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Hanford Site					
1980	34.6	175.0	16.0	0.3	-	-	-	332.0	-	558
1981	34.0	163.0	15.0	0.2	-	-	-	319.0	-	531
1982	33.5	140.2	14.6	0.2	-	-	-	228.2	-	417
1983	29.2	136.9	14.2	3.8	-	-	-	223.0	-	407
1984	28.1	133.7	13.9	148.8	-	-	-	217.8	-	542
1985	26.2	130.5	13.6	171.2	-	-	-	212.8	-	554
1986	25.5	127.4	13.2	187.3	-	-	-	207.9	-	561
1987	24.4	124.4	12.9	115.8	-	-	-	203.1	-	481
1988	23.3	121.4	12.6	110.9	-	-	-	177.1	-	445
1989	22.6	118.5	12.3	89.6	-	-	-	173.2	-	416
1990	21.9	115.7	12.1	74.6	-	-	-	168.4	-	393
1995	8.7	102.7	10.7	63.2	-	-	-	149.9	-	335
2000	7.7	91.1	9.5	93.7	-	-	-	133.4	-	335
2005	6.8	80.8	8.5	89.2	-	-	-	118.7	-	304
2010	6.1	71.7	7.5	79.1	-	-	-	105.6	-	270
2015	5.4	63.6	6.7	70.4	-	-	-	94.0	-	240
2020	4.8	56.4	6.0	62.7	-	-	-	83.7	-	214
					West Valley Demonstration Project					
1980	18.2	16.0	-	-	-	-	-	-	-	34.2
1981	17.8	15.6	-	-	-	-	-	-	-	33.4
1982	17.4	15.3	-	-	-	-	-	-	-	32.7
1983	17.0	14.9	-	-	-	-	-	-	-	31.9
1984	16.6	14.6	-	-	-	-	-	-	-	31.2
1985	16.2	14.2	-	-	-	-	-	-	-	30.4
1986	15.8	13.9	-	-	-	-	-	-	-	29.7
1987	15.5	13.7	-	-	-	-	-	-	-	29.2
1988	12.7	13.4	-	-	-	-	2.6	-	-	28.7
1989	8.3	13.0	-	-	-	-	6.6	-	-	27.9
1990	5.3	12.7	-	-	-	-	9.3	-	-	27.3
1995	2.1	11.5	-	-	-	-	10.9	-	-	24.5
2000	-	-	-	-	-	-	-	-	22.0	22.0
2005	-	-	-	-	-	-	-	-	20.0	20.0
2010	-	-	-	-	-	-	-	-	17.4	17.4
2015	-	-	-	-	-	-	-	-	15.5	15.5
2020	-	-	-	-	-	-	-	-	13.8	13.8

[a]Historical inventories for HLW are taken from the previous edition of this report [i.e., DOE/RW-0006, Rev. 6 (October 1990)]. The inventories for 1990 and the projections through 2020 are taken from refs. 1-4.

[b]Capsules contain either strontium (^{90}Sr-^{90}Y) fluoride or cesium (^{137}Cs-^{137m}Ba) chloride.

[c]Glass may be in storage at the site, in transit to a repository, or in a repository.

Table 2.9. Historical and projected total accumulative thermal power of HLW in storage by site through 2020[a]

End of calendar year	Thermal power, 10^3 W									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Savannah River Site					
1980	213.5	1,440.5	396.0	-	-	-	-	-	-	2,050
1981	302.1	2,037.8	560.1	-	-	-	-	-	-	2,900
1982	259.4	1,749.7	480.9	-	-	-	-	-	-	2,490
1983	237.5	1,601.7	440.4	-	-	-	-	-	-	2,280
1984	244.8	1,650.9	453.9	-	-	-	-	-	-	2,350
1985	264.3	1,782.7	490.2	-	-	-	-	-	-	2,537
1986	302.2	1,794.1	479.0	-	-	-	-	-	-	2,575
1987	279.8	1,438.9	432.8	-	-	0.4	-	-	-	2,152
1988	231.9	1,280.5	370.9	-	-	0.4	-	-	-	1,884
1989	217.7	1,105.8	349.5	-	-	0.7	-	-	-	1,674
1990	209.0	1,015.6	341.7	-	-	0.4	-	-	-	1,567
1995	172.7	1,237.9	274.9	-	-	53.7	-	-	223.1	1,962
2000	151.8	1,353.8	251.5	-	-	20.1	-	-	1,019.0	2,796
2005	137.6	1,602.9	209.6	-	-	14.6	-	-	1,318.0	3,283
2010	71.2	745.4	188.9	-	-	-	-	-	1,368.0	2,374
2015	54.6	788.8	176.4	-	-	5.3	-	-	1,226.0	2,251
2020	45.0	836.5	158.3	-	-	12.6	-	-	1,098.0	2,150
					Idaho Chemical Processing Plant					
1980	53.8	-	-	-	115.2	-	-	-	-	169
1981	88.3	-	-	-	121.7	-	-	-	-	210
1982	88.8	-	-	-	128.2	-	-	-	-	217
1983	55.2	-	-	-	134.8	-	-	-	-	190
1984	29.5	-	-	-	141.3	-	-	-	-	171
1985	72.5	-	-	-	137.4	-	-	-	-	210
1986	38.5	-	-	-	137.4	-	-	-	-	176
1987	43.5	-	-	-	139.0	-	-	-	-	183
1988	30.4	-	-	-	165.2	-	-	-	-	196
1989	34.3	-	-	-	164.9	-	-	-	-	199
1990	22.9	-	-	-	161.5	-	-	-	-	184
1995	25.8	-	-	-	190.1	-	-	-	-	216
2000	3.8	-	-	-	232.9	-	-	-	-	237
2005	5.0	-	-	-	340.9	-	-	-	-	346
2010	4.3	-	-	-	394.5	-	-	-	-	399
2015	4.3	-	-	-	577.6	-	-	-	-	582
2020	10.6	-	-	-	627.5	-	-	-	-	638

Table 2.9 (continued)

End of calendar year	Thermal power, 10^3 W									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Hanford Site					
1980	75.1	325.9	32.8	0.5	-	-	-	644.4	-	1,079
1981	114.0	495.0	49.7	0.8	-	-	-	978.5	-	1,638
1982	84.3	460.3	41.1	0.5	-	-	-	625.2	-	1,212
1983	73.3	449.5	40.0	9.6	-	-	-	610.8	-	1,183
1984	70.7	438.7	39.1	561.1	-	-	-	596.7	-	1,706
1985	65.9	428.3	38.2	604.0	-	-	-	582.9	-	1,719
1986	64.1	418.1	37.3	635.0	-	-	-	569.4	-	1,724
1987	61.2	408.2	36.4	353.4	-	-	-	556.3	-	1,415
1988	58.6	398.4	35.5	328.5	-	-	-	487.6	-	1,309
1989	56.7	389.0	34.7	249.7	-	-	-	476.9	-	1,207
1990	55.1	379.7	33.9	200.4	-	-	-	463.7	-	1,133
1995	21.9	336.7	30.1	170.8	-	-	-	412.5	-	972
2000	19.2	298.6	26.8	270.0	-	-	-	367.1	-	982
2005	17.1	264.9	23.8	261.9	-	-	-	326.6	-	894
2010	15.3	235.0	21.2	234.0	-	-	-	290.6	-	796
2015	13.6	208.5	18.8	209.5	-	-	-	258.5	-	709
2020	12.1	185.0	16.7	187.7	-	-	-	230.0	-	632
					West Valley Demonstration Project					
1980	46.9	55.1	-	-	-	-	-	-	-	102
1981	45.7	53.9	-	-	-	-	-	-	-	100
1982	44.5	52.7	-	-	-	-	-	-	-	97
1983	43.4	51.6	-	-	-	-	-	-	-	95
1984	42.3	50.5	-	-	-	-	-	-	-	93
1985	41.2	49.3	-	-	-	-	-	-	-	91
1986	40.3	48.1	-	-	-	-	-	-	-	88
1987	38.0	47.5	-	-	-	-	-	-	-	86
1988	32.1	46.5	-	-	-	-	6.5	-	-	85
1989	21.6	45.2	-	-	-	-	16.4	-	-	83
1990	13.5	44.6	-	-	-	-	23.1	-	-	81
1995	6.3	39.0	-	-	-	-	27.1	-	-	72
2000	-	-	-	-	-	-	-	-	64.2	64
2005	-	-	-	-	-	-	-	-	57.2	57
2010	-	-	-	-	-	-	-	-	51.0	51
2015	-	-	-	-	-	-	-	-	45.5	46
2020	-	-	-	-	-	-	-	-	40.6	41

[a]Historical inventories for HLW are taken from the previous edition of this report [i.e., DOE/RW-0006, Rev. 6 (October 1990)]. The inventories for 1990 and the projections through 2020 are taken from refs. 1-4.

[b]Capsules contain either strontium (^{90}Sr-^{90}Y) fluoride or cesium (^{137}Cs-^{137m}Ba) chloride.

[c]Glass may be in storage at the site, in transit to a repository, or in a repository.

Table 2.10. Significant revisions and changes in the current values for HLW compared to the values in the previous year

Waste characteristics	1989 values[a]	Significant revisions and changes	1990 values	Reasons for significant changes and revisions or for none
		Savannah River Site		
Volume and radioactivity (liquid, sludge, salt cake, and precipitate)	See Tables 2.5 and 2.6	None	See Tables 2.5 and 2.6	No revisions. Changes are explained by routine plant operations and decay of radionuclides
		Idaho Chemical Processing Plant		
Volume and radioactivity (liquid and calcine)	See Tables 2.5 and 2.6	None	See Tables 2.5 and 2.6	No revisions. Changes are explained by routine plant operations and decay of radionuclides
		Hanford Site		
Volume and radioactivity (liquid, sludge, salt cake, slurry, and Sr capsules)	See Tables 2.5 and 2.6	None	See Tables 2.5 and 2.6	No significant revisions. Changes are explained by routine plant operation
Volume (Cs capsules)	2.49 m^3 (see Table 2.5)	-0.01 m^3	2.48 m^3 (see Table 2.5)	Five Cs capsules were disassembled in 1990
		West Valley Demonstration Project		
Volume (alkaline liquid and zeolite)	See Tables 2.5 and 2.6	Decrease in alkaline liquid (-660 m^3) and increase in zeolite (+14 m^3) volumes	See Tables 2.5 and 2.6	Changes in volume are explained by routine plant operations in preparation for operation of West Valley Vitrification Facility in 1996
Radioactivity (acid liquid, alkaline liquid, sludge, and zeolite)	See Tables 2.5, 2.6, and 2.20	None	See Tables, 2.5, 2.6, and 2.20	Changes are explained by routine plant operations and by radioactive decay

[a]See tables cited in Chapter 2 of U.S. Department of Energy, Integrated Data Base for 1990: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 6 (October 1990).

Table 2.11. Representative chemical composition of current and future HLW at SRS[a]

Liquid		Sludge		Salt cake		Precipitate[b]		Glass	
Component	Wt %	Component	Wt %	Component	Wt %	Component	Wt %	Component	Wt %
Ag	Trace	$Fe(OH)_3$	11.8	$NaNO_3$	65.4	$K(C_6H_5)_4B$	9.0	SiO_2	45.6
Hg	Trace	MnO_2	2.0	$NaNO_2$	0.9	$NaNO_3$	0.7	Na_2O	11.0
Pb	Trace	$UO_2(OH)_2$	1.3	NaOH	3.4	Others	1.8	B_2O_3	10.3
U	Trace	$Al(OH)_3$	13.7	$NaAl(OH)_4$	7.8	H_2O	88.5	Fe_2O_3	7.0
F^-	0.003	AlO(OH)	5.2	Na_2CO_3	2.7		100.0	Al_2O_3	4.0
Fe	Trace	$CaCO_3$	1.5	Na_2SO_4	9.4			K_2O	3.6
Cl^-	0.023	$CaSO_4$	0.2	Na_3PO_4	Trace			Li_2O	3.2
OH^-	1.63	CaC_2O_4	0.2	NaF	0.2			FeO	3.1
NO_2^-	1.10	$Ni(OH)_2$	0.8	$Na_2C_2O_4$	0.1			U_3O_8	2.2
NO_3^-	9.63	HgO	0.4	Insolubles	3.7			MnO	2.0
$Al(OH)_4^-$	4.54	SiO_2	0.2	H_2O	6.4			Others	8.0
CO_3^{2-}	0.72	ThO_2	1.8		100.0				100.0
CrO_4^{2-}	0.014	$Ce(OH)_3$	0.2						
SO_4^{2-}	0.22	$ZrO(OH)_2$	0.2						
PO_4^{3-}	0.12	$Cr(OH)_3$	0.2						
NH_4^+	Trace	$Mg(OH)_2$	0.2						
Na^+	11.0	$NaNO_3$	1.1						
H_2O	71.0	NaOH	1.3						
	100.0	Zeolite	1.5						
		Others	1.2						
		H_2O	55.0						
			100.0						
Density (25°C), g/mL	1.1		1.4		1.9		1.05		2.85

[a]Taken from ref. 1.
[b]Precipitate (non-Newtonian fluid) from the in-tank precipitation process.

Table 2.12. Representative radionuclide composition of current (end of 1990) HLW and HLW glass to be generated in 1993 at SRS[a]

Radionuclide	Radioactivity, Ci					
	Liquid	Sludge	Salt cake	Precipitate	Total	Glass
^{90}Sr	8.08E+05	1.27E+08	1.28E+06	2.00E+03	1.29E+08	1.12E+06
^{90}Y	8.08E+05	1.27E+08	1.28E+06	2.00E+03	1.29E+08	1.12E+06
^{99}Tc[b]	6.00E+03	2.09E+05	2.20E+04	-	2.37E+05	1.70E+03
^{106}Ru	1.59E+05	6.54E+05	6.00E+03	-	8.19E+05	-
^{106}Rh	1.59E+05	6.54E+05	6.00E+03	-	8.19E+05	-
^{125}Sb	1.12E+05	2.72E+05	3.00E+03	-	3.87E+05	1.10E+02
^{137}Cs	4.55E+07	1.16E+07	7.63E+07	7.80E+04	1.33E+08	1.05E+07
^{137m}Ba	4.23E+07	1.08E+07	7.09E+07	7.20E+04	1.24E+08	9.66E+06
^{144}Ce	2.50E+05	5.07E+06	6.00E+03	-	5.33E+06	-
^{144}Pr	2.50E+05	5.07E+06	6.00E+03	-	5.33E+06	-
^{147}Pm	1.20E+06	2.90E+07	2.81E+05	-	3.04E+07	7.00E+03
^{233}U	-	2.48E-01	-	-	2.48E-01	1.86E-02
^{235}U	-	2.62E-01	-	-	2.62E-01	1.97E-02
^{238}U	-	2.19E+01	-	-	2.19E+01	1.50E+00
^{238}Pu	-	1.60E+06	-	-	1.60E+06	1.07E+05
^{239}Pu[c]	-	2.20E+04	-	-	2.20E+04	1.62E+03
^{240}Pu	-	1.04E+04	-	-	1.04E+04	6.99E+02
^{241}Pu	-	1.42E+06	-	-	1.42E+06	8.29E+04
^{242}Pu	-	1.70E+01	-	-	1.70E+01	1.15E+00
^{244}Cm	-	1.47E+04	-	-	1.47E+04	8.79E+02
Total	9.16E+07	3.20E+08	1.50E+08	1.54E+05	5.62E+08	2.26E+07
Specific activity, Ci/L	1.49 6.15×10^{7} L	21.6 1.48×10^{7} L	2.70 5.56×10^{7} L	1.23	4.26 1.32×10^{8} L	266 8.5×10^{4} L

[a]Taken or calculated from ref. 1. Liquid, sludge, salt cake, and precipitate curies are as of December 31, 1990. Glass curies are as of December 31, 1993 (the first year glass is to be generated). Liquid, sludge, salt cake, and precipitate will continue to be waste types in 1993.

[b]SRS has determined that these values for ^{99}Tc are much too large and will revise them downward in future editions of this report.

[c]SRS has determined that these values for ^{239}Pu contain some discrepancies and will correct them in future editions of this report.

2.6 × 85 MTHM = 221 MTHM = 234 MTHM

$\frac{15}{34} \times \frac{9390}{170}$

= 26692

Table 2.13. Representative chemical composition of current and future HLW liquid at ICPP[a]

Component	Composition, wt %			
	Zirconium fluoride	Sodium bearing	Nonfluoride	Fluorinel
Al	1.3	0.8-1.6	1.51	0.742
B	0.15	0.005-0.01	0.003	0.241
Ca	–	0.03-0.2	0.27	–
Cl^-	–	0.06-0.1	0.023	–
Cd	–	–	1.42	–
Cr	–	–	0.036	0.0087
F^-	3.4	0.005-0.06	0.032	5.99
Fe	0.04	0.05-0.09	0.19	0.023
H^+	1.12	0.03-0.15	0.12	0.18
K	1.12	0.03-0.15	0.33	–
Mg	–	–	0.062	–
Mn	–	–	0.048	0.0004
Na	0.12	2.1-4.0	1.31	–
Ni	–	–	0.016	0.0049
NO_3^-	13.7	19.4-23.3	23.1	11.47
SO_4^{2-}	–	0.33-0.5	0.65	1.52
Zr	2.47	–	–	3.80
H_2O	76.6	76.6-69.2	70.9	76.0
	100.0	100.0	100.0	100.0
Density, g/mL	1.2	1.2-1.3	1.2	1.2

[a]Taken from U.S. Department of Energy, Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 1 (December 1985).

Table 2.14. Representative chemical composition of current and future HLW calcine at ICPP[a]

Component	Composition, wt %				
	Alumina	Zirconium fluoride	Zirconium-sodium blend	Stainless steel sulfate	Fluorinel-sodium blend
Al_2O_3	82.0-95.0	13.0-17.0	10.0-16.0	4.4	6.5-7.5
$Al_2(SO_4)_3$	-	-	-	81.0	-
B_2O_3	0.5-2.0	3.0-4.0	2.0-3.0	-	3.0-3.2
CaO	-	2.0-4.0	13.0-17.0	-	3.3-3.6
CaF_2	-	50.0-56.0	33.0-39.0	-	46.0-49.0
Cd	-	-	-	-	6.0-6.5
Cr_2O_3	-	-	-	2.0	0.05
Fe_2O_3	-	-	-	7.0	0.2-0.3
Na_2O	1.3	-	6.0-8.0	-	10.0-15.0
NiO	-	-	-	0.9	0.02-0.03
NO_3^-	5.0-9.0	0.5-2.0	7.0-9.5	-	10.0-15.0
SO_4^{2-}	-	-	-	-	-
ZrO_2	-	21.0-27.0	16.0-19.0	-	19.0-20.0
Miscellaneous	0.5-1.5	0.5-1.5	0.5-1.5	4.4	-
Fission products and actinides	0.2-1.0	0.2-1.0	0.2-1.0	0.2-1.0	0.2-1.0
Density, g/mL	1.1	1.4	1.8	1.2	1.4

[a]Taken from U.S. Department of Energy, Spent Fuel And Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 1 (December 1985).

Table 2.15. Representative radionuclide composition of current HLW at ICPP[a]

Radionuclide	Liquid (10^6 Ci)	Calcine (10^6 Ci)
^{90}Sr	1.738	13.139
^{90}Y	1.738	13.139
^{106}Ru	0.024	0.010
^{106}Rh	0.024	0.010
^{134}Cs	0.107	0.192
^{137}Cs	1.901	14.512
^{137m}Ba	1.798	13.728
^{144}Ce	0.067	0.040
^{144}Pr	0.067	0.040
^{147}Pm	0.000	0.0790
^{154}Eu	0.023	0.093
Total	7.487	55.693
Specific activity, Ci/L	0.88	15.9

[a]Taken from ref. 3. Curies as of December 31, 1990. Similar values for actinide nuclides are not available.

Table 2.16. Representative chemical composition of current and future HLW at HANF[a]

Component	Composition, wt %			
	Liquid[b]	Sludge[b]	Salt cake[b]	Slurry[c]
$NaNO_3$	20.8	25.3	81.5	14.8
$NaNO_2$	15.8	3.8	1.7	5.6
Na_2CO_3	0.6	2.2	0.5	1.9
NaOH	6.2	5.3	1.5	7.0
$NaAlO_2$	12.5	1.2	1.4	6.0
NaF	–	–	–	0.4
Na_2SO_4	–	1.0	1.3	0.3
Na_3PO_4	2.3	15.8	1.6	0.8
KF	–	–	–	0.4
FeO(OH)	–	1.3	–	0.2
Organic carbon	0.17	–	–	1.2
NH_4^+	–	–	–	0.08
$Al(OH)_3$	–	2.9	–	4.9
$SrO \cdot H_2O$	–	0.1	–	–
Na_2CrO_4	1.3	–	–	–
$Cr(OH)_3$	–	0.2	–	0.02
$Cd(OH)_2$	–	0.1	–	–
$Ni(OH)_2$	–	–	–	<0.1
$BiPO_4$	–	0.5	–	–
Cl^-	–	0.1	–	–
$Ni_2Fe(CN)_6$	–	0.6	–	–
$P_2O_5 \cdot 24WO_2 \cdot 44H_2O$	–	<0.1	–	–
$ZrO_2 \cdot 2H_2O$	–	0.5	–	0.2
Fission products	–	–	–	<0.01
H_2O	40.2	33.6	10.5	56.2
Other	<0.1	5.5	–	<0.01
Hg^+	–	0.12 ppm	–	–
Total	100.0	100.0	100.0	100.0
Density, g/mL	1.6	1.7	1.4	~1.3

[a]Taken from U.S. Department of Energy, Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 1 (December 1985).

[b]Stored in single-shell tanks.

[c]Stored in double-shell tanks.

Table 2.17. Representative radionuclide composition (Ci) of current HLW at HANF[a]

Radionuclide	Liquid	Sludge	Salt cake	Slurry	Capsules	
					^{90}Sr-^{90}Y	^{137}Cs-^{137m}Ba
^{14}C	1.97E+03	-	2.50E+03	5.69E+02	-	-
^{55}Fe	-	-	-	8.09E+03	-	-
^{60}Co	-	4.19E+03	-	1.34E+04	-	-
^{59}Ni	-	-	-	9.06E+00	-	-
^{63}Ni	-	3.12E+05	-	1.06E+03	-	-
^{79}Se	-	-	-	6.58E+01	-	-
^{89}Sr	-	-	-	2.05E-01	-	-
^{90}Sr	4.56E+05	5.35E+07	2.31E+06	1.14E+07	2.66E+07	-
^{90}Y	4.56E+05	5.35E+07	2.31E+06	1.14E+07	2.66E+07	-
^{91}Y	-	-	-	3.83E+00	-	-
^{93}Zr	-	9.70E+03	-	3.21E+02	-	-
^{95}Zr	-	-	-	1.94E+01	-	-
^{93m}Nb	-	8.06E+03	-	9.78E+01	-	-
^{95}Nb	-	-	-	4.30E+01	-	-
^{95m}Nb	-	-	-	1.43E-01	-	-
^{99}Tc	1.89E+04	-	-	1.33E+04	-	-
^{103}Ru	-	-	-	6.47E-04	-	-
^{103m}Rh	-	-	-	5.83E-04	-	-
^{106}Ru	-	3.88E+01	-	1.20E+06	-	-
^{106}Rh	-	3.88E+01	-	1.20E+06	-	-
^{107}Pd	-	-	-	8.21E+00	-	-
^{110}Ag	-	-	-	1.65E+00	-	-
^{110m}Ag	-	-	-	1.24E+02	-	-
^{113m}Cd	-	-	-	4.12E+03	-	-
^{115m}Cd	-	-	-	1.73E-05	-	-
^{113}Sn	-	-	-	6.45E+00	-	-
^{119m}Sn	-	-	-	2.31E+03	-	-
^{121m}Sn	-	-	-	6.57E+01	-	-
^{123}Sn	-	-	-	8.88E+01	-	-
^{126}Sn	-	-	-	1.04E+02	-	-
^{124}Sb	-	-	-	2.01E-04	-	-
^{125}Sb	-	-	-	4.88E+05	-	-
^{126}Sb	-	-	-	1.46E+01	-	-
^{126m}Sb	-	-	-	1.15E+02	-	-
^{123m}Te	-	-	-	4.12E-04	-	-
^{125m}Te	-	-	-	1.19E+05	-	-
^{127}Te	-	-	-	6.82E+01	-	-
^{127m}Te	-	-	-	6.90E+01	-	-
^{129}Te	-	-	-	1.87E-07	-	-
^{129m}Te	-	-	-	2.88E-07	-	-
^{129}I	-	-	-	2.65E-01	-	-
^{134}Cs	-	-	-	2.75E+05	-	-
^{135}Cs	-	-	-	5.92E+01	-	-
^{137}Cs	1.08E+07	3.78E+06	3.83E+06	1.64E+07	-	5.92E+07
^{137m}Ba	1.02E+07	3.57E+06	3.62E+06	1.55E+07	-	5.60E+07
^{141}Ce	-	-	-	4.81E-06	-	-
^{144}Ce	-	-	-	2.75E+06	-	-
^{144}Pr	-	-	-	2.74E+06	-	-
^{144m}Pr	-	-	-	3.29E+04	-	-
^{147}Pm	-	-	-	1.05E+07	-	-

Table 2.17 (continued)

Radionuclide	Liquid	Sludge	Salt cake	Slurry	Capsules	
					^{90}Sr-^{90}Y	^{137}Cs-^{137m}Ba
^{148}Pm	-	-	-	1.05E-06	-	-
^{148m}Pm	-	-	-	1.87E-05	-	-
^{151}Sm	-	8.46E+05	-	2.34E+05	-	-
^{152}Eu	-	-	-	5.99E+02	-	-
^{154}Eu	-	-	-	7.93E+04	-	-
^{155}Eu	-	-	-	1.31E+05	-	-
^{153}Gd	-	-	-	8.70E-01	-	-
^{160}Tb	-	-	-	1.07E-03	-	-
^{234}U	-	-	-	1.23E+00	-	-
^{235}U	-	-	-	5.18E-02	-	-
^{236}U	-	-	-	1.08E-01	-	-
^{238}U	-	-	-	9.45E-01	-	-
^{237}Np	2.15E-03	-	-	4.51E+01	-	-
^{238}Np	-	-	-	2.19E-01	-	-
^{238}Pu	-	-	-	3.72E+02	-	-
^{239}Pu	-	2.20E+04	-	3.28E+03	-	-
^{240}Pu	-	5.30E+03	-	8.85E+02	-	-
^{241}Pu	-	5.78E+04	-	3.69E+04	-	-
^{242}Pu	-	-	-	8.68E-02	-	-
^{241}Am	7.77E+02	4.53E+04	-	5.24E+04	-	-
^{242}Am	-	-	-	4.35E+01	-	-
^{242m}Am	-	-	-	4.38E+01	-	-
^{243}Am	-	-	-	7.16E+00	-	-
^{242}Cm	-	-	-	4.35E+01	-	-
^{244}Cm	-	1.69E+02	-	1.39E+03	-	-
Total	2.19E+07	1.16E+08	1.21E+07	7.46E+07	5.32E+07	1.15E+08
Specific activity, Ci/L	2.64×10^7 L. 8.3E-01	4.64×10^7 2.5E+00	1.3E-01	8.78×10^7 8.5E-01	5.0E+04	4.6E+04

[a]Taken from ref. 3. Curies as of December 31, 1990.

Table 2.18. Chemical composition of alkaline liquid HLW (from reprocessing via a PUREX flowsheet) at WVDP[a]

Compound	Wet basis (wt %)	Dry basis (wt %)	Total (kg)
$NaNO_3$	21.10	53.38	602,659
$NaNO_2$	10.90	27.57	311,326
Na_2SO_4	2.67	6.75	76,261
$NaHCO_3$	1.49	3.77	42,557
KNO_3	1.27	3.21	36,274
Na_2CO_3	0.884	2.24	25,249
NaOH	0.614	1.55	17,537
K_2CrO_4	0.179	0.45	5,113
NaCl	0.164	0.42	4,684
Na_3PO_4	0.133	0.34	3,799
Na_2MoO_4	0.0242	0.06	691
Na_3BO_3	0.0209	0.05	597
$CsNO_3$	0.0187	0.05	534
NaF	0.0176	0.04	503
$Sn(NO_3)_4$	0.00858	0.02	245
$Na_2U_2O_7$	0.00809	0.02	231
$Si(NO_3)_4$	0.00805	0.02	230
$NaTcO_4$	0.00620	0.02	177
$RbNO_3$	0.00417	0.01	119
Na_2TeO_4	0.00287	0.007	82
AlF_3	0.0027	0.0068	77
$Fe(NO_3)_3$	0.00151	0.004	43
Na_2SeO_4	0.00053	0.0013	15
$LiNO_3$	0.00049	0.0012	14
H_2CO_3	0.00032	0.00080	9
$Cu(NO_3)_3$	0.00021	0.00053	6
$Sr(NO_3)_2$	0.00014	0.00035	4
$Mg(NO_3)_2$	0.00007	0.00018	2
Subtotal	39.53	100.00	1,129,038
H_2O (by difference)	60.47	0.00	1,727,116
Grand total	100.00	100.00	2,856,154

[a]Taken from ref. 4.

Table 2.19. Chemical composition of alkaline sludge HLW (from reprocessing via a PUREX flowsheet) at WVDP[a]

Compound	Weight, kg
Fission products	
$Ge(OH)_3$	0.2
$SrSO_4$	217
$Y(OH)_3$	103
$Zr(OH)_4$	964
$Ru(OH)_4$	458
$Rh(OH)_4$	79
$Pd(OH)_2$	34
AgOH	0.7
$Cd(OH)_2$	1.7
$In(OH)_3$	0.3
$Sn(OH)_4$	2.5
$Sb(OH)_3$	0.7
$BaSO_4$	303
$La(OH)_3$	185
$Ce(OH)_3$	354
$Pr(OH)_3$	170
$Nd(OH)_3$	621
$Pm(OH)_3$	1.5
$Sm(OH)_3$	143
$Eu(OH)_3$	7.5
$Gd(OH)_3$	1.7
$Tb(OH)_3$	0.3
$Dy(OH)_3$	0.2
Subtotal	3,648.3
Actinides	
$UO_2(OH)_2$	3,087
NpO_2	35
PuO_2	37
AmO_2	27
CmO_2	0.4
Subtotal	3,186.4
Others	
$Fe(OH)_3$	66,040
$FePO_4$	6,351
$Al(OH)_3$	5,852
AlF_3	613
MnO_2	4,581
$CaCO_3$	3,208
SiO_2	1,263
$Ni(OH)_2$	1,088
$MgCO_3$	826
$Cu(OH)_2$	376
$Zr(OH)_4$	964[b]
$Zn(OH)_2$	128
$Cr(OH)_3$	65
$Hg(OH)_2$	23
Subtotal	91,378
Grand total	98,213

[a]Taken from ref. 4.
[b]Excludes fission product zirconium.

Table 2.20. Chemical composition of acid liquid HLW (from reprocessing via a THOREX flowsheet) at WVDP[a]

Compound	Wt %	Total, kg
$Th(NO_3)_4$	36.42	31,054
$Fe(NO_3)_3$	9.92	8,462
$Al(NO_3)_3$	4.90	4,175
HNO_3	3.29	2,805
$Cr(NO_3)_3$	2.25	1,918
$Ni(NO_3)_2$	0.93	79
H_3BO_3	0.56	480
$NaNO_3$	0.27	227
KNO_3	0.22	191
Na_2SO_4	0.21	180
Na_2SiO_3	0.15	126
$KMnO_4$	0.11	98
$Nd(NO_3)_3$	0.086	73
$Mg(NO_3)_2$	0.067	57
Na_2MoO_4	0.063	54
NaCl	0.059	50
$Ce(NO_3)_4$	0.050	43
$Ru(NO_3)_4$	0.049	42
ZrO_2	0.041	35
$Ca(NO_3)_2$	0.035	30
$CsNO_3$	0.033	28
$Ba(NO_3)_2$	0.032	27
$La(NO_3)_3$	0.026	22
$Pr(NO_3)_3$	0.025	21
$Sr(NO_3)_2$	0.019	16
$Y(NO_3)_3$	0.016	14
$Sm(NO_3)_3$	0.016	14
$Zr(NO_3)_4$	0.014	12
Na_3PO_4	0.014	12
$NaTcO_4$	0.013	11
$Rh(NO_3)_4$	0.013	11
$Zn(NO_3)_2$	0.012	10
$Pd(NO_3)_4$	0.0094	8
$UO_2(NO_3)_2$	0.0070	6
$RbNO_3$	0.0070	6
Na_2TeO_4	0.0059	5
$Co(NO_3)_2$	0.0035	3
Na_2SeO_4	0.0012	1
NaF	0.0012	1
$Eu(NO_3)_3$	0.0012	1
$Np(NO_3)_4$	0.0011	0.9
$Cu(NO_3)_2$	0.00094	0.8
$Sn(NO_3)_3$	0.00082	0.7
$Pa(NO_3)_4$	0.00082	0.7
$Pu(NO_3)_4$	0.00082	0.7
$Gd(NO_3)_3$	0.00047	0.4
$Cd(NO_3)_2$	0.00035	0.3
$Sb(NO_3)_3$	0.00012	0.1
$AgNO_3$	0.000094	0.08
$In(NO_3)_3$	0.000047	0.04
$Ge(NO_3)_4$	0.000023	0.02
$Pm(NO_3)_2$	0.000011	0.01
$Tb(NO_3)_3$	0.0000047	0.004
$Dy(NO_3)_3$	0.0000023	0.002
Solids	59.95	51,125
H_2O (by difference)	40.05	34,148
Total	100.00	85,273

[a]Adapted from ref. 4.

Table 2.21. Reference (end of 1990) radionuclide composition of HLW at WVDP[a,b]

Radionuclide	Alkaline waste (PUREX) Liquid[c] (Ci)	Alkaline waste (PUREX) Sludge (Ci)	Acid waste (THOREX) Liquid (Ci)	Zeolite waste (Ion exchanger) Slurry[d] (Ci)	Total (Ci)
^{3}H	7.78E+01	0.00E+00	1.47E+00	0.00E+00	7.93E+01
^{14}C	1.37E+02	0.00E+00	1.30E-01	0.00E+00	1.37E+02
^{55}Fe	0.00E+00	3.44E+02	2.53E+02	0.00E+00	5.97E+02
^{60}Co	0.00E+00	2.78E+00	7.68E+02	0.00E+00	7.71E+02
^{59}Ni	0.00E+00	8.56E+01	2.03E+01	0.00E+00	1.06E+02
^{63}Ni	8.63E+02	5.18E+03	2.45E+03	0.00E+00	8.50E+03
^{79}Se	5.68E+01	0.00E+00	3.35E+00	0.00E+00	6.01E+01
^{90}Sr	2.63E+03	6.13E+06	4.23E+05	0.00E+00	6.55E+06
^{90}Y	2.63E+03	6.13E+06	4.23E+05	0.00E+00	6.55E+06
^{93}Zr	2.56E-01	2.56E+02	1.62E+01	0.00E+00	2.72E+02
^{93m}Nb	1.77E-01	1.75E+02	1.11E+01	0.00E+00	1.86E+02
^{99}Tc	1.60E+03	0.00E+00	1.04E+02	0.00E+00	1.70E+03
^{106}Ru	7.07E-03	7.07E+00	7.96E-02	0.00E+00	7.15E+00
^{106}Rh	7.07E-03	7.07E+00	7.97E-02	0.00E+00	7.16E+00
^{107}Pd	1.09E-02	1.09E+01	1.14E-01	0.00E+00	1.10E+01
^{113m}Cd	1.99E+00	1.99E+03	3.25E+01	0.00E+00	2.03E+03
^{121m}Sn	1.67E-02	1.67E+01	5.75E-01	0.00E+00	1.72E+01
^{126}Sn	1.01E-01	1.01E+02	3.11E+00	0.00E+00	1.04E+02
^{125}Sb	1.80E+01	5.55E+03	1.36E+02	0.00E+00	5.70E+03
^{126}Sb	1.41E-02	1.41E+01	4.35E-01	0.00E+00	1.46E+01
^{126m}Sb	1.01E-01	1.01E+02	3.11E+00	0.00E+00	1.04E+02
^{125m}Te	4.41E+00	1.36E+03	3.34E+01	0.00E+00	1.40E+03
^{129}I	2.10E-01	0.00E+00	1.80E-01	0.00E+00	3.90E-01
^{134}Cs	7.24E+02	0.00E+00	1.13E+02	2.90E+03	3.73E+03
^{135}Cs	3.12E+01	0.00E+00	5.47E+00	1.25E+02	1.61E+02
^{137}Cs	1.32E+06	0.00E+00	4.43E+05	5.30E+06	7.06E+06
^{137m}Ba	1.25E+06	0.00E+00	4.19E+05	5.01E+06	6.68E+06
^{144}Ce	5.95E-07	2.62E-01	9.63E-03	0.00E+00	2.72E-01
^{144}Pr	5.95E-07	2.62E-01	9.64E-03	0.00E+00	2.72E-01
^{146}Pm	2.88E-02	9.24E+00	3.47E-01	0.00E+00	9.62E+00
^{147}Pm	1.98E+02	6.42E+04	4.12E+03	0.00E+00	6.85E+04
^{151}Sm	4.88E-01	7.90E+04	4.67E+03	0.00E+00	8.37E+04
^{152}Eu	3.73E-02	3.07E+02	4.14E+01	0.00E+00	3.49E+02
^{154}Eu	1.04E+01	8.62E+04	1.99E+03	0.00E+00	8.82E+04
^{155}Eu	1.36E+00	2.02E+04	5.55E+02	0.00E+00	2.08E+04
^{207}Tl	3.29E-08	8.37E-04	8.19E+00	0.00E+00	8.19E+00
^{208}Tl	8.38E-02	1.18E+00	2.18E+00	0.00E+00	3.45E+00
^{209}Pb	1.88E-04	2.63E-03	2.08E-01	0.00E+00	2.10E-01
^{211}Pb	3.30E-08	8.39E-04	8.22E+00	0.00E+00	8.22E+00
^{212}Pb	2.34E-01	3.30E+00	6.08E+00	0.00E+00	9.61E+00
^{211}Bi	3.30E-08	8.39E-04	8.22E+00	0.00E+00	8.22E+00
^{212}Bi	2.34E-01	3.30E+00	6.08E+00	0.00E+00	9.61E+00
^{213}Bi	1.88E-04	2.63E-03	2.08E-01	0.00E+00	2.10E-01
^{212}Po	1.50E-01	2.11E+00	3.90E+00	0.00E+00	6.16E+00
^{213}Po	1.84E-04	2.57E-03	2.03E-01	0.00E+00	2.06E-01
^{215}Po	3.30E-08	8.39E-04	8.22E+00	0.00E+00	8.22E+00
^{216}Po	2.34E-01	3.30E+00	6.08E+00	0.00E+00	9.61E+00
^{217}At	1.88E-04	2.63E-03	2.08E-01	0.00E+00	2.10E-01
^{219}Rn	3.30E-08	8.39E-04	8.22E+00	0.00E+00	8.22E+00
^{220}Rn	2.34E-01	3.30E+00	6.08E+00	0.00E+00	9.61E+00
^{221}Fr	1.88E-04	2.63E-03	2.08E-01	0.00E+00	2.10E-01
^{223}Fr	4.56E-10	1.16E-05	1.13E-01	0.00E+00	1.13E-01
^{223}Ra	3.30E-08	8.39E-04	8.22E+00	0.00E+00	8.22E+00
^{224}Ra	2.34E-01	3.30E+00	6.08E+00	0.00E+00	9.61E+00
^{225}Ra	1.88E-04	2.63E-03	2.08E-01	0.00E+00	2.10E-01
^{228}Ra	0.00E+00	5.17E-09	1.52E+00	0.00E+00	1.52E+00
^{225}Ac	1.88E-04	2.63E-03	2.08E-01	0.00E+00	2.10E-01
^{227}Ac	3.30E-08	8.39E-04	8.22E+00	0.00E+00	8.22E+00
^{228}Ac	0.00E+00	5.17E-09	1.52E+00	0.00E+00	1.52E+00

Table 2.21 (continued)

Radionuclide	Alkaline waste (PUREX) Liquid[c] (Ci)	Alkaline waste (PUREX) Sludge (Ci)	Acid waste (THOREX) Liquid (Ci)	Zeolite waste (Ion exchanger) Slurry[d] (Ci)	Total (Ci)
^{227}Th	3.26E-08	8.28E-04	8.10E+00	0.00E+00	8.10E+00
^{228}Th	2.34E-01	3.30E+00	6.08E+00	0.00E+00	9.61E+00
^{229}Th	1.88E-04	2.63E-03	2.08E-01	0.00E+00	2.10E-01
^{230}Th	1.01E-05	1.46E-02	4.38E-02	0.00E+00	5.85E-02
^{231}Th	6.41E-03	8.94E-02	5.17E-03	0.00E+00	1.01E-01
^{232}Th	0.00E+00	5.87E-09	1.64E+00	0.00E+00	1.64E+00
^{234}Th	5.71E-02	7.97E-01	7.11E-05	0.00E+00	8.54E-01
^{231}Pa	5.42E-07	3.02E-04	1.52E+01	0.00E+00	1.52E+01
^{233}Pa	5.68E-06	2.31E+01	3.02E-01	0.00E+00	2.34E+01
^{234m}Pa	5.71E-02	7.97E-01	7.11E-05	0.00E+00	8.54E-01
^{232}U	3.02E-01	4.23E+00	2.66E+00	0.00E+00	7.19E+00
^{233}U	4.98E-01	6.94E+00	2.09E+00	0.00E+00	9.53E+00
^{234}U	2.81E-01	3.99E+00	2.21E-01	0.00E+00	4.49E+00
^{235}U	6.41E-03	8.94E-02	5.17E-03	0.00E+00	1.01E-01
^{236}U	1.91E-02	2.67E-01	9.80E-03	0.00E+00	2.96E-01
^{238}U	5.71E-02	7.97E-01	7.11E-05	0.00E+00	8.54E-01
^{236}Np	0.00E+00	9.35E+00	1.23E-01	0.00E+00	9.47E+00
^{237}Np	5.68E-06	2.31E+01	3.02E-01	0.00E+00	2.34E+01
^{239}Np	0.00E+00	3.39E+02	7.83E+00	0.00E+00	3.47E+02
^{236}Pu	5.14E-03	8.29E-01	1.09E-02	0.00E+00	8.45E-01
^{238}Pu	1.23E+02	7.76E+03	4.69E+02	0.00E+00	8.35E+03
^{239}Pu	2.54E+01	1.61E+03	1.54E+01	0.00E+00	1.65E+03
^{240}Pu	1.87E+01	1.18E+03	8.09E+00	0.00E+00	1.21E+03
^{241}Pu	1.20E+03	7.61E+04	7.36E+02	0.00E+00	7.81E+04
^{242}Pu	2.54E-02	1.61E+00	1.19E-02	0.00E+00	1.65E+00
^{241}Am	8.49E+00	5.32E+04	2.44E+02	0.00E+00	5.35E+04
^{242}Am	0.00E+00	2.87E+02	6.66E+00	0.00E+00	2.94E+02
^{242m}Am	0.00E+00	2.89E+02	6.70E+00	0.00E+00	2.95E+02
^{243}Am	0.00E+00	3.39E+02	7.83E+00	0.00E+00	3.47E+02
^{242}Cm	0.00E+00	2.38E+02	5.53E+00	0.00E+00	2.44E+02
^{243}Cm	0.00E+00	1.31E+02	2.18E-01	0.00E+00	1.31E+02
^{244}Cm	0.00E+00	7.34E+03	1.22E+01	0.00E+00	7.36E+03
^{245}Cm	0.00E+00	8.62E-01	2.00E-02	0.00E+00	8.82E-01
^{246}Cm	0.00E+00	9.86E-02	2.29E-03	0.00E+00	1.01E-01
Total	2.58E+06	1.27E+07	1.72E+06	1.03E+07	2.73E+07
Specific activity, Ci/L	1.08×10^6 L 2.4E+00	4.54×10^4 L 2.8E+02	5.1×10^4 L 3.4E+01	4.5×10^4 L 2.3E+02	2.2E+01

[a]Taken from ref. 4.

[b]Includes all radionuclides >0.1 Ci prior to year 3090.

[c]Does not include radioactivity associated with the alkaline liquid in the interstices of loaded zeolite slurry.

[d]Includes radioactivity associated with the alkaline liquid in interstices.

	6.888×10^6 L	0.040×10^6	1.088×10^6	0.072×10^6	50 P
Pu-239	21	1631	13		1700
Pu-240	15	1195	7		1300
Am-241	7	53894	206		92000
Cm-244		7436	10		22000
Np-237	4.69×10^{-6}	23	0.2		11

ORNL PHOTO 7873-91

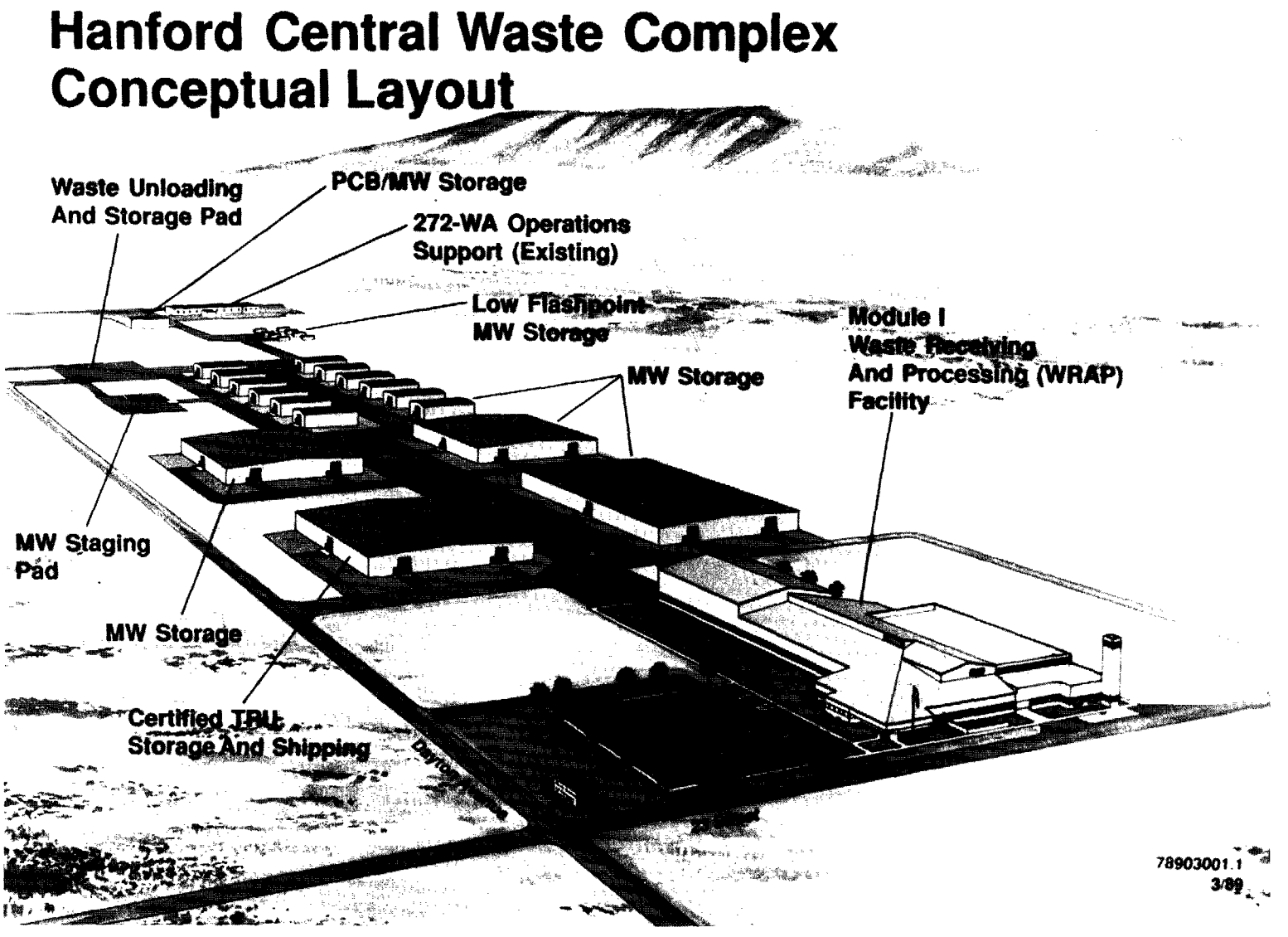


Photo 3.1. An artist's layout of the Hanford Central Waste Complex to be used, in part, for storage of certified transuranic waste. (Courtesy of Westinghouse Hanford Company, Richland, Washington.)

3. TRANSURANIC WASTE

3.1 INTRODUCTION

Transuranic (TRU) waste refers to waste materials containing elements with atomic numbers greater than 92. These elements are generally alpha-emitting radionuclides with half-lives greater than 20 years. To be "transuranic," these waste materials must contain transuranic elements in quantities greater than 100 nCi/g of waste material.[1] These wastes are the result of reprocessing plutonium-bearing fuel and/or fabricating nuclear weapons. Most TRU waste is trash (e.g., coveralls, rags, metals, sludges, gloves, and tools) that has become contaminated during operations.

Prior to 1970, all DOE-generated TRU waste was disposed of in several landfill-type configurations at DOE sites. In 1970, the Atomic Energy Commission (AEC, predecessor to DOE) concluded that these wastes should have greater confinement from the environment. Consequently, since then, TRU wastes have been placed in "retrievable" storage.[2] As noted above, most of this waste is alpha-emitting; therefore, the waste package provides sufficient containment, and the packages are designated as "contact handled" (CH) TRU waste. A small percentage (2.6%) of the waste in retrievable storage contains sufficient penetrating beta, gamma, and neutron radiation (greater than 200 mrem/h) to require remote handling. These wastes are designated as "remote-handled" (RH) TRU waste.

Early disposal practices did not include the current requirements of waste identification and categorization. Consequently, listings of early data were based on various studies and summaries.[3] As these efforts continue and more disposal locations are characterized, significant changes in the overall quantity of TRU waste are anticipated.

Table 3.1 summarizes the current inventory and projected accumulation at DOE storage sites for buried, potentially contaminated soil and retrievably stored TRU wastes from DOE activities. The locations of these sites and associated volumes of waste are given in Fig. 3.1. It is planned that the retrievably stored TRU waste and newly generated TRU waste from defense activities will be shipped to and emplaced in the Waste Isolation Pilot Plant (WIPP). WIPP is currently preparing for a test phase, which is anticipated to last 5 to 7 years. During this phase, experimental wastes will be emplaced to support demonstration that WIPP will meet federal and state regulations covering long-term disposal of radioactive waste and disposal of hazardous wastes and land disposal restricted wastes. If successful, the retrievable TRU inventory will be emplaced through 2013. Based on the current WIPP test phase strategy and schedule, a 20-year emplacement schedule would extend this date to 2018. This change will be incorporated into the tables of the 1992 IDB report.

The points of origin and storage sites of DOE TRU waste are identified in Fig. 3.2. Figures 3.3 and 3.4 show the waste volume and mass of TRU radionuclides that have been disposed of at the major DOE sites. The volume and TRU mass of the retrievably stored TRU waste currently at DOE sites are given in Figs. 3.5 and 3.6, respectively. The relationship of the various data tables and the method by which the WIPP inventory is determined can be seen in Fig. 3.7.

3.2 INVENTORIES

Prior to the AEC's directive of March 1970,[2] LLW containing DOE-generated TRU nuclides was disposed of by shallow-land burial at various AEC (now DOE) sites. The estimated total waste volume and the associated quantity of nuclear material currently disposed of at DOE sites are given in Table 3.2.[4,5] The radioactivity has been estimated from historical records.

Over the years, many of the older disposed containers have breached and contaminated the adjacent soil. The estimates of this soil volume are contained in Table 3.3. Also, at some sites, soil was contaminated by liquid spills or by the use of soil as an ion-exchange medium for dilute liquid waste streams. These data are contained in Table 3.4. It is very difficult to accurately determine the actual quantity of contaminated soil, as noted by the ranges in the reported data. Additional characterization efforts will be required to reduce the uncertainty in these data.

The CH waste inventories are reported in "as packaged" volumes for shipment to WIPP. These volumes assume a drum volume of 0.208 m^3 and a standard waste box volume of 1.9 m^3 for storage. Remote-handled waste volumes are reported as currently packaged for storage. Prior to emplacement at WIPP, RH waste will be placed

in canisters. Each canister can hold three 30-gal drums, three 55-gal drums, or loose waste in a total canister volume of 0.89 m^3. Therefore, the volume of RH waste emplaced in canisters will be larger than the current inventory volume. Current estimates are that approximately 8000 canisters will be available for disposal.

The percentage of TRU waste certified for acceptance at the WIPP is not included in this year's report. In past years, these data have been based on the quantity certified to WIPP operational criteria. Although these certifications are still valid, it has not been established how much of this certified waste meets the current requirements for shipment in TRUPACT-II containers or how much meets the WIPP characterization requirements for RCRA constituents. A table on certification status will be included in next year's report.

In 1970, when AEC initiated the policy of retrievable storage for TRU waste, the definition for TRU waste was 10 nCi/g. In 1984, the definition was changed to 100 nCi/g.[6] Consequently, the waste currently in storage is composed of wastes that were stored under both criteria. Those wastes currently in storage that contain less than 100 nCi/g of TRU nuclides are considered LLW. Table 3.5 summarizes DOE site data on the volume, TRU elemental mass, and radioactivity for both the potentially certifiable TRU waste and the LLW quantities of the retrievably stored TRU waste. It is estimated that 40% (39,197 m^3) of the current inventory will be designated as LLW.

The ongoing efforts at the DOE sites in reviewing historical records and the current sampling and characterization programs generate updated information which makes previously published information obsolete. Table 3.6 (based on refs. 4 and 7) reports the modifications made to TRU waste inventories since the previous IDB report (only stored wastes are affected). This table has been prepared to provide continuity to the IDB publications. Listed below is a description of the major changes involved in this year's data.

- Hanford Site: Volume changes — The certified CH TRU volume reduction is due to changes in the anticipated TRU waste/LLW ratio for boxed waste currently in storage, based on historical records. RH TRU volume increase is also based on a review of historical records. The future generation volume indicates a significant increase due to the inclusion of off-site generators in the CH value and refinements in the RH projections.

- Idaho National Engineering Laboratory: The reduction in newly generated waste volume is due to the deletion of the waste associated with the Special Isotope Separation project.

- Los Alamos National Laboratory: The mass of TRU elements increased in the RH TRU waste due to the inclusion of ^{235}U in the value.

- Lawrence Livermore National Laboratory: No CY 1990 data were reported; the CY 1989 data were used.[7]

- Mound Plant: This is the initial reporting of the waste currently in temporary storage.

- Nevada Test Site: Revisions to the data are based on historical record review and upgrading.

- Savannah River Site: There is a significant reduction in the radioactivity projections for future wastes. This change is based on a reevaluation of these wastes.

3.3 WASTE CHARACTERIZATION

3.3.1 Physical Composition

The physical species of the TRU waste inventory are given in Table 3.7. These data are based on historical records, current activities, and projections for future operations.

3.3.2 Isotopic Composition

Isotopic compositions are given in Table 3.8 for buried, CH, and RH TRU waste at the DOE sites. These data are reported as a composite mixture for a site (Hanford CH TRU) or as individual mixtures for the various types of site operations (SRS). In those situations in which data were not available (ORNL and SRS buried waste), a knowledge of the background of the site operations was utilized to estimate the isotopic composition. These data were utilized in the calculations of thermal power and radioactivity using a simplified version of the ORIGEN2 computer program to produce the data for Tables 3.1 and 3.9. The site radioactivity data are the "as reported" values and do not include radioactive decay or the contribution of daughter products. Consequently, the computed values of Tables 3.1 and 3.9 will not be the same as the corresponding values reported by the sites.

3.4 SHIPMENT AND DISPOSAL

It is the goal of DOE's Transuranic Waste Program to terminate interim storage and to achieve permanent disposal of DOE TRU waste.[8] In compliance with Public Law 96-164,[9] the WIPP project is being constructed "... as a defense activity of the DOE for the purpose of providing a research and development facility to demonstrate the safe disposal of radioactive waste resulting from defense activities and programs of the United States."

The WIPP will receive TRU wastes to conduct various experiments related to regulatory compliance of the repository. If WIPP meets the requirements, the waste will be emplaced on an operational basis through the year 2013. As noted previously, based on the current WIPP test phase strategy and schedule, a 20-year emplacement schedule would extend this date to 2018. Waste received at WIPP must meet the waste acceptance criteria (WAC) and associated quality assurance requirements specified in WIPP/DOE-069 and 120.[10,11] Table 3.10 provides the data on estimated future generation of waste. The volume inventory as packaged for shipment to the WIPP is given in Table 3.11. Small quantities of TRU waste will also be generated in environmental restoration activities as discussed in Sect. 6.2.1.

3.5 REFERENCES

1. U.S. Department of Energy, Radioactive Waste Management, DOE Order 5820.2A, Washington, D.C. (Sept. 26, 1988).

2. K. S. Hollingsworth, Policy Statement Regarding Solid Waste Burial, AEC Directive IAD No. 0511-21, Washington, D.C. (Mar. 20, 1970).

3. U.S. Department of Energy, Defense Waste Management Plan for Buried Transuranic-Contaminated Waste, Transuranic-Contaminated Soil, and Difficult-to-Certify Transuranic Waste, DOE/DP-0044, Washington, D.C. (June 1987).

4. M. H. McFadden, U.S. Department of Energy, Field Office, Albuquerque, WIPP Project Office, Carlsbad, New Mexico, memorandum to J. A. Klein, Oak Ridge National Laboratory, Oak Ridge, Tennessee, detailing TRU Waste Program's IDB submittal through December 31, 1990, dated July 24, 1991.

5. D. M. Lund, U.S. Department of Energy, Field Office, Albuquerque, Albuquerque, New Mexico, memorandum to J. A. Klein, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "TRU Waste Program's IDB Submittal through Dec. 31, 1986," dated Mar. 31, 1987.

6. U.S. Department of Energy, Radioactive Waste Management, DOE Order 5820.2, Washington, D.C. (Feb. 6, 1984).

7. U.S. Department of Energy, Integrated Data Base for 1990: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 6, Oak Ridge National Laboratory, Oak Ridge, Tennessee (October 1990).

8. U.S. Department of Energy, Long Range Master Plan for Defense Transuranic Waste Program, DOE/WIPP 88-028, Carlsbad, New Mexico (December 1988).

9. U.S. Congress, Department of Energy National Security and Military Application of Nuclear Energy Authorization Act of 1980, Pub. L. 96-164 (1980).

10. U.S. Department of Energy, TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant, WIPP/DOE-069, Rev. 3, Carlsbad, New Mexico (January 1989).

11. U.S. Department of Energy, Quality Assurance Requirements for Certification of TRU Waste for Shipment to WIPP, WIPP/DOE-120, Rev. 2, Carlsbad, New Mexico (August 1988).

ORNL DWG 91-8662

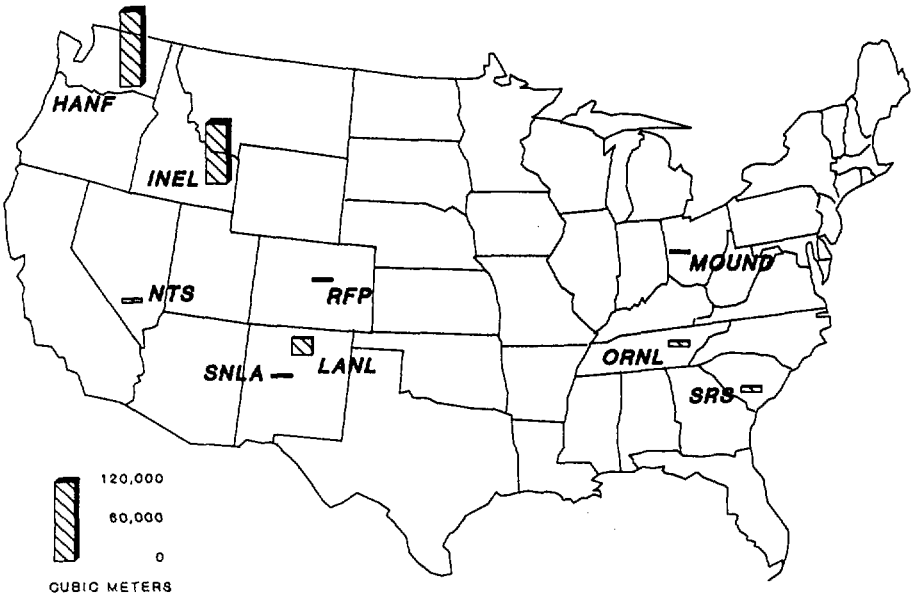


Fig. 3.1. Locations and total volumes of buried and stored DOE TRU waste through 1990.

ORNL DWG 91-8663

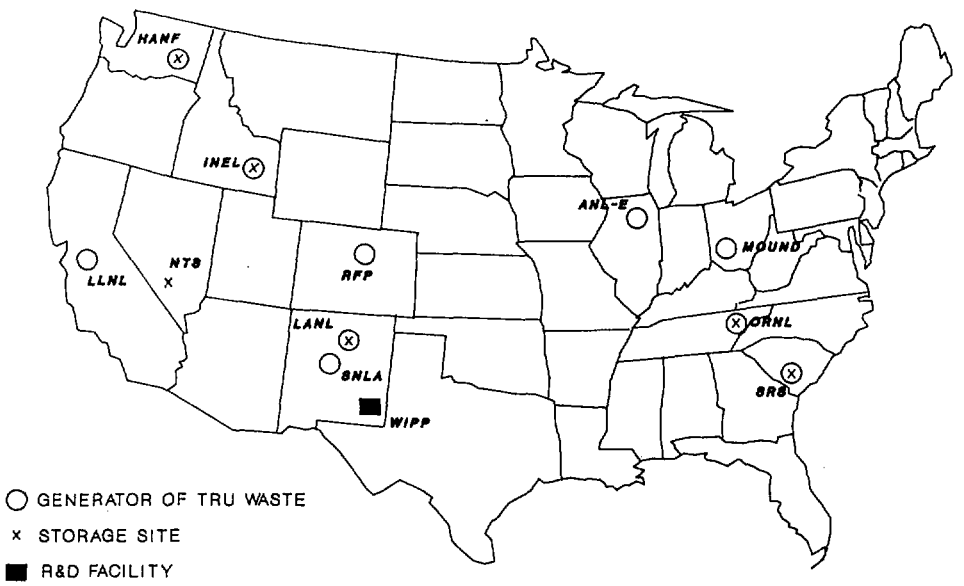
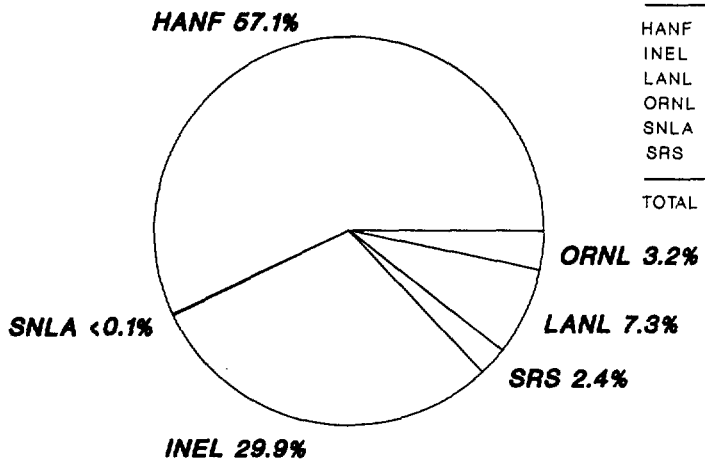


Fig. 3.2. Points of origin and storage sites of DOE TRU waste.

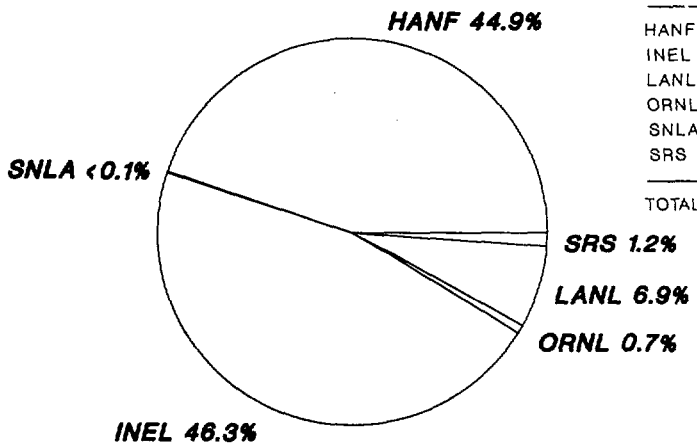
ORNL DWG 91-8664



SITE	CUBIC METERS
HANF	1.09E+05
INEL	5.71E+04
LANL	1.40E+04
ORNL	6.20E+03
SNLA	3.00E+00
SRS	4.53E+03
TOTAL	1.91E+05

Fig. 3.3. Total volume of buried DOE TRU waste through 1990.

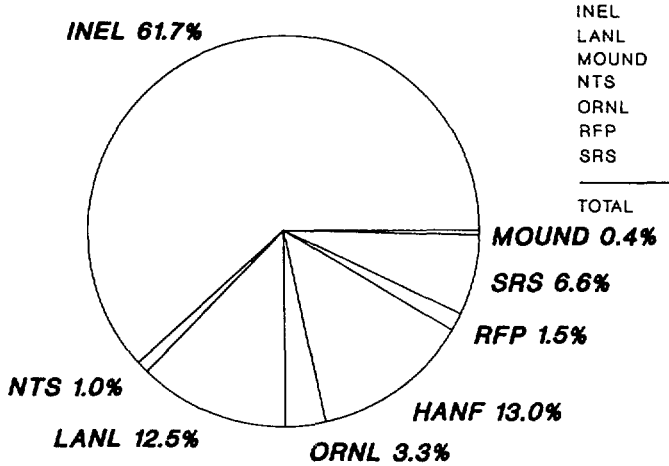
ORNL DWG 91-8665



SITE	KILOGRAMS
HANF	3.46E+02
INEL	3.57E+02
LANL	5.35E+01
ORNL	5.60E+00
SNLA	<1.00E+00
SRS	9.10E+00
TOTAL	7.71E+02

Fig. 3.4. Total mass of TRU elements in buried DOE TRU waste through 1990.

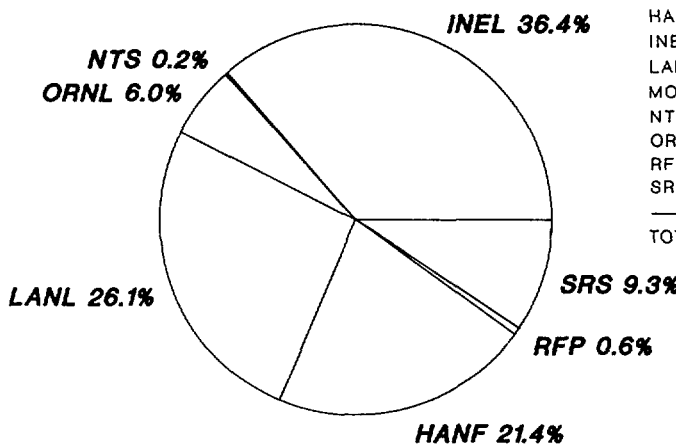
ORNL DWG 91-8666



SITE	CUBIC METERS
HANF	7.87E+03
INEL	3.76E+04
LANL	7.58E+03
MOUND	2.22E+02
NTS	6.87E+02
ORNL	1.97E+03
RFP	9.15E+02
SRS	3.99E+03
TOTAL	6.06E+04

Fig. 3.5. Total volume of retrievably stored DOE TRU waste through 1990.

ORNL DWG 91-8667



SITE	KILOGRAMS
HANF	4.78E+02
INEL	8.12E+02
LANL	5.82E+02
MOUND	1.00E-01
NTS	4.30E+00
ORNL	1.33E+02
RFP	1.43E+01
SRS	2.09E+02
TOTAL	2.23E+03

Fig. 3.6. Total mass of TRU elements in retrievably stored DOE TRU waste through 1990.

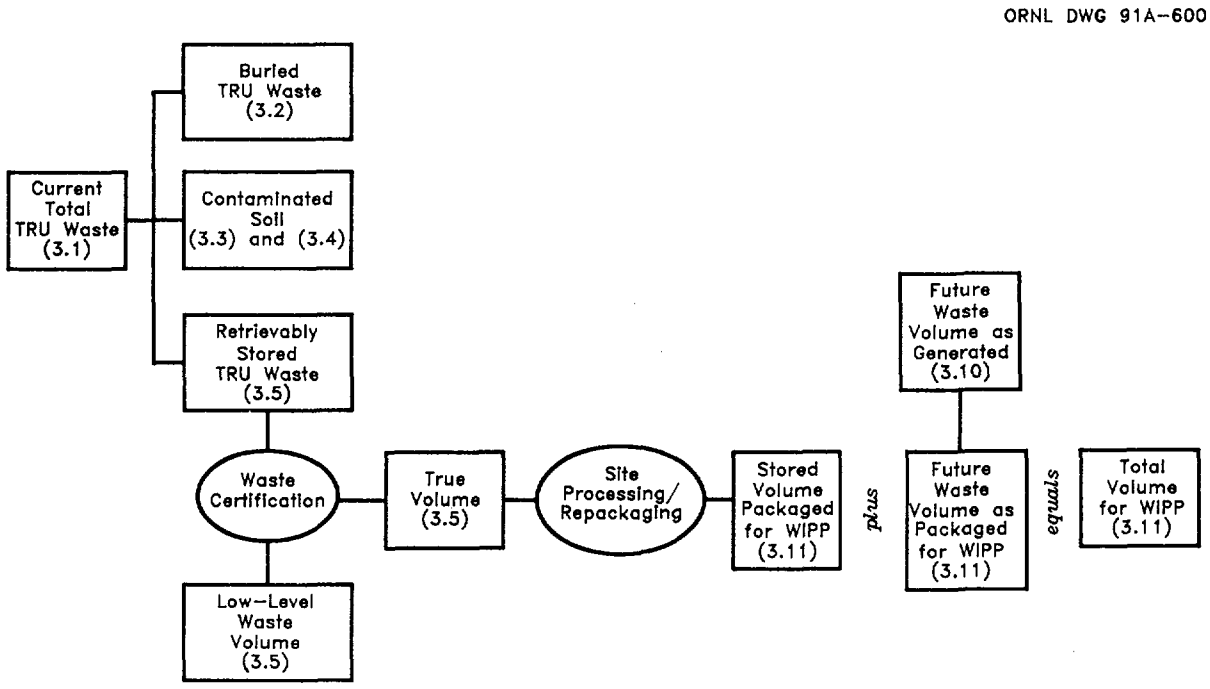


Fig. 3.7. TRU waste volume data relationships applicable to both CH and RH waste. (The number in parentheses is the data table reference.)

Table 3.1. Total system inventories, projections, and characteristics of all buried contaminated soil and stored DOE TRU waste in 5-year increments[a]

End of calendar year	Volume (m^3)		Mass[b] (kg)		Radioactivity[c] (10^3 Ci)		Thermal power[c] (10^3 W)	
	Annual rate[d]	Accumulation	Annual rate[d]	Accumulation	Annual rate[d]	Accumulation	Annual rate[d]	Accumulation
				Buried[e]				
1990	0.0	190,837.0	0.0	771.2	0.0	70.9	0.0	1.67
				Potentially contaminated soil				
1990	0.0	140,000.0-1,795,000.0	f	f	f	f	f	f
				Stored, contact-handled[g]				
1990	1,478.2	59,022.1	37.5	2,114.5	166.70	2,534.45	5.26	68.42
1991	2,108.9	61,131.0	120.5	2,235.0	535.65	3,020.68	16.90	84.41
1995	2,108.9	69,566.6	120.5	2,717.0	535.65	4,896.56	16.90	146.15
2000	2,108.9	80,111.1	120.5	3,319.5	535.65	7,098.98	16.90	218.71
2005	2,108.9	90,655.6	120.5	3,922.0	535.65	9,160.70	16.90	286.71
2010	2,108.9	101,200.1	120.5	4,524.5	535.65	11,097.70	16.90	350.64
2013	2,108.9	107,526.8	120.5	4,886.0	535.65	12,205.72	16.90	387.23
2015[h]								
				Stored, remote-handled[g,i]				
1990	14.4	1,585.4	0.03	118.2	30.38	2,244.76	0.18	6.15
1991	191.1	1,776.5	0.1	118.3	101.26	3,345.43	0.60	12.31
1995	191.1	2,540.9	0.1	118.7	101.26	2,966.12	0.60	10.87
2000	191.1	3,496.4	0.1	119.2	101.26	2,675.07	0.60	9.91
2005	191.1	4,451.9	0.1	119.7	101.26	2,420.13	0.60	9.07
2010	191.1	5,407.4	0.1	120.2	101.26	2,193.49	0.60	8.32
2013	191.1	5,980.7	0.1	120.5	101.26	2,069.82	0.60	7.91
2015[h]								
				Total stored[i]				
1990	1,492.6	60,607.5	37.5	2,232.7	197.08	4,779.21	5.44	74.57
1991	2,300.0	62,907.5	120.6	2,353.3	636.91	6,366.11	17.50	96.72
1995	2,300.0	72,107.5	120.6	2,835.7	636.91	7,862.68	17.50	157.01
2000	2,300.0	83,607.5	120.6	3,438.7	636.91	9,774.05	17.50	228.62
2005	2,300.0	95,107.5	120.6	4,041.7	636.91	11,580.83	17.50	295.78
2010	2,300.0	106,607.5	120.6	4,644.7	636.91	13,291.19	17.50	358.96
2013	2,300.0	113,507.5	120.6	5,006.5	636.91	14,275.53	17.50	395.14
2015[h]								
				TRU waste total[j]				
1990	1,492.6	391,444.5-2,046,444.5	37.5	3,003.9	197.08	4,850.11	5.44	76.24

[a]Assembled from data provided in Tables 3.2, 3.5, 3.8, and 3.9.

[b]Mass of TRU nuclides.

[c]Values were calculated using the estimated isotopic compositions for TRU waste at the several sites given in Table 3.8. See Sect. 3.3 for details.

[d]Annual rate is an average.

[e]No TRU waste was buried after 1978.

[f]Unknown.

[g]Excludes waste managed as LLW. See Table 3.5.

[h]The destination of TRU waste after 2013 not defined.

[i]The total radioactivity and thermal power columns do not include values for Hanford's projected stored, remote-handled waste. The isotopic composition of this waste is unknown.

[j]These totals are the sum of the contributions from buried wastes, potentially contaminated soils, and all stored (CH and RH) wastes.

Table 3.2. Inventories and characteristics of DOE buried TRU waste through 1990

Burial site	Values reported by storage site as of December 31, 1990[a]		
	Volume (m^3)	Mass of TRU nuclides (kg)	TRU alpha radioactivity[b] (Ci)
HANF[c]	109,000	346	29,200
INEL	57,100	357	73,267
LANL	14,000	53.5	9,230
ORNL	6,200	5.6	270[d]
SNLA[e]	3	<<1	1
SRS	4,534	9.1	9,831
Total	190,837	771.2	121,799

[a]Data from ref. 4.
[b]As reported by storage sites. Does not include beta and gamma radioactivity or radiation from decay products.
[c]Includes soils mixed with buried waste.
[d]Total of all radioactivity.
[e]Data from ref. 5.

Table 3.3. Inventories and characteristics of soil contaminated by DOE TRU solid waste through 1990[a]

Site	Volume (m^3)	Mass of TRU nuclides (kg)	TRU alpha radioactivity (Ci)
HANF	b	b	b
INEL	56,000-156,000[c]	d	d
LANL	1,000	d	d
ORNL	12,000-1,600,000[e]	d	d
SRS	38,000	d	d
Total	107,000-1,795,000		

[a]Data from ref. 4.
[b]Included with buried TRU wastes (Table 3.2).
[c]Larger value assumes that all the pit backfill soil is now contaminated.
[d]Reported as unknown.
[e]Larger value assumes that TRU wastes cannot be separated from LLW.

Table 3.4. Inventories and characteristics of soil contaminated by DOE TRU liquid waste through 1990[a]

Site	Volume (m^3)	Mass of TRU nuclides (kg)	TRU alpha radioactivity (Ci)
HANF	31,960	190.2	16,706
LANL	140	0.12	8.6
MOUND	106	0.0003	39.6
ORNL	1,000	b	b
Total	33,206	190.32	16,754.2

[a]Data from ref. 4.
[b]Reported as unknown.

Table 3.5. Inventories and characteristics of retrievable DOE TRU waste at each storage site through 1990[a]

Site	Certifiable TRU waste		Managed as LLW		Total		
	Volume (m^3)	Mass of TRU nuclides (kg)	Volume (m^3)	Mass of TRU nuclides (kg)	Containerized volume[b] (m^3)	Mass of TRU nuclides[b] (kg)	Alpha radioactivity[b,c] (Ci)
				Contact-handled			
HANF	7,665	472	7,665	0	15,330	472	54,467
INEL	37,422	811.4	27,335	11.6	64,757	823.0	207,412
LANL	7,552	577	272.2	0.2	7,824.2	577.2	191,194
MOUND[d]	222.4	0.1	8.5	0	230.9	0.1	1,352
NTS	586.9	4.3	0	0	586.9	4.3	806
ORNL	666.8	26.7	17.7	<<0.1	684.5	26.7	18,348
RFP[d]	915	14.3	0	0	915	14.3	4,760
SRS	3,992	208.7	3,878	2.6	7,870	211.3	666,338
Total	59,022.1	2,114.5	39,176.4	14.4	98,198.5	2,128.9	1,144,677
				Remote-handled			
HANF	201	6	0	0	201	6	873
INEL	49.9	0.56	21	0.01	70.9[e]	0.57	100.0
LANL	27.45	5.4	0	0	27.5	5.4	118.9
ORNL	1,307	106.2	0	0	1,307[f]	106.2	2,619
Total	1,585.35	118.16	21	0.01	1,606.4	118.17	3,710.9

[a]Data from ref. 4.

[b]Includes waste certifiable as TRU waste plus stored waste that is to be managed as LLW.

[c]As reported by storage site. Does not include beta and gamma radioactivity or radiation from decay products.

[d]Temporary on-site storage.

[e]INEL data include RH waste to be shipped to ORNL-WHPP for processing but do not include 9 canisters that will be returned to ICPP.

[f]This is total waste volume, not container volume.

Table 3.6. Revisions and changes in historical inventories of stored DOE TRU waste from previous IDB report[a]

Site	Contact-handled: Value as of Dec. 31, 1989[b]	Contact-handled: Revisions and/or corrections to 1989 data[c]	Contact-handled: Quantity added during 1990	Contact-handled: Value as of Dec. 31, 1990	Remote-handled: Value as of Dec. 31, 1989[b]	Remote-handled: Revisions and/or corrections to 1989 data[c]	Remote-handled: Quantity added during 1990	Remote-handled: Value as of Dec. 31, 1990
				Total volume, m^3				
HANF	10,041	-2,454	78	7,665	137	64	0	201
INEL	37,420	0	2	37,422	29.5	6	14.4	49.9
LANL	7,393.1	7.4	151.5	7,552	28.4	-0.9	0	27.5
MOUND[d]	0	0	222.4	222.4	0	0	0	0
NTS	606.3	-21.7	2.3	586.9	0	0	0	0
ORNL	661.6	0.2	5	666.8	1,307[e]	0	0	1,307[e]
RFP[d]	792	0	123	915	0	0	0	0
SRS	3,143	-45	894	3,992	0	0	0	0
Total	60,057	-2,513.1	1,478.2	59,022.1	1,501.9	69.1	14.4	1,585.4
				Mass of TRU elements, kg				
HANF	465	+5	2	472	11	-5	0	6
INEL	811.1	0	0.3	811.4	0.41	0.11	0.03	0.55
LANL	552.4	0	24.6	577	1.8	3.6	0	5.4
MOUND[d]	0	0	0.1	0.1	0	0	0	0
NTS	4.1	0	0.1	4.2	0	0	0	0
ORNL	26.6	0	0.1	26.7	106.2	0	0	106.2
RFP[d]	12.4	0	1.9	14.3	0	0	0	0
SRS	200.3	0	8.4	208.7	0	0	0	0
Total	2,071.9	+5	37.5	2,114.4	119.41	-1.29	0.03	118.15
				Alpha radioactivity, Ci				
HANF	53,707	577	183	54,467	1,476	-603	0	873
INEL	207,386	0	26	207,412	39.9	9	51.1	100
LANL	187,225	0	3,969	191,194	150	-31.1	0	118.9
MOUND[d]	0	0	1,352	1,352	0	0	0	0
NTS	712	51.6	42.4	806	0	0	0	0
ORNL	17,520	0	828	18,348	2,619	0	0	2,619
RFP[d]	410	0	4,350	4,760	0	0	0	0
SRS	659,524	0	6,814	666,338	0	0	0	0
Total	1,126,484	628.6	17,564.4	1,144,677	4,284.9	-625.1	51.1	3,710.9

[a]Data from ref. 4.
[b]Data from ref. 7.
[c]Discussion of major changes in Sect. 3.2.
[d]Temporary on-site storage.
[e]Value reported is volume of waste only, not container volume.

Table 3.7. Estimated physical composition of retrievably stored, newly generated, and buried TRU waste at DOE sites[a]

Waste type	Waste composition, vol %				
	Contact-handled		Remote-handled		
	RSW[b]	NGW[c]	RSW[b]	NGW[c]	Buried
ANL-E					
Absorbed liquids or sludges		36			
Combustibles		32		50	
Glass, metal, or similar noncombustibles		30		50	
Filter or filter media		2			
HANF					
Absorbed liquids or sludges		43			1
Combustibles	43	19	93	22	43
Concreted or cemented sludge	6	5	3	39	
Dirt, gravel, or asphalt	3	14		9	3
Filters or filter media		6		15	1
Glass, metal, or similar noncombustibles	48	13	4	15	48
Other					4
INEL					
Absorbed liquids or sludges	12				23.4
Combustibles	25	43.3	8	8	31.8
Concreted or cemented sludges	13	15.8			3.9
Dirt, gravel, or asphalt					6.7
Filters or filter media	5	0.5	11	11.2	1.3
Glass, metal, or similar noncombustibles	35	14.6	80[d]	80[d]	10.5
Other	10	25.8	1	0.8	22.4
LANL					
Absorbed liquids or sludges	22	1			4
Combustibles	25	40.5	50	50	7
Concreted or cemented sludges	4	18			44
Dirt, gravel, or asphalt	1				30
Filters or filter media	3	2.5			2
Glass, metal, or similar noncombustibles	45	38	50	50	13
LLNL					
Combustibles		73			
Concreted or cemented sludges		1			
Filters or filter media		7			
Glass, metal, or similar noncombustibles		15			
Other		4			
MOUND					
Combustibles		1			
Concreted or cemented sludges		1			
Dirt, gravel, or asphalt		89			
Glass, metal, or similar noncombustibles		9			

Table 3.7 (continued)

Waste type	Waste composition, vol %				
	Contact-handled		Remote-handled		
	RSW[b]	NGW[c]	RSW[b]	NGW[c]	Buried
NTS					
Combustibles	51.5				
Glass, metal, or similar noncombustibles	48.5				
ORNL					
Absorbed liquids or sludges			64		e
Combustibles	59	12	20		e
Dirt, gravel, or asphalt	1	1			e
Filters or filter media	5	5	1	1	e
Glass, metal, or similar noncombustibles	35	82	14	97	e
Other			1	2	e
RFP					
Combustibles		15.5			
Concreted or cemented sludges		36.3			
Dirt, gravel, or asphalt		0.7			
Filters or filter media		0.7			
Glass, metal, or similar noncombustibles		41.3			
Other		5.5			
SRS[f]					
Absorbed liquids or sludges	f	2.0			f
Combustibles	f	64.0			f
Filters or filter media	f	5.0			f
Glass, metal, or similar noncombustibles	f	27.5			f
Other	f	1.5			f

[a]Data from ref. 4.

[b]Retrievably stored waste (RSW). Vol % is best estimate of waste after processing and certification.

[c]Newly generated waste (NGW).

[d]This is alpha hot-cell waste.

[e]For ORNL, the composition of the buried waste is unknown.

[f]For SRS, composition of contact-handled RSW is unknown. The estimated characterization before processing is 30% noncombustible, 70% combustible. Composition of the buried waste is also unknown.

Table 3.8. Calculated isotopic composition (wt %) of buried and retrievably stored TRU waste for each site[a]

Site	Major isotopes[b]	Retrievably stored and newly generated wastes, wt %										Buried
		Contact-handled						Remote-handled				
		Mix-1[c]	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10	Mix-11
ANL-E[d]	^{235}U	-	25.2	-	-	-	-	-	-	-	-	-
	^{238}U	88.5	-	-	-	-	-	57.6	-	-	-	-
	^{239}Pu	11.5	74.8	-	-	-	-	35.4	-	-	-	-
	^{240}Pu	<1.0	-	-	-	-	-	5.7	-	-	-	-
	^{241}Pu	<1.0	<1.0	-	-	-	-	<1.0	-	-	-	-
	^{137}Cs	-	-	-	-	-	-	1.3	-	-	-	-
HANF[e,f]	^{239}Pu	2.2	-	-	-	-	-	2.2	4.8	-	-	2.2
	^{240}Pu	0.1	-	-	-	-	-	0.1	0.7	-	-	0.1
	^{241}Pu	-	-	-	-	-	-	-	0.1	-	-	-
	^{232}Th	3.1	-	-	-	-	-	3.1	16.0	-	-	3.1
	U depleted	72.8	-	-	-	-	-	72.8	21.6	-	-	72.8
	U enriched	1.8	-	-	-	-	-	1.8	54.3	-	-	1.8
	U normal	19.9	-	-	-	-	-	19.9	2.4	-	-	19.9
	Other	0.1	-	-	-	-	-	0.1	0.1	-	-	0.1
INEL[g]	^{241}Am	0.08	5.0	1.7	-	-	-	-	-	-	-	-
	^{238}Pu	Trace	-	Trace	-	-	-	-	-	-	-	Trace
	^{239}Pu	92.99	80.0	91.0	Trace	-	-	5.0	1.35	-	-	-
	^{240}Pu	5.80	10.0	5.7	-	-	-	1.0	0.15	-	-	Trace
	^{241}Pu	0.40	-	0.3	-	-	-	-	-	-	-	Trace
	^{242}Pu	0.03	-	Trace	-	-	-	-	-	-	-	Trace
	^{232}Th	-	-	-	95.0	-	-	-	-	-	-	-
	^{233}U	-	-	-	5.0	-	-	-	-	-	-	-
	^{235}U	-	-	0.6	-	-	-	38.20	39.40	-	-	0.1
	^{238}U	-	-	-	-	-	-	55.20	59.10	-	-	99.8
	MFP	-	-	-	-	-	-	0.60	-	-	-	-
	Other	0.70	5.0	-	-	-	-	-	-	h	i	0.1[j]
LANL[k]	^{235}U	1.9	-	-	-	-	-	47.0	47.0	-	-	-
	^{238}U	67.0	-	-	-	-	-	28.0	28.0	-	-	5.0
	^{238}Pu	0.5	0.5	1.2	0.5	-	-	-	-	-	-	0.01
	^{239}Pu	30.5	21.5	98.8	93.0	100	-	22.7	22.7	-	-	91.0
	^{240}Pu	-	-	-	-	-	-	2.1	2.1	-	-	-
	^{241}Pu	-	-	-	-	-	-	0.2	0.2	-	-	-
	^{241}Am	0.2	78.0	-	6.5	-	-	-	-	-	-	3.3
	MFP	-	Trace	-	-	-	-	l	m	-	-	-
	Other	-	-	-	-	-	-	-	-	-	-	0.69

Table 3.8 (continued)

Site	Major isotopes[b]	Retrievably stored and newly generated wastes, wt %										
		Contact-handled						Remote-handled				Buried
		Mix-1[c]	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10	Mix-11
LLNL[n]	^{238}Pu	0.02	0.07	0.01	0.05	0.04	-	-	-	-	-	-
	^{239}Pu	93.46	78.96	73.66	63.56	86.15	-	-	-	-	-	-
	^{240}Pu	5.90	17.43	24.90	14.03	11.71	-	-	-	-	-	-
	^{241}Pu	0.38	1.18	0.42	0.95	0.78	-	-	-	-	-	-
	^{242}Pu	0.04	0.43	0.02	0.35	0.24	-	-	-	-	-	-
	^{241}Am	0.20	1.94	0.99	21.07	1.08	-	-	-	-	-	-
MOUND[o]	^{238}Pu	80.0	-	-	-	-	-	-	-	-	-	-
	^{239}Pu	16.3	-	-	-	-	-	-	-	-	-	-
	^{240}Pu	3.0	-	-	-	-	-	-	-	-	-	-
	Other	0.7	-	-	-	-	-	-	-	-	-	-
NTS[p]	^{238}Pu	Trace	-	-	-	-	-	-	-	-	-	-
	^{239}Pu	93.55	-	-	-	-	-	-	-	-	-	-
	^{240}Pu	5.89	-	-	-	-	-	-	-	-	-	-
	^{241}Pu	0.54	-	-	-	-	-	-	-	-	-	-
	^{242}Pu	Trace	-	-	-	-	-	-	-	-	-	-
	^{241}Am	Trace	-	-	-	-	-	-	-	-	-	-
ORNL[q]	^{233}U	28.8	6.13	-	-	-	-	-	94.57	52.55	-	-
	^{235}U	3.8	2.99	-	-	-	-	-	-	-	-	-
	^{238}U	45.4	7.69	-	-	-	-	-	-	-	-	-
	^{238}Pu	-	4.58	-	-	-	-	-	-	-	-	-
	^{239}Pu	8.5	42.44	99.98	-	-	-	98.77	2.57	29.99	-	-
	^{241}Am	-	1.68	-	-	-	-	Trace	2.11	-	-	-
	^{244}Cm	-	0.96	Trace	-	-	-	Trace	0.75	Trace	-	-
	^{252}Cf	-	0.15	Trace	-	-	-	Trace	-	-	-	-
	^{137}Cs	-	-	-	-	-	-	-	Trace	0.95	-	-
	^{90}Sr	-	-	-	-	-	-	-	-	15.18	-	-
	^{152}Eu	-	-	-	-	-	-	-	-	Trace	-	-
	^{154}Eu	-	-	-	-	-	-	-	-	Trace	-	-
	^{232}Th	13.1	-	-	-	-	-	-	-	-	-	-
	^{237}Np	-	13.03	-	-	-	-	-	-	-	-	-
	^{240}Pu	-	15.42	-	-	-	-	-	-	-	-	-
	^{241}Pu	-	3.78	-	-	-	-	-	-	-	-	-
	Other	0.4	1.15	0.02	-	-	-	1.23	-	1.33	-	-
RFP[r]	^{238}Pu	Trace	-	-	-	-	-	-	-	-	-	-
	^{239}Pu	91.0	-	-	-	-	-	-	-	-	-	-
	^{240}Pu	5.7	-	-	-	-	-	-	-	-	-	-
	^{241}Pu	0.3	-	-	-	-	-	-	-	-	-	-
	^{242}Pu	Trace	-	-	-	-	-	-	-	-	-	-
	^{241}Am	1.7	-	-	-	-	-	-	-	-	-	-
	^{235}U	0.6	-	-	-	-	-	-	-	-	-	-

Table 3.8 (continued)

Site	Major isotopes[b]	Retrievably stored and newly generated wastes, wt %										Buried
		Contact-handled						Remote-handled				
		Mix-1[c]	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10	Mix-11
SRS[s]	^{238}Pu	0.02	83.7	80.6	-	-	-	-	-	-	-	-
	^{239}Pu	93.18	14.0	16.0	-	-	-	-	-	-	-	-
	^{240}Pu	6.0	2.0	2.5	-	-	-	-	-	-	-	-
	^{241}Pu	0.5	0.3	0.7	-	-	-	-	-	-	-	-
	^{242}Pu	-	-	0.2	-	-	-	-	-	-	-	-
	^{241}Am	0.3	-	-	-	Unk	-	-	-	-	-	-
	^{237}Np	-	-	-	Unk	-	-	-	-	-	-	-
	^{244}Cm	-	-	-	-	-	Unk	-	-	-	-	-

[a]Data from ref. 4.

[b]Isotopes listed are those that are either >1%, by weight, or >1%, by activity, of the total. The MFP entries in this column refer to mixed fission products.

[c]The mixes represent major waste stream composition variations or site composite values.

[d]At ANL-E, 30 vol % of the contact-handled TRU waste is Mix-1, 70 vol % is Mix-2, and 100 vol % of the remote-handled TRU waste is Mix-7.

[e]At HANF, 100 vol % of the contact-handled TRU waste is Mix-1, 4 vol % of the remote-handled TRU waste is Mix-7, 1 vol % is Mix-8, and 95 vol % is Mix-9 (which has not been characterized), and 100 vol % of the TRU-contaminated buried waste is Mix-11.

[f]HANF reported isotopic composition of uranium as U depleted, U enriched, and U normal. For radionuclide decay calculations, the data were converted to ^{235}U and ^{238}U by assuming 99.5%, 97.0%, and 99.3% ^{238}U, respectively.

[g]At INEL, 85 vol % of the contact-handled TRU waste is Mix-1, 3 vol % is Mix-2, 11 vol % is Mix-3, and 1 vol % is Mix-4; 29 vol % of the remote-handled TRU waste is Mix-7, 3 vol % is Mix-8, 27 vol % is Mix-9, and 41 vol % is Mix-10. 100 vol % of the TRU-contaminated buried waste is Mix-11.

[h]Mix-9 is ^{144}Ce, 49.8 activity % (A/O); ^{134}Cs, 10 A/O; ^{137}Cs, 19.9 A/O; ^{54}Mn, 0.1 A/O; ^{239}Pu, 0.2 A/O; and ^{90}Sr, 20 A/O.

[i]Mix-10 is ^{137}Cs, 0.9 A/O; ^{239}Pu, trace; ^{90}Sr, 1 A/O; ^{58}Co, 35.1 A/O; ^{60}Co, 7.1 A/O; ^{51}Cr, 0.9 A/O; ^{59}Fe, 0.9 A/O; and ^{54}Mn, 54.1 A/O.

[j]The other in Mix-11 is ^{241}Am, 19 A/O; ^{239}Pu, 8 A/O; ^{240}Pu, 2 A/O; ^{241}Pu, 70 A/O; and ^{242}Pu, 1 A/O.

[k]At LANL, 38 vol % of the contact-handled TRU waste is Mix-1, 11 vol % is Mix-2, 7.1 vol % is Mix-3, 41.9 vol % is Mix-4, and 2 vol % is Mix-5; 79 vol % of the remote-handled TRU waste is Mix-7, and 21 vol % is Mix-8. Also, 100 vol % of the TRU-contaminated buried waste is Mix-11. Mix-2 contains trace wt % MFP but 10.7 A/O MFP.

[l]Trace by wt %, 85% by activity.

[m]Trace by wt %, 95% by activity.

[n]At LLNL, 93.7 vol % of the contact-handled TRU waste is Mix-1, 1 vol % is Mix-2, 3 vol % is Mix-3, 2 vol % is Mix-4, and 0.3 vol % is Mix-5.

[o]At MOUND, 100 vol % of the contact-handled TRU waste is Mix-1.

[p]At NTS, 100 vol % of the contact-handled TRU waste is Mix-1.

[q]At ORNL, 10 vol % of the contact-handled TRU waste is Mix-1, 72.9 vol % is Mix-2, and 17.1 vol % is Mix-3; 27.5 vol % of the remote-handled TRU waste is Mix-7, 6.4 vol % is Mix-8, and 66.1 vol % is Mix-9. No information available on buried waste at ORNL.

[r]At RFP, 100 vol % of the contact-handled TRU waste is Mix-1. Weight % totals <100% due to traces and roundoff.

[s]At SRS, 56.2 vol % of the contact-handled TRU waste is Mix-1, 33.4 vol % is Mix-2, 6.5 vol % is Mix-3, 0.8 vol % is Mix-4, 0.5 vol % is Mix-5, and 2.6 vol % is Mix-6. Mixes 4, 5, and 6 are predominately ^{237}Np, ^{241}Am, and ^{244}Cm, respectively, but the makeup of the rest of the mix is unknown. No information available on buried waste at SRS.

Table 3.9. Volume, mass, radioactivity, and thermal power of DOE TRU waste at each burial and storage site through 1990[a]

Site	Volume (m^3)		Mass[b] (kg)		Radioactivity (10^3 Ci)	Thermal power (10^3 W)
	1990 rate	Accumulation	1990 rate	Accumulation	Accumulation	Accumulation
			Buried[c]			
HANF	0.0	109,000	0.0	346.0	0.55	0.02
INEL	0.0	57,100	0.0	357.0	14.58	0.02
LANL	0.0	14,000	0.0	53.5	9.09	0.29
ORNL	0.0	6,200	0.0	5.6	11.29	0.17
SNLA	0.0	3	0.0	0.0	0.00	0.00
SRS	0.0	4,534	0.0	9.1	35.40	1.16
Total	0.0	190,837	0.0	771.2	70.91	1.66
			Stored, contact-handled[d]			
HANF	78	7,665	2	472	0.75	0.02
INEL	2	37,422	0.3	811.4	380.85	2.16
LANL	151.5	7,552	24.6	577	300.84	9.92
MOUND	222.4	222.4	0.1	0.1	1.38	0.05
NTS	2.3	586.9	0.1	4.3	2.70	0.01
ORNL	5	666.8	0.1	26.7	110.20	1.13
RFP	123	915	1.9	14.3	6.29	0.06
SRS	894	3,992	8.4	208.7	1,731.43	55.06
Total	1,478.2	59,022.1	37.5	2,114.5	2,534.44	68.41
			Stored, remote-handled[d]			
HANF	0	201	0	6	Unknown[e]	Unknown[e]
INEL	14.4	49.9	0.03	0.56	706.91	4.23
LANL	0	27.45	0	5.4	2.07	0.00
ORNL	0	1,307	0	106.2	1,535.78	1.91
Total	14.4	1,585.35	0.03	118.16	2,244.76	6.14

[a]Assembled from data provided in ref. 4 and Tables 3.2, 3.5, and 3.8.

[b]Values were calculated using the estimated isotopic compositions for TRU waste at the several sites given in ref. 4 and Table 3.8. See Sect. 3 for details.

[c]Radioactive decay calculations based on last burial date. No TRU waste was buried after 1978.

[d]Radioactive decay calculations based on an averaged 10-year storage.

[e]Could not be calculated because isotopic composition of this waste is unknown.

Table 3.10. Projected volume, mass, and activity of TRU waste to be generated during 1991-2013[a]

Sites	Average annual container volume[b] (m^3)	Average annual TRU nuclide mass (kg)	Average annual alpha radioactivity[c] (Ci)	Total volume projected for years 1991-2013 (m^3)
		Contact-handled		
Storage[d]				
HANF[e]	387.9	7.4[f]	620.8[f]	8,921.7
INEL[g]	18.0	0.5	85.3	414.0
LANL	200.0	41.0	19,900.0	4,600.0
ORNL	25.0	0.9	580.0	575.0
SRS	759.5	57.6	39,025.0	17,468.5
Generation[h]				
ANL-E	9.5	0.26	15.8	218.5
LLNL	50.3	0.5	105.0	1,156.9
MOUND	4.2	2.1	38.6	96.6
RFP	654.5	10.2	2,517.0	15,053.5
Subtotal	2,108.9	120.46	62,887.5	48,504.7
		Remote-handled		
Storage[d]				
HANF	175.5[i]	Unknown	Unknown	4,036.5
INEL	6.2	0.08	7.0	142.6
LANL	0.2	<<0.01	<0.1	4.6
ORNL	6.0	0.01	8.5	138.0
Generation[b]				
ANL-E	3.2	0.01	5.2	73.6
Subtotal	191.1	0.11	20.8	4,395.3
Total	2,300.0	120.57	62,908.3	52,900.0

[a]Data from ref. 4.

[b]Volumes included are predominantly those associated with alpha activity greater than 100 nCi/g.

[c]Values were generator supplied.

[d]These sites have been designated as TRU waste storage sites.

[e]Projections at Hanford include processing of waste from ANL-E and LLNL. These shipments have not been approved by DOE/EM, DOE/RL or the generator field offices.

[f]These values are determined from 16% of the waste volume; the remaining waste volume has not been characterized.

[g]Summary of CH contributions from ANL-W, Bettis Atomic Power Laboratory (BAPL), and ICPP.

[h]These sites generate but do not store TRU waste. Their waste will be sent to a designated site (HANF, INEL, LANL, NTS, ORNL, or SRS).

[i]Does <u>not</u> include a total of 34,000 m^3 of uncharacterized waste which will probably be RH TRU.

Table 3.11. Total TRU waste volume as packaged for shipment to WIPP through 2013[a,b]

Sites	Inventory, m^3		
	Stored through 1990	Projected future	Total
	Contact-handled		
ANL-E	-	220	220
HANF	7,700	8,922	16,622
INEL	37,442	414	37,856
LANL	6,118	4,600	10,718
LLNL	-	1,156	1,156
MOUND	201	97	298
NTS	587	-	587
ORNL	317	575	892
RFP	915	15,054	15,969
SRS	3,992	17,468	21,460
Total	57,272	48,506	105,778
	Remote-handled		
ANL-E	-	196	196
HANF	213	4,037	4,250
INEL	116	472	588
LANL	20	5	25
ORNL	1,895	229	2,124
Total	2,244	4,939	7,183

[a]Data from ref. 4.

[b]These data include the effects of repackaging the waste into WIPP containers. Consequently, these values differ from those shown in Tables 3.5 and 3.10.

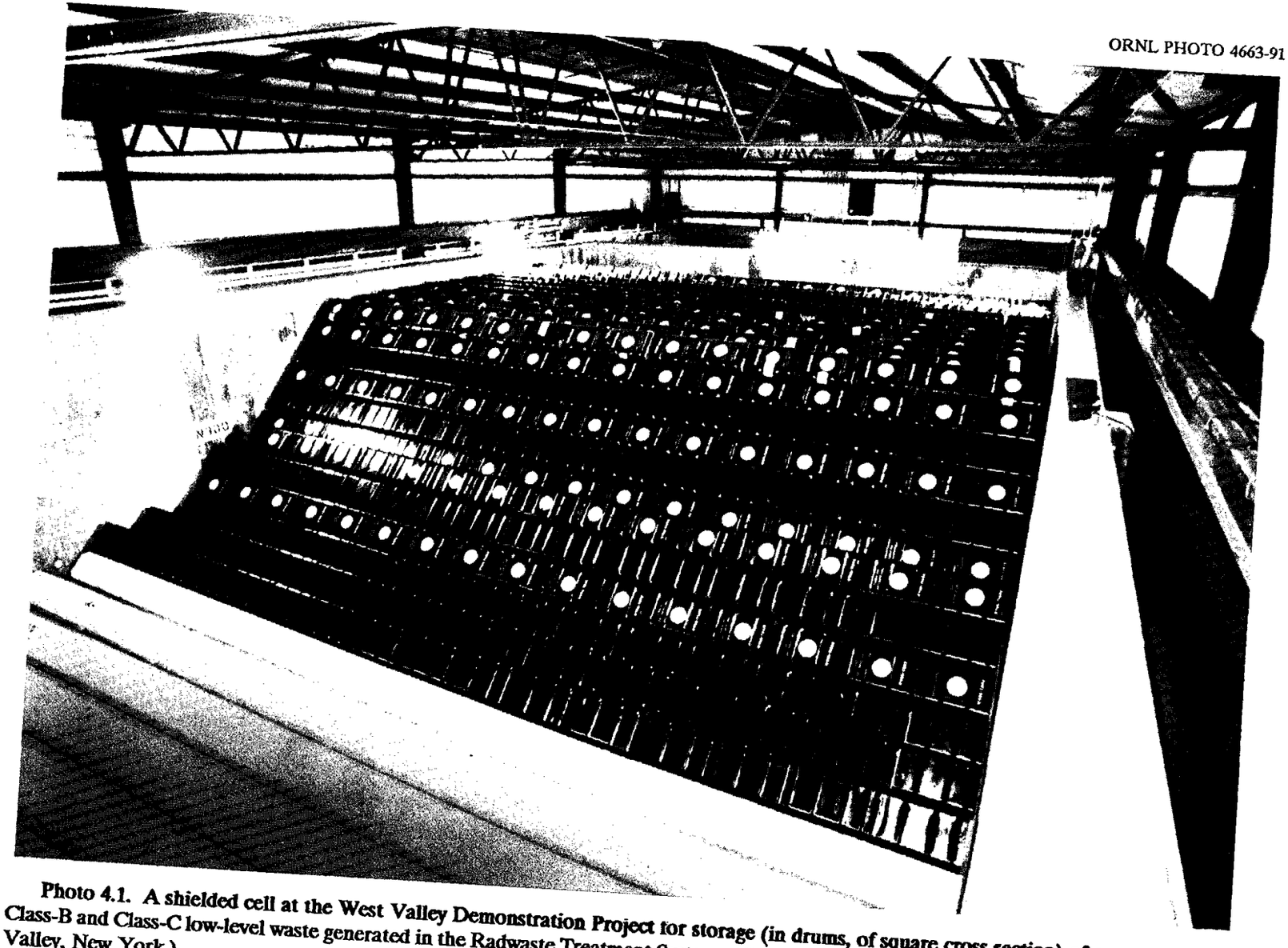


Photo 4.1. A shielded cell at the West Valley Demonstration Project for storage (in drums, of square cross section) of cement-solidified Class-B and Class-C low-level waste generated in the Radwaste Treatment System. (Courtesy of the West Valley Demonstration Project, West Valley, New York.)

4. LOW-LEVEL WASTE

4.1 INTRODUCTION

As used in this chapter, LLW denotes those radioactive wastes containing source, special nuclear, or by-product materials that are acceptable for disposal in a land disposal facility. This definition is the same as that in 10 CFR 61.2, which states that LLW is radioactive waste not classified as HLW, TRU waste, spent nuclear fuel, or by-product material specified as uranium or thorium tailings and waste. The nuclear accelerator-generated radioactive material (NARM) and naturally occurring radioactive material (NORM) that are disposed of at DOE burial or commercial disposal sites are included in the inventories given, but are not treated as separate entities in this chapter. Tailings (viz., mill tailings) are considered in Chapters 5 and 6. Another waste classification not delineated in this chapter is "mixed" waste that contains both chemically hazardous and radioactive constituents (see Chapter 8). The DOE generates LLW through its defense activities, uranium enrichment operations, naval nuclear propulsion program, and various R&D activities.

Commercial nuclear fuel cycle facilities (see Table 4.1) currently account for about three-fourths of the waste volume that is shipped to commercial disposal sites; the remainder comes from other non-fuel cycle related industrial/institutional (I/I) activities. These non-fuel cycle I/I wastes include those from radiochemical manufacturers, research laboratories, hospitals, medical schools, universities, other radioactive materials licensees, and some non-DOE government agencies. More than 20,000 licenses have been issued by the NRC and "Agreement States" (see Glossary of Terms for definition) for the handling and use of radionuclides.

Some LLW is also generated by environmental restoration programs (see Chapter 6). Other LLW will be generated in future years by nonroutine D&D operations. Historical waste from commercial D&D operations is included with the industrial waste in this chapter since it has not been reported separately. However, projections of D&D waste are not included here, but instead, are discussed in Chapter 7.

The categorization of LLW according to DOE activities, commercial reactor operations, and I/I applications permits a comparison of the types, radioactivity levels, and volumes of waste arising from each of these major sources (Figs. 4.1 and 4.2). Summary data on LLW (DOE and commercial) are given in Table 4.1. Historical and projected data by year for DOE LLW are presented in Table 4.2. In Table 4.3, similar data are shown for commercial LLW disposal (I/I and a commercial fuel cycle without spent fuel reprocessing). A plot showing a comparison of historical and projected LLW volumes for DOE and commercial (which includes some non-DOE government agencies classified as commercial) sources is shown in Fig. 4.3.

4.2 DOE LLW

4.2.1 Inventories at DOE LLW Disposal Sites

Prior to October 1979, some LLW generated by DOE contractors was shipped to commercial disposal sites. Currently, all LLW generated by DOE activities is buried at DOE sites (Figs. 4.4 and 4.5). A summary of historical additions, accumulated volumes, and accumulated undecayed radioactivity for solid LLW buried at all DOE sites through 1990 is presented in Tables 4.1, 4.2, and 4.4–4.8. The data in these tables are derived from the Waste Management Information System (WMIS) and subsequent site questionnaires obtained through the Hazardous Waste Remedial Actions Program (HAZWRAP).[1]

There are small quantities of DOE LLW that have been disposed of by sea dumping or by hydrofracture;[2] these wastes are not included in the WMIS data base. Table 4.9 shows the estimated quantity and radioactivity of LLW disposed of by these methods. Sea dumping of LLW was halted by the United States in 1970, and hydrofracture was terminated in 1983.

4.2.2 Characterization of LLW at DOE Sites

Based on information reported in ref. 1, summaries of radionuclide and physical characteristics for DOE LLW are reported in Tables 4.5–4.8. Summaries of representative radionuclide characteristics for generated, stored, and buried LLW at DOE sites are provided in Table 4.5. (Representative radionuclide compositions for the buried

waste types have been developed[3] and are given in Table A.5 of Appendix A.) Summaries of physical characteristics for generated, stored, and buried wastes are given in Table 4.6. Breakdowns of radionuclide characteristics for buried LLW at each DOE site are provided for accumulated waste volume in Table 4.7 and for total gross waste activity in Table 4.8.

Most of the DOE wastes that were disposed of by sea dumping (see Table 4.9) were incorporated into cement matrix material and packaged in steel drums (55- or 80-gal capacity).

Hydrofracture was developed at ORNL for the permanent disposal of locally generated, low-level (approximately 0.25 Ci/L) liquid waste concentrates.[4] Waste was mixed with a blend of cement and other additives, and the resulting grout was injected into shale at a depth of 200 to 300 m. The injected grout hardened into thin, horizontal sheets several hundred meters wide.

4.2.3 DOE LLW Disposal Sites

A digest of data on the current status of land usage at DOE sites with active LLW disposal areas is shown in Table 4.10. Most of the DOE site land usage information currently reported in Table 4.10 is based on data given in ref. 1 with land usage factors taken from ref. 2.

As previously discussed, the LLW ocean disposal sites have not been used for this purpose since 1970. All of the liquid LLW that had been held in long-term storage at ORNL was disposed of during 1982 and 1983 using the new hydrofracture facility.

Significant changes in LLW waste inventory and characteristics data reported in the 1990 edition (1989 data) of this report are summarized in Table 4.11.

4.2.4 DOE LLW Projections

An assumption used in this report is that the level of DOE waste burial activities will remain constant through 2020. Beginning in 1991, the volume and undecayed radioactivity added each year to each active LLW disposal area are assumed to remain constant through 2020 at the values projected for 1991. These volumes and activities are split into waste types using the radionuclide categories given in Tables 4.5, 4.7, and 4.8. The radioactivity (by waste type) is decayed from the year of addition through 2020 using the representative compositions given in Table A.5 of Appendix A.

Projections for burial of DOE LLW are presented in Tables 4.2, 4.12, and 4.13. Table 4.12 summarizes DOE LLW excluding saltstone. Table 4.13 summarizes projections of saltstone, a LLW by-product from the solidification of HLW at SRS. This saltstone (see Fig. A.10 and Table A.7 of Appendix A) is to be stored in concrete vaults at SRS. The grout-immobilized LLW derived from processing double-shell waste at Hanford (see Fig. 2.7 in Chapter 2) is excluded from the projections in Table 4.2, because the schedule and formulation for solidification are not yet firmly defined.

4.3 COMMERCIAL LLW

4.3.1 Inventories at Commercial LLW Disposal Sites

There are six commercial shallow-land disposal sites for LLW (Figs. 4.2, 4.6, and 4.7), but only three are currently in operation. Commercial operations at the Maxey Flats, West Valley, and Sheffield sites have been halted. Until 1986, a second NRC-licensed burial ground at West Valley continued to receive wastes generated on-site from cleanup and water treatment operations. However, disposal operations at the WVDP have been suspended since 1986 pending the preparation of an Environmental Impact Statement (EIS) report for the West Valley site closure. The historical data for annual additions and inventories of volume and radioactivity (undecayed) at each commercial disposal site through the end of 1990 are listed in Tables 4.14 and 4.15, respectively (compiled from refs. 2, 5–10). The volumes are depicted in Figs. 4.2, 4.3, 4.6, and 4.7. Sources of the historical reported data through 1984 are given in ref. 2 and through 1989 in ref. 6. Quantities of LLW shipped to disposal sites during 1990 are listed in Table 4.16 on a state-by-state basis.[7] These state-by-state values reflect the fact that the new Manifest Information Management System (MIMS) is able to assign, to the original shippers, the LLW collected and treated by waste brokers. Table 4.3 is a summary of historical and projected volumes and radioactivity (decayed) for commercial LLW. Not included in Table 4.3 are the drums of cemented LLW to be generated by the WVDP as a result of the vitrification of HLW. This LLW from the WVDP is described in Table A.10 of Appendix A.

A small portion (~5 vol %) of the LLW shipped to commercial sites originates with government operations other than DOE and is included in this chapter in the I/I waste category.

4.3.2 Characterization of LLW at Commercial Disposal Sites

All of the LLW accepted for commercial disposal is classified A, B, or C in compliance with NRC specifications.[11] The LLW that exceeds these specifications is currently in storage at the generator site or at a DOE site which has accepted it for study (see Sect. 4.3.3). A calculated representative radionuclide composition for commercial LLW is given in Table A.6 of Appendix A. This composition is periodically updated to reflect changes in waste management practices and in the regulations governing LLW disposal.

Nuclear power plants in the United States are of two basic types: boiling-water reactors (BWRs) and

pressurized-water reactors (PWRs) (Figs. A.6 and A.7 of Appendix A). The BWRs are further classified as deep-bed or filter/demineralizer types, depending on the condensate cleanup system employed. The reference BWR used in this report is an average composite, based on the historical net electricity generation of both types. Although nonroutine, irradiated-component LLW is disposed of only sporadically, it accounts for a large portion of the total radioactivity (but only a minuscule portion of the volume) of the LLW shipped to disposal from nuclear power plants (see Table 4.1). Characteristics of LLW from the other fuel cycle facilities that ship to commercial disposal sites (UF_6 conversion and fuel fabrication) are presented in Figs. A.2, A.3, and A.5 of Appendix A. The LLW from nuclear power plant operations accounts for approximately 56% of the waste volume shipped to commercial LLW disposal sites (other fuel cycle operations account for about 20%).

Characteristics of the I/I wastes are presented in Table A.11 of Appendix A. Industrial LLW sources include, among others, radiochemical and pharmaceutical companies and manufacturers of smoke detectors and luminous dials, as well as UF_6 conversion and fuel fabrication facilities for LWRs. The latter two are shown separately in this chapter (Tables 4.1, 4.22, and 4.23) so that the contribution of the nuclear fuel cycle to LLW can be delineated.

In March 1981, the NRC removed some of the restrictions on the disposal of radioactive biomedical waste.[12] This was done to decrease the volumes of very low-level radioactive waste shipped to NRC-licensed commercial disposal facilities from hospitals, laboratories, medical schools, and other institutions. Representative characteristics of this institutional waste indicate three distinct waste streams, which can be categorized as bioresearch, nonbioresearch, and medical. This categorization was suggested by the University of Maryland in a survey published in 1979 (see ref. 2 for a succinct summary). Bioresearch waste results mainly from chemical tracers used in animal studies; nonbioresearch waste is derived from physical and earth science studies; and medical waste comes from medical diagnostic and therapeutic practices.

4.3.3 Greater-Than-Class-C Low-Level Waste (GTCC LLW)

In 1980, federal law made each state responsible for providing the disposal capacity for LLW generated within its borders, except for certain waste generated by the federal government.[13] In 10 CFR Part 61 (ref. 11), the NRC codifies disposal requirements for three classes of LLW, as mentioned above, generally suitable for near-surface disposal, namely, A, B, and C (with Class C waste requiring the most rigorous disposal specifications). Waste with concentrations above Class C limits for certain short- and long-lived radionuclides (i.e., GTCC LLW) was found not generally suitable for near-surface disposal, except on a case-by-case evaluation of the waste and the proposed disposal method by NRC or state licensing agency. The LLRWPAA[14] made the states responsible for the disposal of Classes A, B, and C LLW and made the federal government (viz., DOE) responsible for disposal of GTCC LLW. The law also required that GTCC LLW generated by licensees of NRC be disposed of in a facility licensed by NRC. The projected amounts of GTCC LLW are uncertain, both because of regulatory uncertainties affecting the definition of HLW (i.e., a clearly defined all-inclusive list of wastes considered HLW may include more than those described in Chapter 2) and because of the lack of information on the sources, volumes, and characteristics of GTCC LLW.[15]

In May of 1989, NRC promulgated a rule that requires disposal of GTCC LLW in a deep geologic repository unless disposal elsewhere has been approved by NRC.[16] The rule as amended states: "Waste that is not generally acceptable for near-surface disposal is waste for which form and disposal methods must be different and, in general, more stringent than those specified for Class C waste. In the absence of specific requirements in this part, such waste must be disposed of in a geologic repository as defined in Part 60 of this chapter unless proposals for disposal of such waste in a disposal site licensed pursuant to this part are approved by the Commission." A disposal facility for GTCC LLW will probably not be available for several decades due to the complexities of siting and NRC licensing. A generic description of estimated sources and forms of GTCC LLW is presented in Table A.9 of Appendix A.

Existing volume projections of GTCC LLW vary, ranging from 2,000 m^3 in the 1987 report to Congress[15] to 17,000 m^3 in the update of Part 61 Impacts Analysis Methodology.[17] In an effort aimed toward rectifying this situation, DOE initiated a study to provide information about estimates of present and future GTCC LLW to the year 2035 (2055 in some instances). Information garnered by the study[18] includes identification of generators, waste form characteristics, volumes, and radionuclide activities. The study categorizes GTCC LLW as (1) nuclear utilities waste, (2) sealed sources wastes, (3) DOE-held potential GTCC LLW, and (4) other generator waste. Three scenarios for data projection are used: (a) unpackaged volumes; (b) packaged volumes based on the application of packaging factors to the unpackaged volumes; and (c) concentration averaging, mixing or blending of similar materials with different radionuclide concentrations, values applied to the packaged volumes. Each of the three scenarios is treated for three cases: low, base, and high.

The study determined that the largest volume of GTCC wastes, approximately 57%, is generated by nuclear power plants. The other generator waste category contributes approximately 10% of the total GTCC LLW volume projected to the year 2035. Waste held by DOE, which is potential GTCC LLW, accounts for nearly 33% of

all waste projected to the year 2035. To date, no determination of a disposal method has been made for the latter waste. Sealed sources are less than 0.2% of the total projected volume of GTCC LLW. Data trends (1985–2035) between low, base, and high cases for packaged waste show an overall threefold increase. The low-case total (including DOE-held potential GTCC LLW) is approximately 2,220 m^3, while the high-case (to 2055) total is approximately 6,500 m^3. The increases (in the high case) are the result of nuclear power reactor life extension (additional operations waste) and less packaging efficiency. The volume and radioactivity totals for all base-case packaged GTCC LLW are 3,250 m^3 and 6.58×10^7 Ci, respectively. A summary of light-water reactor GTCC LLW projections based on packaged waste volumes (with application of packing factors to the unpackaged volumes) for the three cases (low, base, and high) is presented in Table 4.17.

4.3.4 Commercial LLW Disposal Sites

Three commercial LLW disposal sites in the eastern United States (Maxey Flats, Sheffield, and West Valley) have been closed to further use. Only a small amount of on-site generated LLW from site cleanup is occasionally buried at Maxey Flats. The closure of these three commercial LLW disposal sites resulted in increasing volumes of LLW being shipped to the three remaining operating sites in South Carolina, Nevada, and Washington. The increase prompted South Carolina to impose an upper limit on the volume of LLW that could be accepted at Barnwell. Eventually, a general concern developed that the responsibility for LLW disposal should not rest with only three states and that a coordinated national plan was needed. As described above, the LLRWPA[13] was passed in 1980, making each state responsible for its own LLW and encouraging formation of regional interstate compacts to deal with the disposal problem. The Act provided that any compact approved by Congress could restrict access to its LLW disposal facility to member states after Jan. 1, 1986. However, by 1984, it became evident that no new regional disposal facilities would be operating by the end of 1985. This gave rise to new legislation, the LLRWPAA,[14] which continued to encourage interstate compact formation while requiring that nonsited (i.e., without an operating disposal site) states and compacts meet specific milestones, leading to the operation of new regional facilities by Jan. 1, 1993. Additionally, the LLRWPAA established rates and limits of acceptance at the three commercial disposal sites now in operation, as well as space allocations for utility wastes. The utilities are required to meet certain waste volume reductions during a 7-year transition period, which is provided for the opening of new LLW disposal sites under state compact arrangements. The full impact of the law is being studied and evaluated by the nuclear industry as well as by federal and state regulators.

Barnwell now receives about 69% of the total volume of commercial LLW shipped for burial. The Beatty, Nevada, site is receiving about 5%, while the site at Richland, Washington, now receives about 26% (see Table 4.14). The nationwide distribution of this waste among the various LLW categories is shown in Fig. 4.1. Chem-Nuclear Systems, Inc., operates the Barnwell disposal site, and U.S. Ecology, Inc., operates the disposal sites at both Beatty and Richland. The land usage at existing commercial disposal sites is summarized in Table 4.10. Updated information reported for these commercial sites is based on data provided by state health and environmental control agencies (refs. 2, 5, and 9).

Since the end of 1980, individual states have been encouraged to form compacts for the purpose of developing new regional LLW disposal sites.[13] The Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA) stipulates areas of responsibility in LLW disposal and defines penalties for future noncompliance.[14]

4.3.5 Commercial LLW Projections

All fuel-cycle LLW projections in this report are based on the DOE/EIA No-New-Orders Case (see Chapter 1 and Table A.8 of Appendix A), the fuel requirements needed to support this scenario, and the various processing steps required to provide the fuel. The source terms used in projecting the volume and radioactivity of commercial LLW are derived from reported historical data.[2,3,6,10,19-22] The UF_6 conversion and fuel fabrication LLW source terms (Figs. A.2, A.3, and A.5 of Appendix A) are taken from ref. 3. The reported historical waste data for BWR and PWR plants[6,10,20-22] and their net electrical outputs[19,20,22,23] provide the data for the reactor source terms in Figs. A.6 and A.7 of Appendix A. The source term composition used for I/I waste (Table 4.18) for 1980 through 2020 is presented in Table A.11 of Appendix A. The historical values for the volume and radioactivity of I/I wastes were obtained as the difference between the total volume (Table 4.14) and radioactivity (Table 4.15) reported shipped for disposal each year and the corresponding total fuel cycle (UF_6 conversion and fuel fabrication plus LWR operations) values from Tables 4.19–4.23. The composition of the radioactivity in pre-1980 I/I waste is given in ref. 2.

The projections for LLW resulting from nuclear reactor operations, normalized to the net electrical generation, are presented in Tables 4.19–4.21. The calculated historical and projected data for UF_6 conversion are given in Table 4.22; similar data for fuel fabrication are presented in Table 4.23. In 1990 UF_6 conversion and fuel fabrication facilities account for about 25 vol % of the total fuel-cycle LLW, while reactor operations account for the remaining approximately 75 vol %. The projections may be modified by legal changes. Under the LLRWPAA,[14] permissible waste volumes from reactors are not related

directly to electrical generating capacity but are based on the reactor type (BWR or PWR) and its present and anticipated operating status.

The basis for the LLW projections from I/I sources (Table 4.18) was the assumption that the average annual addition of these wastes will remain essentially constant (at the 1990 value) from 1991 through 2020, because most measures to maximize volume reduction and minimize the radioactivity of these wastes have already been put into practice.[24]

Table 4.3 summarizes the LLW projected to result from I/I and commercial fuel-cycle sources through the year 2020. These waste projections may be altered as the I/I waste source terms are updated and the provisions in the LLRWPAA[14] are implemented.

Because of timing uncertainties, projected decommissioning wastes are not included in the projections of this chapter. Rather, decommissioning waste projections are reported separately in Chapter 7. Former commercial facilities that will be affected by environmental restoration activities are discussed in Chapter 6 and are also excluded from the projected values in this chapter.

4.4 REFERENCES

1. U.S. Department of Energy, Waste Management Information System (WMIS), DOE site LLW questionnaires issued and maintained by the Hazardous Waste Remedial Actions Program (HAZWRAP) of Martin Marietta Energy Systems, Inc., submitted to the Integrated Data Base Program during April–September 1991.

2. U.S. Department of Energy, Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 1, Oak Ridge National Laboratory, Oak Ridge, Tennessee (December 1985).

3. C. W. Forsberg, W. L. Carter, and A. H. Kibbey, Flowsheets and Source Terms for Radioactive Waste Projections, ORNL/TM-8462, Oak Ridge National Laboratory, Oak Ridge, Tennessee (March 1985).

4. U.S. Energy Research and Development Administration, Environmental Statement, Radioactive Waste Facilities, Oak Ridge National Laboratory, Oak Ridge, Tennessee, WASH-1532 (Draft) (January 1974).

5. V. R. Autry, South Carolina Department of Health and Environmental Control, Columbia, South Carolina, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, dated June 18, 1991.

6. U.S. Department of Energy, Integrated Data Base for 1990: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 6, Oak Ridge National Laboratory, Oak Ridge, Tennessee (October 1990).

7. U.S. Department of Energy, National Low-Level Waste Management Program, facsimile to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, from R. L. Fuchs, EG&G Idaho, Inc., dated Apr. 17, 1991, containing commercial LLW information from the Manifest Information Management System (MIMS).

8. T. J. Rowland, DOE-West Valley Demonstration Project Office, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update to the DOE 1991 Integrated Data Base Report," dated Apr. 15, 1991.

9. D. Mills, Commonwealth of Kentucky, Department for Environmental Protection, Frankfort, Kentucky, letter to A. H. Kibbey, Oak Ridge National Laboratory, Oak Ridge, Tennessee, dated Feb. 5, 1990.

10. U.S. Department of Energy, National Low-Level Radioactive Waste Management Program, The 1989 State-By-State Assessment of Low-Level Radioactive Wastes Shipped to Commercial Disposal Sites, DOE/LLW-88, EG&G Idaho, Inc., Idaho Falls, Idaho (December 1990).

11. U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Wastes," Code of Federal Regulations, Title 10, Part 61, Jan. 1, 1990.

12. U.S. Nuclear Regulatory Commission, "Biomedical Waste Disposal," Fed. Regist. 46(47), 16230-34 (Mar. 11, 1981).

13. U.S. Congress, The Low-Level Radioactive Waste Policy Act, Pub. L. 95-573, Dec. 22, 1980.

14. U.S. Congress, The Low-Level Radioactive Waste Policy Amendments Act of 1985, Pub. L. 99-240, Jan. 15, 1986.

15. U.S. Department of Energy, Recommendations for Management of Greater-than-Class-C Low-Level Radioactive Waste, report to Congress in response to Public Law 99-240, DOE/NE-0077 (February 1987).

16. U.S. Nuclear Regulatory Commission, amendments to 10 CFR Part 61, "Disposal of Radioactive Wastes," final rule, Fed. Regist. 54(100), 22578–83 (May 25, 1989).

17. O. I. Oztunali, W. D. Pon, R. Eng, and G. W. Roles, Update of Part 61 Impacts Analysis Methodology, Vol. 2, NUREG/CR-4370 (January 1986).

18. R. A. Hulse, Greater-than-Class-C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics, DOE/LLW-114, EG&G Idaho, Inc., Idaho Falls, Idaho (August 1991).

19. U.S. Nuclear Regulatory Commission, The Licensed Operating Reactor Status Summary Report, NUREG-0002, Vols. 1–11, No. 1 (Gray Book Data for 1974–1986), tape available from W. H. Lovelace, Management Branch, Division of Data Automation and Management Information, Office of Resource Management, Washington, D.C. 20555 (May 1987). Volumes 12–14, No. 1, published in January 1988, 1989, and 1990, respectively, were obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

20. A. H. Kibbey and S. M. DePaoli, A Compilation of the Electricity Generated and Low-Level Radioactive Wastes Shipped for Disposal by U.S. Nuclear Power Plants, 1959–1985, ORNL/TM-10440, Oak Ridge National Laboratory, Oak Ridge, Tennessee (December 1987).

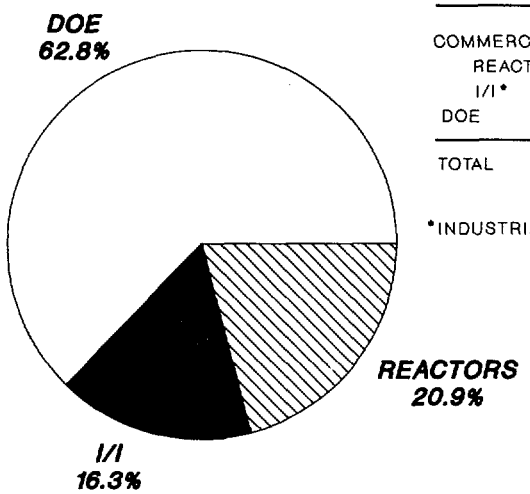
21. Semiannual operating plant effluent release reports for 1986, 1987, 1988, 1989, and 1990 submitted to the NRC.

22. A. H. Kibbey, H. W. Godbee, and S. M. DePaoli, An Update of the Source Terms and Rationale Used for Low-Level Radioactive Waste Projections in the 1988 Department of Energy Integrated Data Base, ORNL/TM-11710, Oak Ridge National Laboratory, Oak Ridge, Tennessee (in preparation).

23. U.S. Department of Energy, Energy Information Administration, Commercial Nuclear Power 1991: Prospects for the United States and the World, DOE/EIA-0438(91), Washington, D.C. (August 1991).

24. G. J. Weir, Jr., M.D., Characteristics of Medically Related Low-Level Radioactive Waste, DE-FG07-85ID012605, American College of Nuclear Physicians, p. 47 (July 1986).

ORNL DWG 91-8668

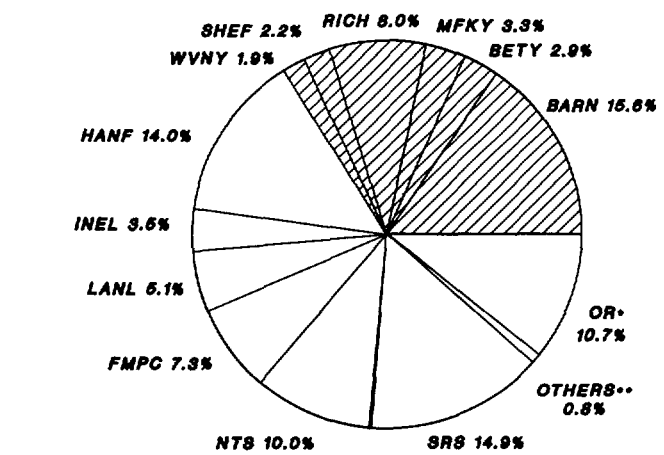


SOURCE	CUBIC METERS
COMMERCIAL	
REACTORS	1.82E+04
I/I*	1.42E+04
DOE	5.45E+04
TOTAL	8.69E+04

*INDUSTRIAL/INSTITUTIONAL

Fig. 4.1. Volume of LLW disposed in 1990.

ORNL DWG 91-8669



Commercial

DOE

SITE	CUBIC METERS
BARN	6.383E+05
BETY	1.183E+05
MFKY	1.353E+05
RICH	3.266E+05
SHEF	8.833E+04
WVNY	7.707E+04
FMPC	2.985E+05
HANF	5.738E+05
INEL	1.441E+05
LANL	2.099E+05
NTS	4.086E+05
OR*	4.391E+05
SRS	6.128E+05
OTHERS**	3.288E+04
TOTAL	4.104E+06

*Includes contributions from ORNL, K-25 Site, and Y-12 Plant.

**Includes contributions from AMES, BNL, LLNL, PAD, PORTS, SLAC, and SNLA.

Fig. 4.2. Total volume of LLW disposed through 1990.

ORNL DWG 91-8670

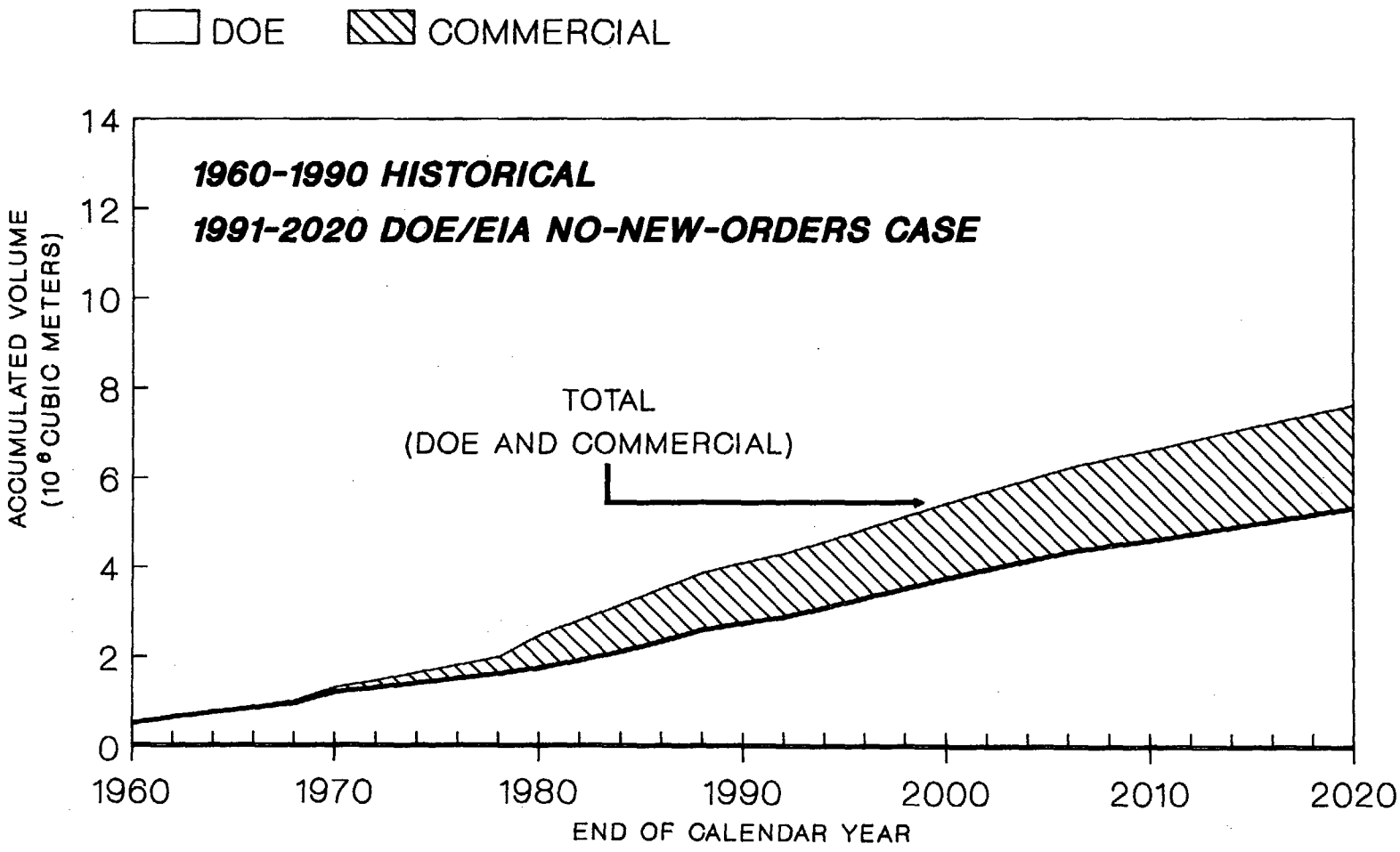
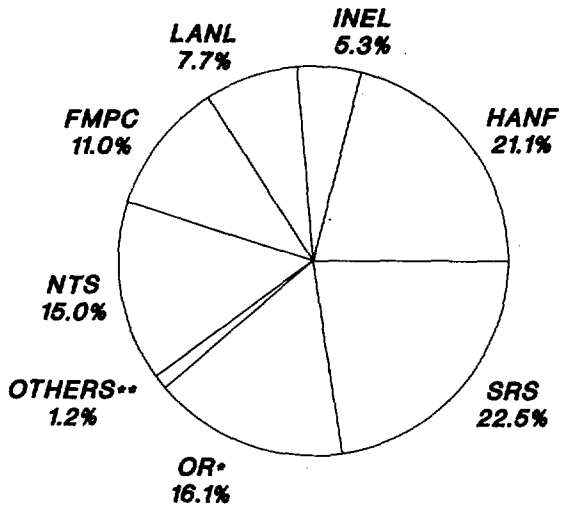


Fig. 4.3. Historical and projected accumulated volume of LLW.

ORNL DWG 91-8671



SITE	CUBIC METERS
FMPC	2.985E+05
HANF	5.738E+05
INEL	1.441E+05
LANL	2.099E+05
NTS	4.086E+05
OR*	4.391E+05
SRS	6.128E+05
OTHERS**	3.288E+04
TOTAL	2.720E+06

*Includes contributions from ORNL, K-25 Site, and Y-12 Plant.

**Includes contributions from AMES, BNL, LLNL, PAD, PORTS, SLAC, and SNLA.

Fig. 4.4. Total volume of DOE LLW disposed through 1990.

ORNL DWG 91-8672

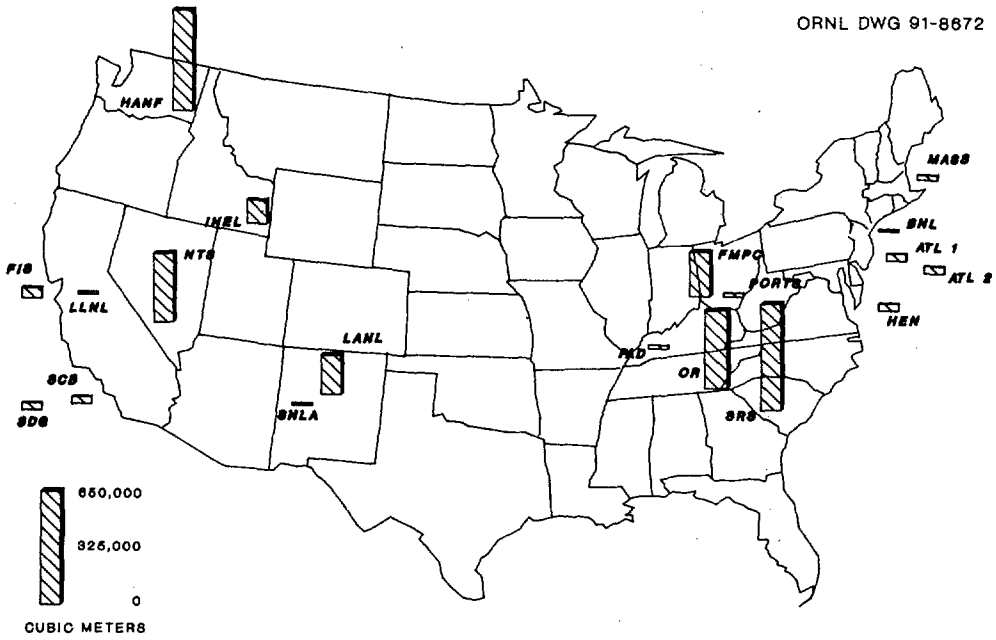
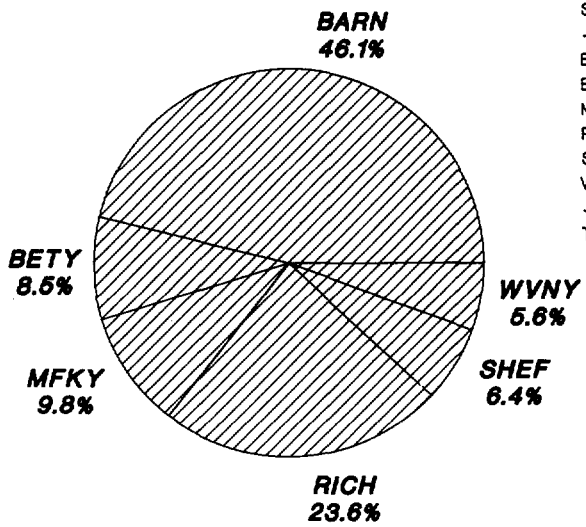


Fig. 4.5. Locations and total volumes of DOE LLW disposed through 1990.

ORNL DWG 91-8673



SITE	CUBIC METERS
BARN	6.383E+05
BETY	1.183E+05
MFKY	1.353E+05
RICH	3.266E+05
SHEF	8.833E+04
WVNY	7.707E+04
TOTAL	1.384E+06

Fig. 4.6. Total volume of commercial LLW disposed through 1990.

ORNL DWG 91-8674

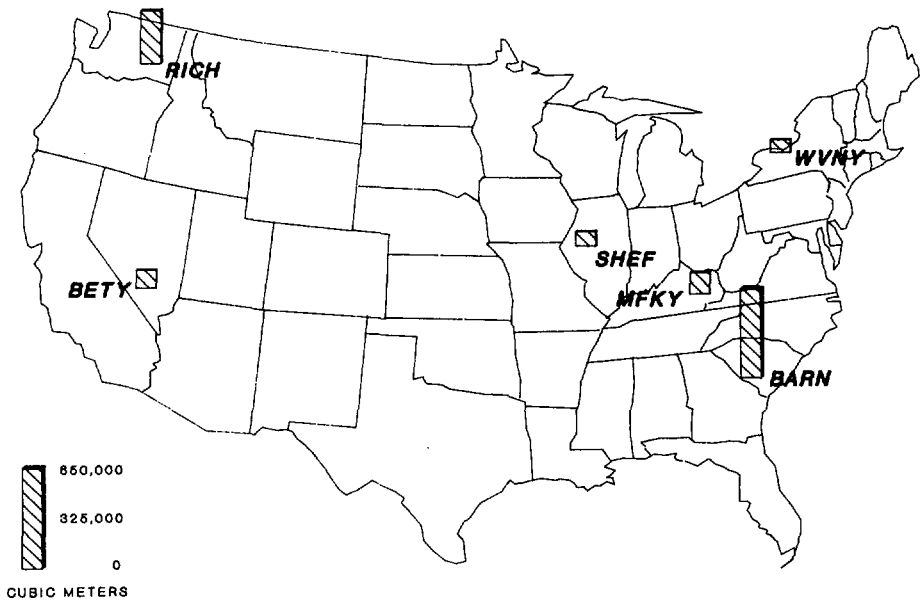


Fig. 4.7. Locations and total volumes of commercial LLW disposed through 1990.

Table 4.1. A summary of characteristics for buried/disposed LLW as of December 31, 1990

Category	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
DOE sites	54.52	2,720	297.0	12,683	1,146	15,785
Commercial sources						
I/I activities[a]	7.85	699.2	34.6	2,915	77.6	3,026
Fuel cycle activities						
LWR operations						
Routine	18.12	612.6	60.9	430.0	436.7	2,893
Nonroutine	0.08	5.6	452.4	2,004	4,088	19,739
UF_6 conversion	0.76	11.6	0.0006	0.009	0.009	0.14
Fuel fabrication	5.55	54.9	0.013	0.17	0.37	3.8
Commercial sites	32.36	1,384	547.9	5,349	4,603	25,662
Total disposed LLW	86.88	4,104	844.9	18,032	5,749	41,447

[a]I/I activities include academic, government (non-DOE), industry (other than fuel cycle operations), and medical generators of LLW. In other words, LLW from reactor operations, UF_6 conversion, and fuel fabrication are included in fuel cycle activities in this chapter, except in Fig. 4.1 where UF_6 conversion and fuel fabrication are included in I/I waste.

Table 4.2. Historical and projected volume, radioactivity, and thermal power of DOE LLW[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[b]	Annual rate	Accumulation
1980	59.4	1,721	436	10,912	1,752	14,464
1981	69.0	1,790	1,119	11,029	3,958	15,400
1982	107.7	1,898	1,941	11,951	6,305	18,661
1983	76.0	1,974	1,800	12,454	3,805	17,971
1984	114.0	2,088	1,432	12,825	3,023	17,973
1985	123.2	2,211	981	12,804	1,772	16,991
1986	104.8	2,316	792	12,705	1,255	16,086
1987	154.1	2,470	2,595	14,513	4,778	19,249
1988	104.6	2,575	399	13,554	1,474	16,349
1989	90.5	2,665	1,118	13,771	5,067	19,388
1990	54.5	2,720	297	12,683	1,146	15,785
1991	54.5	2,774	603	12,426	2,821	16,548
1992	82.8	2,857	615	12,018	2,835	16,320
1993	97.6	2,954	628	11,633	2,845	16,061
1994	107.6	3,062	632	11,267	2,849	15,804
1995	106.7	3,169	627	10,912	2,846	15,551
1996	108.4	3,277	622	10,568	2,841	15,302
1997	110.9	3,388	617	10,236	2,836	15,059
1998	106.7	3,495	626	9,930	2,843	14,831
1999	110.1	3,605	616	9,629	2,836	14,604
2000	109.2	3,714	614	9,341	2,835	14,386
2001	107.5	3,821	613	9,066	2,834	14,174
2002	97.6	3,919	611	8,804	2,834	13,971
2003	97.6	4,016	611	8,554	2,834	13,772
2004	97.6	4,114	610	8,315	2,833	13,581
2005	97.6	4,211	609	8,088	2,833	13,395
2006	97.6	4,309	609	7,871	2,833	13,213
2007	82.7	4,392	609	7,665	2,832	13,038
2008	57.7	4,449	603	7,463	2,821	12,856
2009	57.8	4,507	603	7,271	2,821	12,680
2010	57.7	4,565	603	7,087	2,821	12,507
2011	72.7	4,637	603	6,912	2,821	12,341
2012	72.7	4,710	603	6,745	2,821	12,179
2013	72.7	4,783	604	6,587	2,824	12,024
2014	72.7	4,855	604	6,435	2,824	11,872
2015	72.7	4,928	604	6,291	2,824	11,726
2016	72.7	5,001	604	6,153	2,824	11,582
2017	72.7	5,073	604	6,020	2,824	11,442
2018	72.7	5,146	604	5,894	2,824	11,305
2019	72.7	5,219	604	5,772	2,824	11,172
2020	72.7	5,291	604	5,656	2,824	11,043

[a]Summation of values in Tables 4.12 and 4.13 (LLW saltstone at SRS).

[b]The radioactivity added each year for each waste type is decayed as described in the footnotes of Tables 4.12 and 4.13.

Table 4.3. Historical and projected volume, radioactivity, and thermal power of commercial LLW shipped for disposal[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[b]	Annual rate	Accumulation
1980	92.4	768	333	4,547	1,322	8,003
1981	83.7	852	280	4,483	1,092	7,961
1982	76.5	929	414	4,568	2,539	9,442
1983	78.0	1,007	506	4,732	3,604	11,860
1984	76.4	1,083	601	4,954	4,405	14,769
1985	76.7	1,160	749	5,282	5,680	18,580
1986	53.2	1,213	234	5,059	1,619	17,991
1987	52.2	1,265	270	4,924	2,035	18,072
1988	40.5	1,306	260	4,793	1,948	18,095
1989	46.1	1,352	867	5,284	7,569	23,776
1990	32.4	1,384	548	5,349	4,603	25,662
1991	31.8	1,416	456	5,307	3,410	26,134
1992	31.9	1,448	459	5,288	3,436	26,732
1993	32.2	1,480	462	5,270	3,462	27,314
1994	32.3	1,512	463	5,250	3,467	27,854
1995	32.4	1,545	465	5,230	3,480	28,365
1996	32.9	1,578	471	5,216	3,531	28,887
1997	32.8	1,610	471	5,200	3,528	29,362
1998	32.9	1,643	473	5,186	3,541	29,814
1999	33.1	1,676	473	5,173	3,548	30,237
2000	33.3	1,710	480	5,167	3,600	30,681
2001	33.7	1,743	481	5,160	3,608	31,097
2002	33.3	1,777	481	5,154	3,606	31,479
2003	33.7	1,810	482	5,149	3,615	31,843
2004	33.7	1,844	483	5,145	3,620	32,187
2005	34.1	1,878	492	5,151	3,694	32,582
2006	34.2	1,912	489	5,153	3,668	32,919
2007	33.8	1,946	488	5,154	3,661	33,229
2008	34.3	1,980	493	5,161	3,699	33,557
2009	33.9	2,014	490	5,164	3,676	33,842
2010	33.2	2,048	473	5,152	3,544	33,979
2011	32.2	2,080	455	5,126	3,398	33,976
2012	31.1	2,111	432	5,083	3,214	33,814
2013	29.6	2,141	408	5,026	3,027	33,512
2014	27.4	2,168	367	4,940	2,698	32,947
2015	25.3	2,193	324	4,830	2,361	32,148
2016	24.3	2,217	311	4,727	2,257	31,377
2017	23.2	2,241	291	4,622	2,100	30,573
2018	22.6	2,263	283	4,528	2,040	29,834
2019	22.5	2,286	279	4,445	2,004	29,175
2020	22.2	2,308	277	4,374	1,991	28,603

[a]The values in this table are a summation of the corresponding values in Tables 4.18-4.23.

[b]The radioactivity added each year for each waste type is decayed as described in the footnotes of Tables 4.18-4.23.

Table 4.4. Historical annual additions and total volume of LLW buried at DOE sites[a]

Year	Volume of waste buried annually, 10^3 m^3										
	FMPC	HANF	INEL	LANL	NTS	ORNL	SRS	Y-12	All other[b]	Total annual addition	Total volume accumulated
1975[c]	264.7	358.8	84.6	131.6	8.3	181.5	256.7	58.4	83.9	1,428.5	1,429
1976	14.4	5.3	6.2	8.8	0.0	3.8	7.9	2.7	0.9	50.0	1,479
1977	2.8	11.3	6.6	3.6	0.5	2.4	14.9	1.5	1.1	44.7	1,523
1978	1.9	10.4	5.9	7.5	10.4	2.0	15.9	1.4	3.2	58.6	1,582
1979	1.6	17.9	5.3	4.9	15.8	2.1	16.5	1.1	1.1	66.3	1,648
1980	1.3	11.3	5.1	4.8	13.3	2.0	19.8	1.4	0.7	59.7	1,708
1981	1.5	13.5	3.1	5.5	21.1	1.4	20.3	1.2	1.6	69.2	1,777
1982	2.8	12.2	3.2	4.5	56.8	1.3	22.5	2.2	2.0	107.5	1,885
1983	3.4	18.3	5.5	3.2	12.1	1.8	26.7	3.4	1.7	76.1	1,961
1984	3.5	19.1	3.9	5.4	36.0	2.2	26.2	7.2	10.6	114.1	2,075
1985	0.7	17.5	3.1	6.7	41.7	2.2	30.7	18.7	2.1	123.4	2,198
1986	0	21.2	3.4	4.5	27.9	1.8	30.1	15.0	1.0	104.9	2,303
1987	0	20.4	3.0	3.7	81.1	0.5	34.1	16.2	1.0	160.0	2,463
1988	0	16.8	2.0	4.3	39.1	0.6	36.7	10.5	1.0	111.0	2,574
1989	0	11.9	1.3	6.4	35.0	1.3	27.2	5.7	2.1	90.9	2,665
1990	0	7.9	1.8	4.5	9.1	0.3	26.6	4.4	0.0	54.6	2,720
Total	298.5	573.8[d]	144.0	209.9	408.4	207.2	612.8	150.9	114.1	2,720	

[a]No TRU waste included; data from ref. 1. Slight differences in values shown and those actually reported result from rounding off and truncation of numbers.

[b]Includes contributions from Ames, BNL, K-25, LLNL, PAD, PORTS, SLAC, and SNLA. See Tables 4.5-4.8 for breakdown of 1990 accumulation.

[c]Values for 1975 are cumulative volumes to this date (ref. 2).

[d]Does not include 5,190 m^3 of grouted liquid LLW disposed of at Hanford.

Table 4.5. Summary of radionuclide characteristics for LLW at DOE sites[a]

Waste type	Radionuclide characteristic[b]	Volume, m^3			Activity, Ci		
		1990	Cumulative[c]	1991 (projected)	1990	Total gross[d]	1991 (projected)
Generated on-site	Uranium/thorium	30,841	NA[e]	31,476	824,018	NA	1,066,623
	Fission product	21,411	NA	20,314	135,483	NA	103,764
	Induced activity	4,314	NA	4,710	225,915	NA	1,645,882
	Tritium	1,307	NA	1,191	38,475	NA	26,670
	Alpha	9,347	NA	11,428	33	NA	34
	Other	979	NA	1,465	5,069	NA	25,859
	Total	68,199	NA	70,584	1,228,993	NA	2,868,832
Stored	Uranium/thorium	5,996	42,395	4,943	11	28	16
	Fission product	366	1,284	404	133,611	2,416,148	101,760
	Induced activity	239	1,175	268	4,843	3,647,808	4,650
	Tritium	710	2,043	605	54,986	629,465	50,010
	Alpha	3,820	2,466	5,250	20	113	21
	Other	1,554	6,175	339	2,417	2,421	2,429
	Total	12,685	55,538	11,809	195,888	6,695,983	158,886
Buried	Uranium/thorium	21,347	841,559	25,268	35	861,304	70
	Fission product	18,459	1,157,195	17,447	1,634	7,572,193	1,790
	Induced activity	2,244	182,786	2,033	3,762	6,788,485	3,990
	Tritium	1,749	77,791	1,309	83,432	15,059,719	77,791
	Alpha	8,275	309,900	5,976	482	65,559	13
	Other	2,462	150,438	2,473	207,634	11,877,579	519,030
	Total	54,536	2,719,669	54,506	296,979	42,224,839	602,684

[a]Based on DOE site information provided by the Waste Management Information System (ref. 1).

[b]Radionuclide characteristics: (1) uranium/thorium – those waste materials in which the principal hazard results from naturally occurring uranium and thorium isotopes. The hazard from all other radioactive contaminants should be insignificant. Examples of these wastes include depleted uranium, natural uranium ore, and slightly enriched uranium; (2) fission product – waste materials that are contaminated with beta-gamma-emitting radionuclides which originate as a result of fission processes. Primary examples are ^{137}Cs and ^{90}Sr; (3) induced activity – waste materials that are contaminated with beta-gamma-emitting radioisotopes which are generated through neutron activation. Of major concern is ^{60}Co; (4) tritium – waste materials in which the principal hazard results from tritium (^{3}H); (5) alpha – waste materials contaminated with alpha-emitting radionuclides not listed under U/Th or low levels (<100 nCi/g) of TRU isotopes; and (6) other – unknown or not defined.

[c]From beginning of operations through 1990.

[d]Sum of annual additions without decay.

[e]Not applicable.

Table 4.6. Summary of physical characteristics for LLW at DOE sites[a]

Waste type	Physical characteristic[b]	Volume, m^3			Activity, Ci		
		1990	Cumulative[c]	1991 (projected)	1990	Total gross[d]	1991 (projected)
Generated on-site	Biological	56	NA[e]	45	<<1	NA	1
	Contaminated equipment	18,350	NA	19,427	7,214	NA	1,188,547
	Decontamination debris	3,325	NA	5,376	890,206	NA	1,247,718
	Dry solids	30,737	NA	31,663	327,965	NA	407,939
	Solidified sludge	14,377	NA	1,871	45	NA	39
	Other	1,354	NA	12,202	3,563	NA	24,588
	Total	68,199	NA	70,584	1,228,993	NA	2,868,832
Stored	Biological	3	INA[f]	1	<<1	INA	<<1
	Contaminated equipment	1,223	INA	1,218	7,082	INA	8,574
	Decontamination debris	2,433	INA	4,381	8	INA	10
	Dry solids	3,308	INA	2,724	188,683	INA	150,175
	Solidified sludge	3,338	INA	1,818	7	INA	7
	Other	2,380	INA	1,667	108	INA	120
	Total	12,685	INA	11,809	195,888	INA	158,886
Buried	Biological	104	INA	92	<<1	INA	1
	Contaminated equipment	15,730	INA	13,029	9,879	INA	9,299
	Decontamination debris	3,827	INA	11,110	1,467	INA	1,137
	Dry solids	29,355	INA	26,488	77,060	INA	72,250
	Solidified sludge	41	INA	46	131	INA	10
	Other	5,479	INA	3,741	208,442	INA	519,987
	Total	54,536	INA	54,506	296,979	INA	602,684

[a]Based on DOE site information provided by the Waste Management Information System (ref. 1).

[b]Physical characteristics: (a) biological (sewage sludge, animal carcasses, excreta, etc.); (b) contaminated equipment (components, maintenance wastes, etc.); (c) decontamination debris (wastes resulting from decontamination and decommissioning efforts, construction debris, etc.); (d) dry solids (normal plant wastes, blotting paper, combustible materials, etc.); (e) solidified sludge (any wastes solidified from a process sludge such as evaporator bottoms solidification, solidification of precipitated salts, etc.); and (f) other (materials which are outside of the above categories).

[c]From beginning of operations through 1990.

[d]Sum of annual additions without decay.

[e]Not applicable.

[f]Information not available.

Table 4.7. Breakdown of cumulative volumes of LLW buried at DOE sites by radionuclide characteristic[a]

	Volume, m^3						
DOE site[b]	Uranium/ thorium	Fission product	Induced activity	Tritium	Alpha	Other[c]	Total
Ames	200	0	0	0	0	0	200
ANL-E[d]							
ANL-W	0	0	0	0	0	0	0
BNL	0	0	4	832	0	3	839
FMPC	298,459	0	0	0	0	0	298,459
FNAL	0	0	0	0	0	0	0
HANF	52,846	407,618	84,232	29,091	0	0	573,787
INEL	4,108	25,520	356	<1	989	113,100	144,074
ITRI[d]							
KCP	0	0	0	0	0	0	0
K-25	81,048	0	0	0	0	0	81,048
LANL	61,413	10,059	9,424	3,176	125,849	0	209,921
LBL	0	0	0	0	0	0	0
LLNL[e]	9,102	<<1	<<1	0	0	0	9,102
MOUND	0	0	0	0	0	0	0
NR sites[f]	0	0	0	0	0	0	0
NTS	71,781	216,804	12,853	8,346	81,207	17,421	408,412
ORNL	18,969	122,429	33,929	3,787	12,972	15,068	207,154
PAD[d]	7,613	<<1	0	0	0	0	7,613
PANT	0	0	0	0	0	0	0
Pinellas	0	0	0	0	0	0	0
PORTS	12,110	0	0	0	0	0	12,110
PPPL	0	0	0	0	0	0	0
RFP	0	0	0	0	0	0	0
RMI	0	0	0	0	0	0	0
SLAC	0	0	12	0	0	0	12
SNLA	3,179	7	33	1	<<1	<<1	3,220
SNLL	0	0	0	0	0	0	0
SRS	69,831	374,758	41,942	32,557	88,884	4,846	612,818
Y-12	150,900	0	0	0	0	0	150,900
Total	841,559	1,157,195	182,786	77,791	309,900	150,438	2,719,669

[a]From beginning of operations through 1990. Based on DOE site information provided by the Waste Management Information System (ref. 1).

[b]Radionuclide characteristics are described in footnote b of Table 4.5.

[c]Unknown or mixture.

[d]Updated information for 1990 was not available from this site.

[e]No wastes are buried on the LLNL site. The inventory reported is for wastes buried at the Site 300 Area, an explosives disposal area located off, but near, LLNL.

[f]NR sites include KAPL, BAPL, and NRF.

Table 4.8. Breakdown of total gross activity of LLW buried at DOE sites by radionuclide characteristic

	Total gross activity, Ci[a]						
DOE site[b]	Uranium/ thorium	Fission product	Induced activity	Tritium	Alpha	Other[c]	Total
Ames	<1	0	0	0	0	0	<1
ANL-E[d]							
ANL-W	0	0	0	0	0	0	0
BNL	0	0	2	3	0	<1	6
FMPC	1,811	0	0	0	0	0	1,811
FNAL	0	0	0	0	0	0	0
HANF	824,425	6,358,748	1,314,294	453,822	INA[e]	INA	8,951,289
INEL	47	1,524	35	15	85	11,500,000	11,501,706
ITRI[d]							
KCP	0	0	0	0	0	0	0
K-25	58	0	0	0	0	0	58
LANL	253	17,825	25,185	1,053,662	4,056	0	1,100,981
LBL	0	0	0	0	0	0	0
LLNL[f]	13	<<1	<<1	0	0	0	13
MOUND	0	0	0	0	0	0	0
NR sites[g]	0	0	0	0	0	0	0
NTS	2,444	90,322	7,095	9,258,998	54,714	361,323	9,774,896
ORNL	1,349	382,960	853,381	12,235	754	41	1,250,720
PAD[d]	20,396	3	0	0	0	0	20,399
PANT	0	0	0	0	0	0	0
Pinellas	0	0	0	0	0	0	0
PORTS	26	0	0	0	0	0	26
PPPL	0	0	0	0	0	0	0
RFP	0	0	0	0	0	0	0
RMI	0	0	0	0	0	0	0
SLAC	0	0	<<1	0	0	0	<<1
SNLA	12	611	5,493	2,984	3	4	9,107
SNLL	0	0	0	0	0	0	0
SRS	69	720,000	4,583,000	4,278,000	5,947	16,210	9,603,426
Y-12	10,400	0	0	0	0	0	10,400
Total	861,304	7,572,193	6,788,485	15,059,719	65,559	11,877,579	42,224,839

[a]Sum of annual additions without decay, from beginning of operations through 1990. Based on DOE site information provided by the Waste Management Information System (ref. 1).

[b]Radionuclide characteristics are described in footnote b of Table 4.5.

[c]Unknown or mixture.

[d]Updated information for 1990 was not available from this site.

[e]INA = information not available.

[f]No wastes are buried on the LLNL site. The inventory reported is for wastes buried at the Site 300 Area, an explosives disposal area located off, but near, LLNL.

[g]NR sites include KAPL, BAPL, and NRF.

Table 4.9. DOE LLW disposed by methods other than shallow-land burial[a]

Site	Location	Site use (year)	Waste containers buried[b]	Undecayed radioactive content (Ci)
		Atlantic Ocean		
Atlantic	38°30′N 72°06′W	1951-1956; 1959-1962	14,300	74,400[c]
Atlantic	37°50′N 70°35′W	1957-1959	14,500	2,100
Massachusetts Bay	42°25′N 70°35′W	1952-1959	4,008	2,400
Cape Henry	36°56′N 74°23′W	1949-1967	843	87
Central Atlantic	36°20′N/ 43°49′N 45°00′W	1959-1960	432	480
Subtotal			34,083	79,507
		Pacific Ocean		
Farallon Islands (Subsite A)	37°38′N 123°08′W	1951-1953	3,500	1,100
Farallon Islands (Subsite B)	37°37′N 123°17′W	1946-1950; 1954-1956	44,000	13,400
Santa Cruz Basin	33°40′N 119°40′W	1946-1962	3,114	108
Cape Scot	50°56′N 136°03′W 52°25′N 140°12′W	1958-1969	360	124
San Diego	32°00′N 121°30′W	1959-1962	4,415	34
Subtotal (oceans)			55,389	14,766
Total			89,472	94,273
		Hydrofracture facility		
ORNL	Bedded Conasauga shale underlying the ORNL site	1959-1965	Small experimental amounts	
		1966-1980[d]	8.0×10^3 m^3 of grout	600,000
		1982[e]	3.8×10^3 m^3 of grout	200,000
		1983[e]	5.5×10^3 m^3 of grout	500,000
Total			17.3×10^3 m^3	1,300,000

[a]Radioactivity is given at time of burial. Data taken from Table 4.5 of ref. 2.
[b]Estimated number of containers.
[c]Includes approximately 33,000 Ci of induced activity associated with the U.S.S. Seawolf reactor vessel.
[d]Retired after 18 injections.
[e]New facility started up with four injections in 1982 and completed campaign with seven injections in 1983.

Table 4.10. Status of land usage at LLW burial and disposal sites[a]

Site	Site size[b] (ha)	Estimated total usable area[b] (ha)	Calculated land usage factor[c] (m^3/ha)	Estimated area utilized through 1990 (ha)[b]
DOE (burial sites)				
LANL	48.8	37.1	29,500	17.0
INEL	37.7	35.6	20,000	21.2
NTS	42.5	d	d	d
ORNL	26.0	10.0	6,600	6.0
HANF[e]	385.0	235.0	4,900	150.0
SRS	78.8	72.7	11,200	72.1
SNLA	0.412	0.412	31,000	0.103
SNLL	0.033	0.029	f	f
Total	619	>391		>266.4
Commercial (disposal sites)				
West Valley, NY (Closed Mar. 11, 1975)[g]	8.9	7.2	20,300	3.8
Maxey Flats, KY (Closed Dec. 27, 1977)	102	<51	13,600	10.4
Sheffield, IL (Closed Apr. 8, 1978)	8.9	8.1	10,900	8.1
Barnwell, SC[h]	121	60.7	20,300	29.8
Beatty, NV	32	18.6	7,400	15.7
Richland, WA[i]	40	35.4	42,200	7.8
Total	313	181		75.6
Grand total	932	>572		>342

[a]Note: 1 acre = 0.4047 ha and 1 ha = 10,000 m^2.

[b]DOE site size, usable area, and area utilized (except where noted) are taken from ref. 1. Comparable commercial values (except where noted) are taken from ref. 6.

[c]Land usage factors are taken from refs. 2 and 6.

[d]This pertains to the radioactive waste management site in Area 5 of the NTS. The availability of land that could be used for shallow-land burial is not clearly defined because of the classified nature of the site and the abundance of land. A land usage factor is not applicable at NTS.

[e]Utilized land value is for the 200-Area only; in addition, the closed 100- and 300-Area burial grounds include a total of 16.8 ha.

[f]Information not available.

[g]WVDP LLW was buried on-site in the noncommercial NRC disposal area from 1982 until late 1986. No waste was buried at West Valley in 1987, 1988, 1989, or 1990 (see Table 4.14).

[h]Based on information provided in ref. 5. Anticipated closure date for this site is December 31, 1992.

[i]Estimated area utilized through 1990 was calculated by dividing volume added in 1990 (Table 4.14) by the average land usage factor to obtain area used in 1990. This value was added to the 1989 value reported in Table 4.6 in ref. 6.

Table 4.11. Significant revisions and changes in the current values for LLW compared to the values in the previous year

Burial/ disposal site	DOE/RW-0006, Rev. 6 (1990) Table No.	DOE/RW-0006, Rev. 7 (1991) Table No.	Net change	Explanation
DOE/commercial LLW	NA[a]	4.1	New table	Summary of DOE and commercial values for buried/disposed LLW as of December 31, 1990
DOE LLW	4.1, 4.3, 4.5, 4.6, 4.7, 4.8, and 4.9	4.2, 4.4, 4.9, 4.10, 4.11, 4.12, and 4.13	None	Updates of corresponding tables in DOE/RW-0006, Rev. 6 (1990)
	NA	4.5, 4.6, 4.7, and 4.8	New tables	Summary of DOE data for 1990 [DOE/RW-0006, Rev. 7 (1991)] on generated, stored, and buried LLW
Commercial GTCC LLW	4.13	4.17	New table	Table 4.13 of DOE/RW-0006, Rev. 6 (1990) is in Appendix A (Table A.9) of update
LLW	4.2, 4.6, 4.10, 4.11, 4.12, 4.14, 4.15, 4.16, 4.17, 4.18, and 4.19	4.3, 4.10, 4.14, 4.15, 4.16, 4.18, 4.19, 4.20, 4.21, 4.22, and 4.23	None	Updates of corresponding tables in DOE/RW-0006, Rev. 6 (1990)

[a]Not applicable.

Table 4.12. Historical and projected volume, radioactivity, and thermal power characteristics of DOE LLW, except SRS saltstone

End of calendar year	Volume[a,b] (10^3 m^3)		Radioactivity[a,b] (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
1980	59.4	1,721	436	10,912	1,752	14,464
1981	69.0	1,790	1,119	11,029	3,958	15,400
1982	107.7	1,898	1,941	11,951	6,305	18,661
1983	76.0	1,974	1,800	12,454	3,805	17,971
1984	114.0	2,088	1,432	12,825	3,023	17,973
1985	123.2	2,211	981	12,804	1,772	16,991
1986	104.8	2,316	792	12,705	1,255	16,086
1987	154.1	2,470	2,595	14,513	4,778	19,249
1988	104.6	2,575	399	13,554	1,474	16,349
1989	90.5	2,665	1,118	13,771	5,067	19,388
1990	54.5	2,720	297	12,683	1,146	15,785
1991	54.5	2,774	603	12,426	2,821	16,548
1992	54.5	2,829	603	12,006	2,821	16,306
1993	54.5	2,883	603	11,598	2,821	16,023
1994	54.5	2,937	603	11,208	2,821	15,741
1995	54.5	2,992	603	10,836	2,821	15,467
1996	54.5	3,046	603	10,483	2,821	15,203
1997	54.5	3,101	603	10,147	2,821	14,950
1998	54.5	3,155	603	9,827	2,821	14,705
1999	54.5	3,210	603	9,522	2,821	14,470
2000	54.5	3,264	603	9,232	2,821	14,243
2001	54.5	3,319	603	8,956	2,821	14,024
2002	54.5	3,373	603	8,693	2,821	13,813
2003	54.5	3,428	603	8,442	2,821	13,607
2004	54.5	3,482	603	8,202	2,821	13,409
2005	54.5	3,537	603	7,974	2,821	13,216
2006	54.5	3,591	603	7,756	2,821	13,028
2007	54.5	3,645	603	7,549	2,821	12,846
2008	54.5	3,700	603	7,350	2,821	12,670
2009	54.5	3,754	603	7,161	2,821	12,498
2010	54.5	3,809	603	6,980	2,821	12,330
2011	54.5	3,863	603	6,807	2,821	12,168
2012	54.5	3,918	603	6,642	2,821	12,009
2013	54.5	3,972	603	6,484	2,821	11,855
2014	54.5	4,027	603	6,333	2,821	11,704
2015	54.5	4,081	603	6,189	2,821	11,558
2016	54.5	4,136	603	6,051	2,821	11,415
2017	54.5	4,190	603	5,918	2,821	11,276
2018	54.5	4,244	603	5,792	2,821	11,140
2019	54.5	4,299	603	5,671	2,821	11,008
2020	54.5	4,353	603	5,555	2,821	10,879

[a]Historical (beginning of operations through 1989) annual values of volume and radioactivity (by waste type) for each site are from ref. 6. Similar values for 1990 are from ref. 1. See Tables 4.4, 4.5, 4.7, and 4.8 for more detail. Radioactivity (by waste type) is decayed from the year of addition using the representative compositions given in Table A.5 of Appendix A.

[b]Beginning in 1991, the volume and radioactivity added each year are assumed to remain constant through 2020 at the 1991 values projected (ref. 1) by each site. The radioactivity (by waste type) is decayed from the year of addition using the representative compositions given in Table A.5 of Appendix A.

Table 4.13. Projected volume, radioactivity, and thermal power characteristics of DOE LLW saltstone at SRS[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity[b] (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
1992	28.3	28.3	12.1	12	14	14
1993	43.1	71.4	25.2	35	24	38
1994	53.1	124.5	29.2	59	28	63
1995	52.2	176.7	24.2	76	25	84
1996	53.9	230.6	19.0	85	20	99
1997	56.4	287.0	14.3	89	15	109
1998	52.2	339.2	23.5	103	22	126
1999	55.6	394.8	13.7	107	15	134
2000	54.7	449.5	11.6	109	14	143
2001	53.0	502.5	10.0	110	13	150
2002	43.1	545.6	8.7	111	13	158
2003	43.1	588.7	7.8	112	13	165
2004	43.1	631.8	7.2	113	12	172
2005	43.1	674.9	6.7	114	12	179
2006	43.1	718.0	6.4	115	12	185
2007	28.2	746.2	5.9	116	11	192
2008	3.2	749.4	0.0	113	0	186
2009	3.3	752.7	0.0	110	0	182
2010	3.2	755.9	0.0	107	0	177
2011	18.2	774.1	0.0	105	0	173
2012	18.2	792.3	0.0	103	0	170
2013	18.2	810.5	1.7	103	3	169
2014	18.2	828.7	1.7	102	3	168
2015	18.2	846.9	1.6	102	3	168
2016	18.2	865.1	1.6	102	3	167
2017	18.2	883.3	1.5	102	3	166
2018	18.2	901.5	1.5	102	3	165
2019	18.2	919.7	1.5	101	3	164
2020	18.2	937.9	1.5	101	3	164

[a]Taken from ref. 1 of Chapter 2. Solidification of HLW begins in 1993 at SRS. Feed preparation for this operation begins in 1992 and generates LLW saltstone (see Fig. A.10 and Table A.7 of Appendix A).

[b]Radionuclide composition as a function of time is given in Table A.7 of Appendix A.

Table 4.14. Historical annual additions and total volume of LLW at commercial disposal sites[a]

	Volume, m^3							
Year	Beatty	West Valley[b]	Maxey Flats[c]	Richland	Sheffield[d]	Barnwell	Annual total	Total accumulation
1962	1,861						1,861	1,861
1963	3,512	127	2,206				5,845	7,706
1964	2,836	5,940	3,872				12,648	20,354
1965	1,988	5,192	5,753	668			13,601	33,955
1966	3,533	3,951	5,557	2,402			15,443	49,398
1967	3,206	7,475	7,820	773	2,527		21,801	71,199
1968	3,576	3,490	8,178	1,359	2,713		19,316	90,515
1969	4,526	4,099	10,354	438	2,012		21,429	111,944
1970	5,152	4,906	12,521	423	2,825		25,827	137,771
1971	4,916	7,002	13,173	584	4,430	1,171	31,276	169,047
1972	4,301	9,045	15,578	654	5,956	3,757	39,291	208,338
1973	4,076	7,535	10,074	1,033	8,524	15,839	47,081	255,419
1974	4,103	8,866	8,898	1,411	12,373	18,244	53,895	309,314
1975	4,943	2,243	17,098	1,500	14,116	18,072	57,972	367,286
1976	3,864	427	13,775	2,867	13,480	40,227	74,640	441,926
1977	4,742	351	423	2,718	17,643	45,663	71,540	513,466
1978	8,874	144		7,422	1,735	61,554	79,729	593,195
1979	6,491	138		12,185		63,861	82,675	675,870
1980	12,717	141		24,819		54,723[e]	92,400	768,270
1981	3,351	216		40,732		39,427[e]	83,726	851,996
1982	1,505	632		39,606		34,779	76,522	928,518
1983	1,111	1,284		40,458		35,132	77,985	1,006,503
1984	2,067	966		38,481		34,879	76,393	1,082,896
1985	1,388	809		40,135		34,389	76,721	1,159,617
1986	2,668	2,095		18,833		29,612	53,208	1,212,825
1987	9,414			15,765		27,060	52,239	1,265,064
1988	2,645			11,430		26,391	40,466	1,305,530
1989	3,291			11,562		31,242	46,095	1,351,625
1990	1,684			8,362		22,315	32,361	1,383,986
Total	118,341	77,074	135,280	326,620	88,334	638,337		1,383,986

[a]For a summary of historical additions (1962-1984), see Table 4.6 in ref. 2. For operating sites (Beatty, Richland, and Barnwell), the additions for 1985-1989 are from Table 4.11 in ref. 6 and for 1990 are from ref. 7.

[b]West Valley includes a commercial state-licensed facility which opened Nov. 18, 1963, and closed Mar. 11, 1975, and an NRC-licensed facility (for on-site fuel reprocessing wastes) which opened in 1966 and continued to receive only on-site-generated LLW associated with water treatment and site cleanup until late 1986. This license is in abeyance. Disposal operations at the West Valley Demonstration Project (WVDP) have been suspended pending the preparation of an EIS report for the West Valley site closure. The WVDP began in 1982. The LLW volumes reported for 1982 through 1986 are for the WVDP only and are taken from ref. 6. Since the beginning of 1987, LLW generated at the WVDP is stored on-site in engineered facilities pending final disposal (ref. 6).

[c]Closed Dec. 27, 1977. Small perturbations in waste volumes have occurred during site cleanup operations (ref. 9) but are not included here since they are inconsequential.

[d]Closed Apr. 8, 1978. No additional operations have taken place at the site.

[e]These values exclude almost 19,000 m^3 (approximately 14,506 in 1980 and approximately 4,279 in 1981) of very low-level-activity settling pond sludge that was not counted against the annual quota.

Table 4.15. Historical annual additions and total undecayed radioactivity of LLW at commercial disposal sites[a]

	Radioactivity, Ci							
Year	Beatty	West Valley[b]	Maxey Flats[c]	Richland	Sheffield[d]	Barnwell	Annual total	Total accumulation
1962								
1963	5,690	100	22,556				28,346	28,346
1964	6,477	10,400	147,218				164,095	192,441
1965	6,377	22,600	63,828	144			92,949	285,390
1966	11,974	35,400	52,737	1,606			101,717	387,107
1967	10,894	123,100	23,273	5,378	3,850		166,495	553,602
1968	6,808	10,600	45,577	64,432	2,381		129,798	683,400
1969	9,761	36,000	31,028	55,964	2,192		134,945	818,345
1970	12,304	91,900	46,969	52,820	5,427		209,420	1,027,765
1971	4,316	436,700	720,146	23,916	7,895	4,151	1,197,124	2,224,889
1972	5,228	131,300	217,351	31,809	4,857	13,575	404,120	2,629,009
1973	5,704	346,000	118,359	57,037	2,834	48,212	578,146	3,207,155
1974	23,904	6,600	143,656	12,773	3,229	13,557	203,719	3,410,874
1975	18,388	11,600	289,570	113,341	6,103	17,428	456,430	3,867,304
1976	4,493	1,200	211,359	104,306	7,744	90,205	419,307	4,286,611
1977	23,811	900	267,063	7,465	11,147	390,121	700,507	4,987,118
1978	5,685	700		235,548	2,547	652,061	896,541	5,883,659
1979	8,897	400		164,787		314,938	489,022	6,372,681
1980	148,312	300		41,031		143,502	333,145	6,705,826
1981	52,214	229		43,905		183,744	280,092	6,985,918
1982	80,929	293		59,007		273,962	414,191	7,400,109
1983	1,356	255		120,534		383,450	505,595	7,905,704
1984	544	25		215,286		385,079	600,934	8,506,638
1985	453	39		287,849		460,571	748,912	9,255,550
1986	672	13		116,960		116,094	233,739	9,489,289
1987	11,101	0		47,484		210,966	269,551	9,758,840
1988	8,690	0		32,067		218,901	259,658	10,018,498
1989	42,678	0		99,056		725,164	866,898	10,885,396
1990	11,323	0		92,985		443,594	547,902	11,433,298
Total	528,983	1,266,654	2,400,690	2,087,490	60,206	5,089,275		11,433,298

[a]For a summary of historical additions (1962-1984), see Table 4.6 in ref. 2. For operating sites (Beatty, Richland, and Barnwell), the additions for 1985-1989 are from Table 4.11 in ref. 6 and for 1990 are from ref. 7.

[b]West Valley includes a commercial state-licensed facility which opened Nov. 18, 1963, and closed Mar. 11, 1975, and an NRC-licensed facility (for on-site fuel reprocessing wastes) which opened in 1966 and continued to receive only on-site-generated LLW associated with water treatment and site cleanup until late 1986. This license is in abeyance. Disposal operations at the West Valley Demonstration Project (WVDP) have been suspended pending the preparation of an EIS report for the West Valley site closure. The WVDP began in 1982. The LLW radioactivity values reported for 1982 through 1986 are for the WVDP only and are taken from ref. 6. Since the beginning of 1987, LLW generated at the WVDP is stored on-site in engineered facilities pending final disposal (ref. 6).

[c]Closed Dec. 27, 1977.

[d]Closed Apr. 8, 1978.

Table 4.16. Distribution of total volume and radioactivity, by state, of LLW shipped to commercial disposal sites in 1990[a]

State	Volume (m^3)	Radioactivity (Ci)	State	Volume (m^3)	Radioactivity (Ci)
Alabama	403	4,858	Nebraska	441	378
Alaska	<1	225	Nevada	9	1
Arizona	786	247	New Hampshire	6	<1
Arkansas	177	14	New Jersey	1,497	3,718
California	1,585	5,538	New Mexico	52	1
Colorado	65	1,451	New York	2,019	12,702
Connecticut	967	255,038	North Carolina	1,362	3,051
Delaware	24	<1	North Dakota	<1	<1
District of Columbia	15	5	Ohio	684	4,316
Florida	696	6,808	Oklahoma	622	3
Georgia	1,566	29,054	Oregon	1,684	593
Hawaii	134	1	Pennsylvania	2,877	47,306
Idaho	1	<1	Puerto Rico	0	0
Illinois	2,785	8,253	Rhode Island	5	<1
Indiana	55	44	South Carolina	1,329	2,208
Iowa	157	37,808	South Dakota	33	<1
Kansas	92	67	Tennessee	2,362	1,210
Kentucky	131	61	Texas	261	1,650
Louisiana	321	994	Utah	151	1
Maine	222	193	Vermont	0	0
Maryland	482	4,725	Virgin Islands	0	0
Massachusetts	1,150	86,641	Virginia	1,636	1,924
Michigan	1,021	21,373	Washington	740	1,398
Minnesota	761	1,183	West Virginia	3	<1
Mississippi	169	1,369	Wisconsin	261	570
Missouri	555	920	Wyoming	<1	2
Montana	6	<1	Other[b]	1	1
			Total	32,361[c]	547,902[c]

[a]Data provided by EG&G, Idaho (ref. 7), to be published by the Low-Level Waste Management Program.
[b]Wastes generated U.S. Army bases located inside and outside the United States.
[c]Differences in the 1990 annual totals (i.e., the volume in Table 4.14 and the radioactivity in Table 4.15 and the summations of shipments by state, as shown above) result from rounding off and truncation of numbers.

Table 4.17. Summary of projected GTCC wastes for LWRs based on packaged waste volume[a]

Vendor[b]/LWR	Reactor component	Estimated packaged waste volume (m^3) by expected cases[c] Low	Base	High	Activity[d] (Ci)
GE/BWR	Cartridge filters	5.80E-02	1.16E+00	2.32E+00	6.62E+00
	Control rod components				
	Bearings	1.42E-04	1.42E-04	1.42E-04	8.93E+00
	Blade	3.53E+02	4.41E+02	8.83E+02	1.62E+05
	Inner drive strainers	2.55E-02	5.09E-01	1.02E+00	6.85E+01
	Outer drive strainers	1.12E+00	2.22E+01	4.55E+01	6.76E+01
	Core shroud	1.80E+02	2.57E+02	3.86E+02	4.93E+06
	Dry tubes	1.31E+01	2.13E+01	4.36E+01	1.08E+05
	Fuel in decontamination resins	1.13E+01	5.66E+01	1.13E+02	2.02E+03
	Local power range monitor	5.80E+01	9.67E+01	1.93E+02	6.65E+04
	Poison curtains	6.78E-03	6.78E-03	6.78E-03	1.55E+02
	Pool filters	1.68E+00	3.36E+01	6.72E+01	2.00E+02
	BWR total	6.18E+02	9.30E+02	1.73E+03	5.27E+06
B&W/PWR	Cartridge filters	1.32E+00	2.64E+01	5.29E+01	3.28E+02
	Control rod drive	3.20E-02	3.20E-02	3.20E-02	6.14E+02
	Core barrel	e	e	4.59E+01	3.64E+05
	Core shroud	1.44E+01	2.06E+01	3.09E+01	1.78E+06
	Crud tank filters	2.32E-01	4.64E+00	9.28E+00	3.47E+01
	Flux wire	4.00E-01	4.00E-01	4.00E-01	1.55E+04
	Fuel in decontamination resins	1.70E+00	8.48E+00	1.70E+01	1.18E+03
	In-core detectors	1.17E+01	1.95E+01	3.90E+01	1.75E+04
	Miscellaneous metals	3.80E-02	3.80E-02	3.80E-02	NR[f]
	Primary sources	1.13E-02	1.13E-02	1.13E-02	1.21E+04
	B&W total	2.98E+01	8.01E+01	1.95E+02	2.19E+06
CE/PWR	Cartridge filters	2.30E+00	4.59E+01	9.19E+01	8.33E+01
	Control rod drive	7.40E-01	7.40E-01	7.40E-01	1.45E+03
	Core barrel	e	e	3.69E+02	7.06E+05
	Core shroud	4.63E+01	6.62E+01	9.93E+01	5.54E+06
	Flux wire	6.00E-02	6.00E-02	6.00E-02	NR
	Fuel in decontamination resins	9.34E+00	4.66E+01	9.33E+01	4.54E+03
	In-core detectors	2.75E+01	4.59E+01	9.17E+01	2.39E+04
	Primary sources	7.47E-02	7.47E-02	7.47E-02	9.26E+06
	Miscellaneous metals	3.00E-01	3.00E-01	3.00E-01	NR
	Thimble plug assemblies	4.00E-01	8.00E-01	1.20E+00	NR
	CE total	8.70E+01	2.07E+02	7.48E+02	1.55E+07
WH/PWR	Cartridge filters	8.50E+00	1.70E+02	3.34E+02	3.12E+02
	Control rod drive	1.72E+01	1.72E+01	1.72E+01	6.76E+06
	Core barrel	e	e	5.95E+02	3.94E+06
	Core shroud	1.25E+02	1.79E+02	2.68E+02	2.44E+07
	Fuel in decontamination resins	3.24E+01	1.61E+02	3.22E+02	1.78E+04
	In-core instruments	1.34E+01	2.15E+01	4.47E+01	1.22E+05
	Miscellaneous metals	1.25E+00	1.25E+00	1.25E+00	NR
	Source rods	1.15E+00	1.15E+00	1.15E+00	6.73E+06
	Thimble plug assemblies	3.89E+01	7.78E+01	1.17E+02	1.66E+04
	WH total	2.38E+02	6.29E+02	1.70E+03	4.20E+07
	PWR total	3.55E+02	9.16E+02	2.64E+03	5.97E+07
	LWR total	9.73E+02	1.85E+03	4.37E+03	6.50E+07

[a]Based on ref. 18.
[b]GE = General Electric, B&W = Babcock & Wilcox, CE = Combustion Engineering, and WH = Westinghouse.
[c]These projections cover the time frame 1985-2035. The low case corresponds to the lowest volume expected, the base case to the most likely volume, and the high case to the largest volume expected.
[d]The same amount of activity is associated with each volume projection case.
[e]Not included in the low and base cases.
[f]Not reported (information not reported in ref. 18).

Table 4.18. Historical and projected volume, radioactivity, and thermal power of LLW shipped for disposal from I/I activities[a,b,c]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[d]	Annual rate	Accumulation
1980	40.2	478	232	3,769	520.5	661
1981	34.7	513	191	3,733	429.5	938
1982	26.5	539	168	3,682	377.8	1,201
1983	30.4	569	125	3,596	281.3	1,406
1984	27.1	597	134	3,530	300.9	1,682
1985	30.2	627	175	3,511	392.1	2,068
1986	19.7	646	64	3,380	143.7	2,202
1987	20.4	667	50	3,256	111.6	2,394
1988	12.1	679	46	3,138	102.8	2,603
1989	12.4	691	47	3,029	105.7	2,827
1990	7.8	699	35	2,915	77.6	3,026
1991	7.8	707	35	2,809	77.6	3,235
1992	7.8	715	35	2,709	77.6	3,442
1993	7.8	723	35	2,615	77.6	3,647
1994	7.8	731	35	2,527	77.6	3,847
1995	7.8	738	35	2,444	77.6	4,043
1996	7.8	746	35	2,366	77.6	4,234
1997	7.8	754	35	2,293	77.6	4,420
1998	7.8	762	35	2,224	77.6	4,602
1999	7.8	770	35	2,159	77.6	4,780
2000	7.8	778	35	2,099	77.6	4,953
2001	7.8	786	35	2,042	77.6	5,123
2002	7.8	793	35	1,988	77.6	5,289
2003	7.8	801	35	1,938	77.6	5,452
2004	7.8	809	35	1,891	77.6	5,613
2005	7.8	817	35	1,847	77.6	5,770
2006	7.8	825	35	1,806	77.6	5,925
2007	7.8	833	35	1,767	77.6	6,078
2008	7.8	840	35	1,731	77.6	6,229
2009	7.8	848	35	1,698	77.6	6,378
2010	7.8	856	35	1,666	77.6	6,526
2011	7.8	864	35	1,637	77.6	6,672
2012	7.8	872	35	1,610	77.6	6,817
2013	7.8	880	35	1,585	77.6	6,960
2014	7.8	888	35	1,561	77.6	7,102
2015	7.8	895	35	1,540	77.6	7,244
2016	7.8	903	35	1,520	77.6	7,384
2017	7.8	911	35	1,501	77.6	7,524
2018	7.8	919	35	1,484	77.6	7,663
2019	7.8	927	35	1,468	77.6	7,801
2020	7.8	935	35	1,454	77.6	7,939

[a]Although this table shows 1980 as the beginning, the computer-generated table from which it is extracted goes back to 1962.

[b]The source term composition of the radioactivity in pre-1980 I/I waste is given in ref. 2. The source term composition used for I/I waste for 1980 through 2020 is presented in Table A.11 of Appendix A. The values for the volume and radioactivity of I/I wastes were obtained as the difference between the total volume (Table 4.14) and radioactivity (Table 4.15) reported shipped for disposal each year and the corresponding total fuel cycle (UF_6 conversion and fuel fabrication plus LWR operations) values from Tables 4.19-4.23.

[c]The projected volume of I/I waste is assumed to remain constant from 1990 through 2020 (see ref. 24 for rationale). The radioactivity associated with this volume is calculated using the composition given in Table A.11 of Appendix A.

[d]The radioactivity added each year is decayed as if it had the composition given in Table A.11 of Appendix A.

Table 4.19. Historical and projected volume, radioactivity, and thermal power of routine LLW shipped for disposal from BWRs[a,b]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[c]	Annual rate	Accumulation
1980	26.1	141	41	128	314	1,104
1981	23.0	164	42	144	318	1,254
1982	25.5	190	38	155	285	1,351
1983	22.6	212	56	183	425	1,579
1984	24.4	237	29	178	220	1,565
1985	23.1	260	28	177	210	1,555
1986	17.3	277	32	182	240	1,582
1987	14.3	292	28	183	214	1,580
1988	11.7	303	29	185	217	1,584
1989	14.2	317	32	190	240	1,611
1990	10.3	328	34	196	254	1,649
1991	9.7	337	31	199	228	1,655
1992	9.7	347	32	203	230	1,663
1993	9.7	357	32	206	230	1,671
1994	9.7	367	32	209	230	1,679
1995	9.7	376	32	212	230	1,686
1996	9.9	386	32	215	233	1,696
1997	9.9	396	32	218	233	1,705
1998	9.9	406	32	220	233	1,713
1999	9.9	416	32	223	233	1,721
2000	10.0	426	33	225	236	1,731
2001	10.0	436	33	228	236	1,741
2002	10.0	446	33	230	236	1,749
2003	10.0	456	32	233	235	1,757
2004	10.0	466	32	235	235	1,764
2005	10.2	476	33	238	240	1,775
2006	10.1	486	33	240	238	1,783
2007	10.1	496	33	242	238	1,791
2008	10.2	507	33	245	242	1,801
2009	10.2	517	33	247	239	1,808
2010	9.7	526	31	247	228	1,803
2011	9.1	536	30	246	215	1,787
2012	8.4	544	27	244	199	1,758
2013	8.0	552	26	241	189	1,725
2014	7.0	559	23	236	165	1,674
2015	5.9	565	19	228	139	1,606
2016	5.7	571	19	223	134	1,545
2017	5.3	576	17	217	125	1,483
2018	5.2	581	17	212	123	1,429
2019	5.1	586	17	207	121	1,380
2020	5.1	591	17	204	121	1,337

[a]Although this table shows 1980 as the beginning, the computer-generated table from which it is extracted goes back to 1962.

[b]Annual volume and radioactivity additions through 1990 are reported values (refs. 6, 20, and 21). Beginning in 1991, these values are calculated using the energy values presented in Table A.8 and the source term (which describes routine waste) shown in Fig. A.6 of Appendix A.

[c]The radioactivity added each year is decayed as if it had the composition given in Fig. A.6 of Appendix A.

Table 4.20. Historical and projected volume, radioactivity, and thermal power of routine LLW shipped for disposal from PWRs[a,b]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[c]	Annual rate	Accumulation
1980	22.4	124	24	81	160	496
1981	22.8	147	31	102	207	616
1982	20.8	168	34	122	224	732
1983	21.4	189	32	138	211	817
1984	21.0	210	41	163	275	958
1985	18.7	229	29	171	190	989
1986	11.6	241	22	175	144	982
1987	12.2	253	25	184	166	1,008
1988	10.9	264	36	203	238	1,103
1989	13.4	277	48	231	321	1,258
1990	7.8	285	27	234	182	1,244
1991	7.6	292	27	240	172	1,242
1992	7.6	300	27	247	173	1,248
1993	7.8	308	28	256	177	1,261
1994	7.9	316	28	264	178	1,274
1995	8.0	324	28	272	180	1,290
1996	8.1	332	29	281	184	1,308
1997	8.1	340	28	289	183	1,326
1998	8.2	348	29	298	185	1,344
1999	8.2	356	29	306	186	1,363
2000	8.4	365	29	315	190	1,384
2001	8.5	373	30	324	191	1,406
2002	8.4	382	30	332	191	1,425
2003	8.5	390	30	341	193	1,445
2004	8.6	399	30	349	194	1,465
2005	8.8	408	31	358	198	1,488
2006	8.7	416	31	366	197	1,508
2007	8.7	425	30	374	196	1,525
2008	8.7	434	31	382	197	1,543
2009	8.7	442	31	389	197	1,559
2010	8.6	451	30	397	194	1,573
2011	8.5	459	30	403	192	1,584
2012	8.3	468	29	409	188	1,591
2013	7.7	476	27	413	174	1,585
2014	7.0	483	25	415	159	1,569
2015	6.5	489	23	416	147	1,546
2016	6.1	495	21	416	137	1,519
2017	5.6	501	20	415	127	1,487
2018	5.3	506	19	414	120	1,454
2019	5.2	511	18	413	118	1,426
2020	5.1	516	18	412	116	1,400

[a]Although this table shows 1980 as the beginning, the computer-generated table from which it is extracted goes back to 1962.

[b]Annual volume and radioactivity additions through 1990 are reported values (refs. 6, 20, and 21). Beginning in 1991, these values are calculated using the energy values presented in Table A.8 and the source term (which describes routine waste) shown in Fig. A.7 of Appendix A.

[c]The radioactivity added each year is decayed as if it had the composition given in Fig. A.7 of Appendix A.

Table 4.21. Historical and projected volume, radioactivity, and thermal power of nonroutine LLW shipped for disposal from LWRs[a,b]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[c]	Annual rate	Accumulation
1980	0.73	3.9	36	569	328	5,741
1981	0.16	4.1	16	504	138	5,153
1982	0.47	4.5	175	610	1,652	6,157
1983	0.16	4.7	292	816	2,686	8,056
1984	0.26	4.9	397	1,083	3,609	10,562
1985	0.30	5.2	518	1,422	4,887	13,966
1986	0.04	5.3	116	1,322	1,091	13,222
1987	0.05	5.3	167	1,302	1,543	13,087
1988	0.02	5.4	149	1,268	1,389	12,801
1989	0.20	5.6	740	1,834	6,902	18,076
1990	0.08	5.6	452	2,004	4,088	19,739
1991	0.53	6.2	363	2,059	2,933	19,998
1992	0.53	6.7	366	2,128	2,956	20,373
1993	0.54	7.2	369	2,192	2,977	20,730
1994	0.54	7.8	369	2,249	2,981	21,049
1995	0.54	8.3	370	2,301	2,992	21,341
1996	0.55	8.9	376	2,354	3,037	21,643
1997	0.55	9.4	376	2,400	3,034	21,905
1998	0.55	10.0	377	2,444	3,045	22,147
1999	0.55	10.5	378	2,484	3,051	22,366
2000	0.56	11.1	383	2,527	3,096	22,604
2001	0.56	11.7	384	2,567	3,103	22,820
2002	0.56	12.2	384	2,603	3,101	23,007
2003	0.56	12.8	385	2,637	3,108	23,180
2004	0.57	13.3	385	2,670	3,113	23,336
2005	0.58	13.9	393	2,708	3,177	23,539
2006	0.57	14.5	391	2,741	3,155	23,693
2007	0.57	15.1	390	2,770	3,149	23,824
2008	0.58	15.6	394	2,803	3,182	23,973
2009	0.57	16.2	392	2,830	3,162	24,085
2010	0.55	16.8	377	2,842	3,044	24,066
2011	0.53	17.3	361	2,839	2,913	23,922
2012	0.50	17.8	341	2,820	2,749	23,636
2013	0.47	18.3	320	2,787	2,586	23,228
2014	0.42	18.7	285	2,728	2,296	22,589
2015	0.37	19.1	248	2,645	1,996	21,739
2016	0.35	19.4	236	2,568	1,907	20,916
2017	0.33	19.7	220	2,489	1,771	20,065
2018	0.32	20.1	213	2,418	1,719	19,273
2019	0.31	20.4	209	2,356	1,688	18,553
2020	0.31	20.7	208	2,304	1,676	17,912

[a]Although this table shows 1980 as the beginning, the computer-generated table from which it is extracted goes back to 1962.

[b]Annual volume and radioactivity additions through 1990 are reported values (refs. 6, 20, and 21). Beginning in 1991, these values are calculated using the energy values presented in Table A.8 and the source terms (which describe nonroutine waste) shown in Figs. A.6 (BWRs) and A.7 (PWRs) of Appendix A.

[c]The radioactivity added each year is decayed as if it had the composition given in Figs. A.6 (BWRs) and A.7 (PWRs) of Appendix A.

Table 4.22. Historical and projected volume, radioactivity, and thermal power of LLW shipped for disposal from UF_6 conversion for LWRs[a,b]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power[d] (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[c]	Annual rate	Accumulation
1980	0.45	4.2	0.0003	0.003	0.005	0.05
1981	0.49	4.7	0.0004	0.004	0.006	0.06
1982	0.64	5.4	0.0005	0.004	0.008	0.06
1983	0.73	6.1	0.0006	0.005	0.009	0.07
1984	0.65	6.8	0.0005	0.005	0.008	0.08
1985	0.91	7.7	0.0007	0.006	0.011	0.09
1986	0.63	8.3	0.0005	0.007	0.007	0.10
1987	0.92	9.2	0.0007	0.007	0.011	0.11
1988	0.77	10.0	0.0006	0.008	0.009	0.12
1989	0.81	10.8	0.0006	0.008	0.009	0.13
1990	0.76	11.6	0.0006	0.009	0.009	0.14
1991	0.77	12.3	0.0006	0.010	0.009	0.15
1992	0.73	13.1	0.0006	0.010	0.009	0.15
1993	0.80	13.8	0.0006	0.011	0.009	0.16
1994	0.82	14.7	0.0006	0.011	0.010	0.17
1995	0.76	15.4	0.0006	0.012	0.009	0.18
1996	0.85	16.3	0.0006	0.013	0.010	0.19
1997	0.83	17.1	0.0006	0.013	0.010	0.20
1998	0.79	17.9	0.0006	0.014	0.009	0.21
1999	0.85	18.8	0.0006	0.015	0.010	0.22
2000	0.75	19.5	0.0006	0.015	0.009	0.23
2001	1.00	20.5	0.0008	0.016	0.012	0.24
2002	0.68	21.2	0.0005	0.016	0.008	0.25
2003	0.92	22.1	0.0007	0.017	0.011	0.26
2004	0.82	22.9	0.0006	0.018	0.010	0.27
2005	0.73	23.6	0.0006	0.018	0.009	0.28
2006	0.97	24.6	0.0007	0.019	0.011	0.29
2007	0.63	25.3	0.0005	0.019	0.007	0.30
2008	0.93	26.2	0.0007	0.020	0.011	0.31
2009	0.70	26.9	0.0005	0.021	0.008	0.32
2010	0.74	27.6	0.0006	0.021	0.009	0.32
2011	0.63	28.3	0.0005	0.022	0.007	0.33
2012	0.60	28.9	0.0005	0.022	0.007	0.34
2013	0.53	29.4	0.0004	0.023	0.006	0.35
2014	0.55	29.9	0.0004	0.023	0.006	0.35
2015	0.53	30.5	0.0004	0.023	0.006	0.36
2016	0.41	30.9	0.0003	0.024	0.005	0.36
2017	0.50	31.4	0.0004	0.024	0.006	0.37
2018	0.47	31.8	0.0004	0.025	0.005	0.37
2019	0.59	32.4	0.0004	0.025	0.007	0.38
2020	0.43	33.1	0.0003	0.026	0.005	0.39

[a]Although this table shows 1980 as the beginning, the computer-generated table from which it is extracted goes back to 1962.

[b]These values are calculated based on the UF_6 conversion demand needed to support the electrical generation shown in Table A.8 of Appendix A and the assumption that the settling pond sludges from the direct-fluorination process (Fig. A.2 of Appendix A) are the only LLW thus far shipped for commercial disposal.

[c]The radioactivity added each year is decayed as if it had the composition given in Fig. A.2 of Appendix A.

[d]These values are small since the radionuclides involved have low energy per disintegration; however, they are presented in the interest of completeness.

Table 4.23. Historical and projected volume, radioactivity, and thermal power of LLW shipped for disposal from fuel fabrication for LWRs[a,b]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power[d] (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[c]	Annual rate	Accumulation
1980	2.4	17	0.006	0.05	0.16	1.1
1981	2.6	19	0.006	0.06	0.17	1.3
1982	2.6	22	0.006	0.07	0.18	1.5
1983	2.7	25	0.006	0.08	0.18	1.7
1984	3.0	28	0.007	0.09	0.20	1.9
1985	3.6	31	0.009	0.10	0.24	2.1
1986	3.9	35	0.009	0.11	0.26	2.4
1987	4.3	39	0.010	0.12	0.29	2.7
1988	4.9	44	0.012	0.14	0.33	3.0
1989	5.1	49	0.012	0.15	0.34	3.4
1990	5.6	55	0.013	0.17	0.37	3.8
1991	5.4	60	0.013	0.19	0.36	4.2
1992	5.4	66	0.013	0.21	0.36	4.5
1993	5.5	71	0.013	0.22	0.37	4.9
1994	5.5	77	0.013	0.24	0.37	5.3
1995	5.5	82	0.013	0.26	0.37	5.7
1996	5.6	88	0.013	0.28	0.38	6.1
1997	5.6	93	0.013	0.29	0.38	6.4
1998	5.7	99	0.013	0.31	0.38	6.8
1999	5.7	105	0.014	0.33	0.38	7.2
2000	5.8	111	0.014	0.35	0.39	7.6
2001	5.8	116	0.014	0.37	0.39	8.0
2002	5.8	122	0.014	0.39	0.39	8.4
2003	5.8	128	0.014	0.40	0.39	8.8
2004	5.9	134	0.014	0.42	0.39	9.2
2005	6.0	140	0.014	0.44	0.40	9.6
2006	5.9	146	0.014	0.46	0.40	10.1
2007	5.9	152	0.014	0.48	0.40	10.5
2008	6.0	158	0.014	0.50	0.40	10.9
2009	6.0	164	0.014	0.52	0.40	11.3
2010	5.8	170	0.014	0.54	0.39	11.7
2011	5.6	175	0.013	0.55	0.38	12.1
2012	5.4	181	0.013	0.57	0.36	12.5
2013	5.1	186	0.012	0.59	0.34	12.8
2014	4.6	190	0.011	0.60	0.31	13.1
2015	4.1	194	0.010	0.62	0.27	13.4
2016	3.9	198	0.009	0.63	0.26	13.7
2017	3.6	202	0.009	0.64	0.24	13.9
2018	3.4	205	0.008	0.65	0.23	14.2
2019	3.4	209	0.008	0.66	0.23	14.4
2020	3.3	212	0.008	0.67	0.22	14.6

[a]Although this table shows 1980 as the beginning, the computer-generated table from which it is extracted goes back to 1962.

[b]Calculated using the energy values presented in Table A.8 and the source term (which describes fuel fabrication waste) in Fig. A.5 of Appendix A.

[c]The radioactivity added each year is decayed as if it had the composition given in Fig. A.5 of Appendix A.

[d]These values are small since the radionuclides involved have low energy per disintegration; however, they are presented in the interest of completeness.

ORNL PHOTO 4662-91

Photo 5.1. A uranium mill tailings pond at the Panna Maria site in Karnes County, Texas. (Courtesy of the U.S. Department of Energy, Energy Information Administration, Washington, D.C.)

5. URANIUM MILL TAILINGS FROM COMMERCIAL OPERATIONS

5.1 INTRODUCTION

Uranium mill tailings are the residual wastes of milled ore that remain after the uranium values have been recovered. Mill tailings at licensed sites and those that will be produced to meet future uranium requirements are "commercial" mill tailings, the subject of this chapter. Tailings resulting from uranium mined for defense purposes are not included. Existing tailings at sites that are no longer licensed are classified as "inactive" mill tailings. Inactive tailings are administered under the remedial action projects discussed in Chapter 6.

Mill tailings are generated during the process of extracting uranium from the ore fed to the mill. Uranium mills employ either an acid leach or an alkaline leach process to recover uranium, depending on the ore's chemical characteristics. Currently, more than 80% of the U.S. milling capacity uses the acid leach process. Mill tailings from both processes consist of slurries of sands and clay-like particles called slimes; the tailings slurries are pumped to tailings impoundment ponds for disposal.

U.S. uranium production from conventional milling has declined since 1980, and, as a consequence, the quantity of mill tailings generated each year has declined (see Table 5.1). During 1990, four mills operated and generated tailings. The location of each of these mills is indicated in the map of Fig. 5.1. At the end of 1990, two conventional mills were operating in the United States,[1,2] capable of processing a total of 3,900 t of uranium ore per day. These two mills represent about 14% of the total available domestic conventional uranium milling capacity.[1,2] This small utilization of U.S. capacity can be attributed in large part to nuclear power plant cancellations and deferments. Since the late 1970s, these have led to lower uranium demand. This, in turn, has contributed to lower uranium prices and a steady decline in domestic uranium mining. In addition, cost increases for domestic uranium mining and milling have led to increased reliance on imports of lower cost uranium.

In recent years, U.S. uranium concentrate production has been from conventional milling of ore; processing of solutions from in situ leach mining, heap-leach solutions, mine water, and other solutions; and from the processing of phosphate and copper ores as by-product uranium.

In 1990, the total processing of ore at conventional mills was 44% less than in 1989. Concentrate production in 1990 was about 2,100 t U_3O_8, about 1,600 t less than 1989 production.[2] Nonconventional concentrate production in 1990 decreased to about 1,900 t U_3O_8, or 25% below 1989 production.[2] In situ leaching (ISL) technology has been increasingly applied in recent years in mining operations. Of the total $80-per-kg U uranium reserves estimated by EIA, the amount for which ISL is the proposed mining method has increased from 28% in 1984 to 32% in 1990. Because ISL mining generally is successful at lower costs compared with conventional mining methods, it could gain even wider use in the near future. ISL and by-product production methods do not generate mill tailings. Residual wastes from nonconventional methods are not considered in this section.

The volumes of historical and projected cumulative mill tailings through the year 2005 are shown in Fig. 5.2. This graph is based on the data reported in Table 5.1. The estimates of projected domestic tailings are based on U.S. production of uranium found in projections from the DOE/EIA uranium mining and milling viability assessment report (ref. 3), as well as ref. 4.

5.2 INVENTORIES

The status of the licensed mills, including their estimated commercial and government-related tailings inventories at the end of 1990, is shown in Table 5.2 (data based on refs. 1–12). For each mill, the amount of tailings generated depends on the amount of ore processed, the ore-feed grade (U_3O_8 assay), and the percentage of U_3O_8 recovered. Table 5.3 lists the annual milling rate, ore grade, and U_3O_8 recovery; the associated mill tailings generated through 1990 are 189×10^6 t (118×10^6 m^3). The DOE/EIA estimates[1] that 0.69×10^6 t (3.70×10^5 m^3) of tailings were added to the tailings piles at operating mill sites during 1990.

5.3 WASTE CHARACTERIZATION

Because the amount of uranium (by weight) extracted from the ore during milling is relatively small, the dry weight of the tailings produced is nearly equal to the dry weight of ore processed. Dry tailings typically are composed of 70 to 80 wt % sand-sized particles and 20 to 30 wt % finer-sized particles. Acid leaching is preferred for ores with low lime content (12% or less). Those with high lime content require excessive quantities of acid for neutralization and, for economic reasons, are best treated by alkaline leaching. In either leach process, most of the uranium is dissolved, together with other materials present in the ore (e.g., iron, aluminum, and other impurities). After the ore is leached, the uranium-laden leach liquor is removed from the tailings solids by decantation. After thorough washing, the tailings are pumped as a slurry to a tailings pond. The waste liquid accompanying the tailings solids to the disposal pond is approximately 1 to 1.5 times the weight of the processed ore. Typical characteristics of the tailings solids and liquid are outlined in Table 5.4 (ref. 9).

In August 1986, the EPA issued its final rules on ^{222}Rn emissions from tailings piles.[8] Mill owners have 6 years (subject to certain extensions) to phase out the use of large existing tailings piles. New tailings piles must be contained in small [i.e., less than 16 ha (40 acre)] impoundments or disposed of by continuous dewatering and burial with no more than 4 ha (10 acres) uncovered at any one time.

5.4 PROJECTIONS

An average tailings density of 1.6 t/m^3 was used in projecting volumes of mill tailings through the year 2005 (Table 5.1). Projections of mill tailings were calculated based on the uranium requirements associated with the DOE/EIA 1990 No-New-Orders-Case nuclear growth scenario.[4] These projections assume a lead time of 2 years for mining/milling of uranium until its use as reactor fuel. The projected annual accumulations (Table 5.1) account only for tailings produced in filling U.S. utility requirements and export commitments by domestic producers. Tailings produced in filling potential DOE requirements for uranium are not included, because the amount would be minor in comparison with the commercial requirements.

The sum of the projected annual generated volume of uranium mill tailings from 1991 through 2000 is somewhat less than that shown in the previous year's report. This may be attributed to the anticipated closing of several underground operations in that period, and with less ore to be processed, fewer tailings will be generated. With market prices possibly edging upward during the period of 2000 through 2005, conventional mining could again become economically feasible. This is reflected by an increase in the generation of tailings in that period.

5.5 REFERENCES

1. U.S. Department of Energy, Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey," Washington, D.C. (1990).

2. U.S. Department of Energy, Energy Information Administration, Uranium Industry Annual 1990, DOE/EIA-0478(90), Washington, D.C. (August 1991).

3. U.S. Department of Energy, Energy Information Administration, Domestic Uranium Mining and Milling Industry 1989 – Viability Assessment, DOE/EIA-0477(89), Washington, D.C. (December 1990).

4. U.S. Department of Energy, Energy Information Administration, World Nuclear Fuel Cycle Requirements 1990, DOE/EIA-0436(90), Washington, D.C. (October 1990).

5. U.S. Department of Energy, Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 5, Oak Ridge National Laboratory, Oak Ridge, Tennessee (November 1989).

6. U.S. Department of Energy, Grand Junction Office, and Bendix Field Engineering Corporation, Commingled Uranium Tailings Study, DOE/DP-0011, Vol. 2, Grand Junction, Colorado (June 1982).

7. W. S. White, Directory and Profile of Licensed Uranium Recovery Facilities, NUREG/CR-2869 (ANL/ES-128), Rev. 1, U.S. Nuclear Regulatory Commission, Washington, D.C. (March 1984).

8. U.S. Environmental Protection Agency, "National Emission Standard for Radon-222 Emissions from Licensed Uranium Mill Tailings," Code of Federal Regulations, 40 CFR Part 61, Subpart W (September 1986).

9. U.S. Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Uranium Milling, Project M-25, NUREG-0706, Washington, D.C. (September 1980).

10. U.S. Department of Energy, Grand Junction Office, Statistical Data of the Uranium Industry, GJ0-100(73), Grand Junction, Colorado (Jan. 1, 1973).

11. U.S. Congress, House of Representatives, Committees on Energy and Commerce, Interior and Insular Affairs, Science, Space, and Technology, and Ways and Means, Uranium Revitalization, Tailings Reclamation and Enrichment Act of 1988: Hearing on H.R. 4489, 100th Congress, 2nd sess., Apr. 28, 1988, pp. 19-21.

12. Paul Estey, Exxon Coal and Minerals Company, Houston, Texas, telephone call to L. L. Smith, Energy Information Administration, Washington, D.C., regarding status of reclamation of Ray Point mill site and Felder mine site, Aug. 22, 1988.

ORNL DWG 91-8675

Fig. 5.1. Locations of uranium mill tailings sites active during at least part of 1990.

ORNL DWG 91-8676

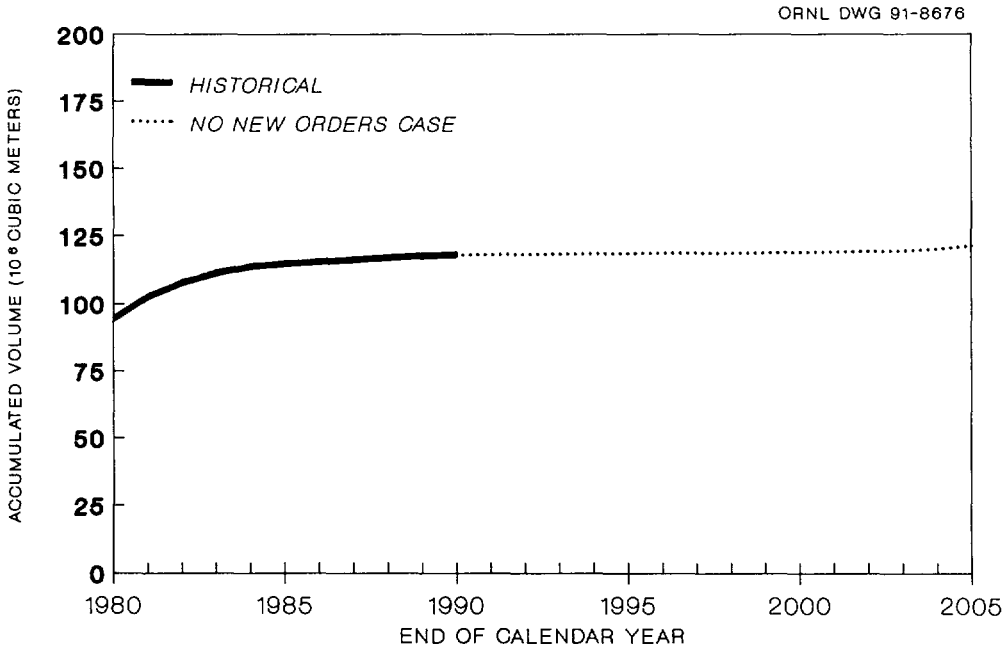


Fig. 5.2. Historical and projected accumulated volume of commercial mill tailings.

Table 5.1. Historical and projected volume of uranium mill tailings[a,b]

End of calendar year	Volume (10^6 m^3) Annual	Cumulative
Prior to 1978		68.0
1978	7.9	75.8
1979	9.1	84.9
1980	9.5	94.4
1981	8.2	102.7
1982	5.0	107.7
1983	3.4	111.1
1984	2.5	113.6
1985	1.0	114.6
1986	0.7	115.4
1987	0.8	116.2
1988	0.7	116.9
1989	0.7	117.6
1990	0.4	118.0
1991	0.2	118.2
1992	0.1	118.3
1993	0.1	118.4
1994	0.1	118.5
1995	0.1	118.6
1996	<0.1	118.7
1997	<0.1	118.7
1998	<0.1	118.7
1999	0.1	118.8
2000	0.1	119.0
2001	0.1	119.1
2002	0.1	119.3
2003	0.2	119.5
2004	0.6	120.1
2005	1.0	121.2

[a]Projections of domestic tailings are generated from estimates of U.S. uranium production under current market conditions described in ref. 3, which is the No-New-Orders Case of ref. 4.

[b]Sources: Prior to 1984 — U.S. Department of Energy, Grand Junction Project Office data files. 1984-1990 — Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey."

Table 5.2. Status of conventional uranium mill sites at the end of 1990[a]

Location	Operator	Rated capacity[b] (t ore/d)	Status		Tailings storage area (ha)[d]	Total tailings		
			Operations[b]	Tailings[c]		Volume[e] (10^6 m^3)	Mass (10^6 t)	Government portion[f] (10^6 t)
Colorado								
Canon City	Cotter	1,090	Shut down 1987	Wood chip covering	81	1.3	2.1	0.3
Uravan	Umetco Minerals	1,180	Shut down 1984	Partially stabilized	44	5.9	9.5	5.2
Subtotal		2,270			125	7.2	11.6	5.5
New Mexico								
Cebolleta	Sohio Western Mining	1,450[g]	Decommissioned, 1986	h	73	1.2	1.9	0
Church Rock	United Nuclear	2,720[g]	Decommissioned, 1986	h	83	2.0	3.2	0
Grants	Anaconda	5,440[g]	Decommissioned, 1987	Partially stabilized	199	13.6	21.7	8.0
Grants	Quivira Mining	6,350	Shut down 1985	Fenced	142	18.8	30.1	9.1
Grants	Homestake Mining	3,080	Shut down 1990	Unstabilized	105	12.7	20.3	10.4
Marquez	Bokum Resources	1,820[g]	New (on standby)	Never operated	0	0	0	0
Subtotal		9,430			602	48.3	77.2	27.5
South Dakota								
Edgemont	TVA	680[g]	Decommissioned, 1983	Partially stabilized	50	1.2	1.8	1.5
Subtotal		0			50	1.2	1.8	1.5
Texas								
Falls City	Continental Oil/ Pioneer Nuclear	3,080[g]	Decommissioned, 1981	h	89	6.5	10.5	0
Hobson	Chevron Resources	2,270	Active	h	101	3.6	5.6	0
Ray Point (Felder Facility)	Exxon	1,000[g]	Decommissioned, 1973[i]	Stabilized[j]	18	0.2	0.4[k]	0
Subtotal		2,270			208	10.3	16.5	0
Utah								
Blanding	Umetco/Energy Fuels Nuclear	1,810	Active	Partially stabilized	135	1.9	3.2	0
La Sal	Rio Algom	680	Shut down 1988	h	14	2.2	3.5	0
Moab	Atlas	1,270[g]	Decommissioning	Unstabilized	>80	6.0	9.6	5.4
Hanksville	Plateau Resources	910	New (on standby)	Never operated	28	0	0	0
Subtotal		3,400			>257	10.1	16.3	5.4

Table 5.2 (continued)

Location	Operator	Rated capacity[b] (t ore/d)	Status: Operations[b]	Status: Tailings[c]	Tailings storage area (ha)[d]	Total tailings: Volume[e] (10^6 m^3)	Total tailings: Mass (10^6 t)	Total tailings: Government portion[f] (10^6 t)
Washington								
Ford	Dawn Mining	410	Shut down 1982	Wood chip covering	43	1.8	2.8	1.1
Wellpinit	Western Nuclear	1,810	Shut down 1984	h	17	1.6	2.6	0
Subtotal		2,220			60	3.4	5.4	1.1
Wyoming								
Gas Hills	American Nuclear	860[g]	Decommissioned, 1988	Unstabilized	52	3.3	5.3	1.9
Gas Hills	Pathfinder	2,540	Shut down 1988	Unstabilized	55	6.6	10.6	2.4
Jeffrey City	Western Nuclear	1,540[g]	Decommissioned, 1988	Interim stabilization	34	4.4	7.0	3.0
Natrona	Umetco	1,270	Shut down 1984	Unstabilized	70	4.6	7.3	1.9
Powder River	Exxon	2,900[g]	Decommissioned, 1984	Partially stabilized	81	6.4	10.3	0
Powder River	Rocky Mountain Energy	1,810[g]	Decommissioned, 1987	Unstabilized	61	2.7	4.3	0
Shirley Basin	Pathfinder	1,630	Inactive Dec. 1988; resumed 1989	h	94	4.6	7.3	0
Shirley Basin	Petrotomics	1,360[g]	Decommissioned, 1985	Unstabilized	65	3.7	5.9	0.7
Red Desert	Minerals Exploration/ Union Energy Mining	2,720	Shut down May 1983	Partially stabilized	121	1.3	2.1	0
Subtotal		8,160			633	37.6	60.1	9.9
1990 total for all sites[b,l,m]		27,750			h	118.1	188.9	50.9[n]

[a]Data based on refs. 1-12. Note: subtotals and totals may not equal sum of components because of independent rounding. Ray Point, Texas (Felder Facility), site was stabilized during 1987 by Exxon Corporation. Historical data are revised based on detailed study of milling data from the Grand Junction Project Office and EIA files. The values shown include all tailings.

[b]From refs. 1, 6, and 10. Values rounded to nearest 10 t.

[c]On Aug. 15, 1986, EPA issued its final rules on ^{222}Rn emissions from tailings piles. Mill owners have 6 years (subject to certain extensions) to phase out the use of large existing tailings piles. New tailings piles may be contained in small impoundments (less than 16 ha) or disposed of continuously by dewatering and burial (i.e., no more than 4 ha are uncovered at any one time). See ref. 8.

[d]From ref. 7; 1 ha = 10,000 m^2 or approximately 2.5 acres.

[e]Calculated from reported mass using density = 1.6 t/m^3.

[f]From ref. 6, Table 8.0. These tailings are from government contracts only and are included in the "Total tailings" column.

[g]This capacity not available (see column labeled "Operations" under "Status" for reason). Estimates provided are not included in the total.

[h]Not available.

[i]From ref. 10.

[j]From ref. 12.

[k]From ref. 11.

[l]These values are cumulative totals that may not equal sum of components due to independent rounding. For annual totals see Table 5.3.

[m]From ref. 1.

[n]Total at the end of government-contracted deliveries in 1970 (ref. 6).

Table 5.3. Uranium ore processed, recovery rate, and tailings generated through 1990[a,b]

End of calendar year	Ore processed		U_3O_8 recovery from ore (%)	U_3O_8 product[d] (10^6 t)	Tailings generated	
	Mass[c] (10^6 t)	Grade (% U_3O_8)			Mass[e] (10^6 t)	Volume[f] (10^6 m^3)
Prior to 1978	g	g	g	g	108.8	68.0
1978	12.5	0.134	91	15.6	12.6	7.9
1979	14.6	0.113	91	15.3	14.5	9.1
1980	15.3	0.118	93	17.2	15.2	9.5
1981	13.2	0.115	94	14.5	13.2	8.2
1982	7.9	0.119	96	9.9	8.1	5.0
1983	5.4	0.128	97	7.0	5.4	3.4
1984	3.9	0.112	95	4.4	4.0	2.5
1985	1.6	0.161	96	2.8	1.6	1.0
1986	1.2	0.338	97	4.0	1.2	0.7
1987	1.3	0.284	96	3.8	1.3	0.8
1988	1.1	0.288	95	3.2	1.1	0.7
1989	1.1	0.323	95	3.7	1.0	0.7
1990	0.7	0.293	94	2.1	0.7	0.4
Total[h]					188.7	117.9

[a]Sources: Prior to 1984 – U.S. Department of Energy, Grand Junction Area Office data files. 1984-1990 – Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey."

[b]This table has been revised based on a detailed study of milling data from the Grand Junction Project Office and EIA files. The values shown include all tailings.

[c]Before in-process inventory adjustments.

[d]Conventional U_3O_8 concentrate production.

[e]Includes adjustments to ore-fed amounts for annual mill circuit inventory changes and uranium concentrate production.

[f]Calculated assuming that the average density of tailings is 1.6 t/m^3 (metric tons per cubic meter).

[g]Not available.

[h]Totals may not equal sum of components due to independent rounding.

Table 5.4. Typical characteristics of uranium mill tailings[a]

Tailings component	Particle size (μm)	Chemical composition	Radioactivity characteristics
Sands	75 to 500	SiO_2 with <1% complex silicates of Al, Fe, Mg, Ca, Na, K, Se, Mn, Ni, Mo, Zn, U, and V; also metallic oxides	0.004 to 0.01% U_3O_8[b] Acid leaching:[c] 26 to 100 pCi ^{226}Ra/g; 70 to 600 pCi ^{230}Th/g
Slimes	45 to 75	Small amounts of SiO_2 but mostly very complex clay-like silicates of Na, Ca, Mn, Mg, Al, and Fe; also metallic oxides	U_3O_8 and ^{226}Ra are almost twice that in the sands Acid leaching:[c] 150 to 400 pCi ^{226}Ra/g; 70 to 600 pCi ^{230}Th/g
Liquids	d	Acid leaching: pH 1.2 to 2.0; Na^+, NH_4^+, SO_4^{-2}, Cl^-, and PO_4^{-3}; dissolved solids up to 1% Alkaline leaching: pH 10 to 10.5; CO_3^{-2} and HCO_3^-; dissolved solids ~10%	Acid leaching: 0.001 to 0.01% U 20 to 7,500 pCi ^{226}Ra/L; 2,000 to 22,000 pCi ^{230}Th/L Alkaline leaching: 200 pCi ^{226}Ra/L; essentially no ^{230}Th (insoluble)

[a]Adapted from information in ref. 9.

[b]U_3O_8 content is higher for acid leaching than for alkaline leaching.

[c]Separate analyses of sands and slimes from the alkaline leaching process are not available. However, total ^{226}Ra and ^{230}Th contents of up to 600 pCi/g (of each) have been reported for the combined sands and slimes.

[d]Particle size does not apply. Up to 70% of the liquid may be recycled. Recycle potential is greater in the alkaline process.

ORNL PHOTO 7874-91

Photo 6.1. Environmental isolation activities being performed on uranium mill tailings deposited at Durango, Colorado. (Courtesy of U.S. Department of Energy, Uranium Mill Tailings Remedial Action Project Office, Albuquerque, New Mexico.)

6. ENVIRONMENTAL RESTORATION WASTES

6.1 INTRODUCTION

The fundamental goal for DOE's Environmental Restoration (ER) Program is to ensure that risks to the environment and to human health and safety posed by inactive and surplus facilities and sites contaminated by radioactive, hazardous, or mixed wastes are either eliminated or reduced to prescribed, safe levels. The cornerstone of DOE's overall goal is to clean up its current inventory within the nuclear complex by the year 2019. Although encompassing all requirements prescribed by applicable federal, state, and local environmental statutes and regulatory requirements, this goal is not limited to regulatory compliance; that is, protection of human health and safety and the environment is the Department's paramount concern.

Environmental restoration activities are proceeding in four major areas: (1) remedial action (RA) and decontamination and decommissioning (D&D) activities, which are defense-funded; (2) RA and D&D activities, which are non-defense funded; (3) Uranium Mill Tailings Remedial Action Program (UMTRAP); and (4) Formerly Utilized Sites Remedial Action Program (FUSRAP).

Defense-funded projects are those projects which supported defense-related activities such as nuclear weapon component fabrication. The 23 defense-funded RA and D&D activities are located in 13 states. Figures 6.1 and 6.2, respectively, show the projected volume of transuranic (TRU) and low-level wastes to be cleaned up in those states. (Information is provided only for those states in which data were reported.) The map in Fig. 6.3 locates the defense-funded sites within the states.

Non-defense-funded projects are those projects which supported civilian nuclear power applications such as the development of heat sources for the space program and the design and operation of small test reactors. The 22 non-defense-funded RA and D&D activities are located in 12 states. The projected TRU waste and low-level waste that remain in each state are shown, respectively, in Figs. 6.4 and 6.5. (Information is provided only for those states in which data were reported.) The map in Fig. 6.6 indicates the specific locations of the non-defense-funded sites.

The UMTRAP activities are located in 11 states. The projected remaining residual radioactive material is shown in Fig. 6.7 and their locations, most of which are in the Rocky Mountain region, in Fig. 6.8.

The FUSRAP sites are located in 13 states, and the projected volume of waste material remaining in each state is shown in Fig. 6.9. Most FUSRAP sites are in the eastern United States, as shown in Fig. 6.10.

The estimated total volumes of waste from the four environmental restoration program areas just described are summarized in Table 6.1. Waste inventories from completed environmental restoration activities are indicated as being in either permanent or interim storage. Projected additional waste volumes from future environmental restoration activities are reported as estimated remaining inventories. Projected volumes, status, and scheduled completion of the remaining defense-funded low-level and TRU wastes from RA and D&D activities are listed in Table 6.2. Projected volumes, status, and scheduled completion of the remaining non-defense-funded low-level and TRU wastes from RA and D&D activities are listed in Table 6.3. Tables 6.2 and 6.3 do not show all RA and D&D waste volumes since waste projections from some facilities were not available.

6.2 THE OFFICE OF ENVIRONMENTAL RESTORATION

The Office of Environmental Restoration encompasses RA and D&D activities.[1] Remedial action involves the assessment and cleanup of inactive sites and deals primarily with contaminated soil and groundwater. Decontamination and decommissioning entails the safe caretaking of surplus nuclear facilities and their complete dismantling and removal or in-place stabilization and isolation. In addition to RA and D&D activities, two programs are managed under the Office of Environmental Restoration. They are the Uranium Mill Tailings Remedial Action Program (UMTRAP) and the Formerly Utilized Sites Remedial Action Program (FUSRAP).

To facilitate the management of all activities under the Office of Environmental Restoration, the Office of Environmental Restoration has been divided into three divisions: the Eastern Area Programs Division, the Northwestern Area Programs Division, and the Southwestern Area Programs Division. Each division

manages both RA and D&D activities. In addition, UMTRAP, which was authorized by Congress in 1978, is managed through the Southwestern Area Programs Division; FUSRAP, which was authorized by DOE in 1977, is managed through the Eastern Area Programs Division.

6.2.1 Activities

Remedial action activities were formerly supported under DOE defense programs. Decontamination and decommissioning activities are comprised of activities under the former Surplus Facilities Management Program (SFMP), the former Defense D&D Program, and projects of the Office of Energy Research.

6.2.1.1 Remedial action

Remedial action encompasses site discovery, preliminary assessment, and site inspection; site characterization, analysis of cleanup alternatives, and selection of remedy; cleanup and site closure; and site compliance monitoring. Although remedial actions may deal with surface water contamination or with tanks, buildings, or structures, most remedial actions are concerned with contaminated soil and groundwater. The estimated number of hazardous substance release sites exceeds 3,700.

For remedial actions, the principal regulatory requirements are those derived from the Resource Conservation and Recovery Act (RCRA);[2] the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA);[3] and the National Environmental Policy Act (NEPA).[4] Remedial action activities may further be subject to important regulatory requirements imposed by the states. Other requirements are set forth in various DOE Orders, standards, and other guidance documents.[5]

6.2.1.2 Decontamination and decommissioning

D&D activities emphasize the safe caretaking of surplus nuclear facilities and their decontamination for dismantlement and removal. They include surveillance and maintenance; assessment and characterization; environmental review; engineering; decontamination or decommissioning operation; and closeout. Most D&D activities are performed on facilities such as reactors, hot cells, processing plants, storage tanks, and other structures from which, in general, there have been no known releases. There are approximately 500 contaminated facilities currently included under D&D. The objectives of D&D activities are to decontaminate these facilities and to eliminate any potential hazards to public health and the environment.

Decontamination and decommissioning activities are carried out in accordance with the provisions prescribed in the NEPA and the Atomic Energy Act (AEA)[6] and with requirements set forth in various DOE Orders, standards, and other guidance documents. Although the intent of D&D is to prevent occurrences of releases, for facilities from which there has been a release or from which there is a potential for release, the provisions of the CERCLA and the RCRA also apply. State requirements may apply in certain instances.

6.2.2 Programs

6.2.2.1 Uranium Mill Tailings Remedial Action Program

The Uranium Mill Tailings Radiation Control Act of 1978 (Public Law 95-604) authorized DOE to undertake the stabilization and control of uranium mill tailings in a safe and environmentally sound manner and, where appropriate and practical, to reprocess existing tailings to extract residual uranium and other mineral values. The Act also specifies remedial action as required on properties in the vicinity of the tailings sites.[7] Initial tasks under UMTRAP were to (1) designate inactive uranium mill tailings sites for remedial action and (2) evaluate the economic viability of reprocessing tailings. The primary criterion for inclusion of mill tailings sites in UMTRAP was that the processing site must have had all or substantially all of the uranium produced for sale to any federal agency prior to January 1971. Evaluation of the economic viability of reprocessing has shown the residual content of uranium and other metals in the tailings to be too low to make reprocessing worthwhile.

Twenty-four inactive uranium processing sites and associated vicinity properties located in 10 states and 4 Indian Reservations, and the vicinity properties associated with the Edgemont, South Dakota, inactive uranium mill, currently owned by the Tennessee Valley Authority (TVA), are presently included in UMTRAP. All of the sites are located in the western United States except for one area in Canonsburg, Pennsylvania. Engineering assessment and economic evaluation documents about each site have been published.[8]

During FY 1990, the UMTRAP achieved the following major accomplishments:

- Completed remedial actions at the Durango, Colorado (to be finalized summer of 1991), and Tuba City, Arizona, processing sites.
- Completed 24% of the Phase II remedial actions at Grand Junction, Colorado.
- Completed remedial actions on 711 vicinity properties; certified 624 vicinity properties; initiated contracts covering remedial actions on 7 vicinity properties; and completed vicinity property activities at Shiprock, New Mexico, Lakeview, Oregon, and Tuba City, Arizona, UMTRAP sites.
- Exceeded the $5.0 million goal for the Cost Reduction/Productivity Improvement Program with a net benefit of $9.1 million.

- Issued draft NEPA documents for Rifle, Gunnison, Maybell, and Naturita in Colorado, and Lowman, Idaho.
- Completed final remedial action plans (RAPs) for Green River, Utah, and Ambrosia Lake and Shiprock, New Mexico (modification number 4 for Shiprock). Prepared draft RAPs for Gunnison and Naturita, Colorado, and Lowman, Idaho.
- Implemented a project-wide quality assurance plan approved by the U.S. Nuclear Regulatory Commission (NRC) and hailed as a model for similar remediation projects.

Table 6.4 gives the current remedial action status, duration schedules, and stored waste volume inventory for 24 UMTRAP sites. At the end of 1990, over 9.8 million cubic meters of mill tailings and other (subordinate) wastes, referred to in aggregate as residual radioactive material (RRM), had been stabilized at 10 sites where site remedial action activities were completed.[9] The subordinate wastes include soils contaminated by windblown tailings, ore in storage areas, material underlying tailings piles, and contaminated soils from vicinity properties. It should be noted that quantities of subordinate wastes typically increase as remedial action work commences and efforts are made to ensure the adequacy of the cleanup procedures.

The uranium mill tailings at the UMTRAP sites have a low specific activity that is the result of naturally occurring radioactive elements. Depending on specific site characteristics, these tailings may be stabilized on-site or removed to other locations and stabilized. The criteria used in UMTRAP site cleanup and waste disposal work are based on EPA standards[10] that became effective in March 1983. As shown in Table 6.4, UMTRAP activities are scheduled to be completed by September 1994.

Projected characteristics of wastes from uncompleted UMTRAP sites are given in Table 6.5. The values for radioactivity given in this table are calculated based on the assumption that the ore is 3.2 billion years old and that all of the decay products from the uranium present in the ore are also present in the tailings. The radioactivity reported for ^{226}Ra has been determined from representative samples.

6.2.2.2 Formerly Utilized Sites Remedial Action Program

The Formerly Utilized Sites Remedial Action Program (FUSRAP) is primarily concerned with the waste cleanup of sites that were formerly used to support the nuclear activities of DOE's predecessor agencies, the Manhattan Engineer District (MED), established for the Manhattan Project, and the Atomic Energy Commission (AEC). The sites of concern were mostly privately and institutionally owned and were used primarily for research, processing, and storage of uranium and thorium ores, concentrates, and residues.[11,12] When these sites were no longer required to support the nuclear activities of MED and AEC, they were decommissioned in accordance with the health and safety guidelines that were applicable at that time. Those guidelines do not necessarily meet today's more stringent radiological criteria for restricted and unrestricted use. In 1974, AEC initiated a survey program whose aim was to identify formerly utilized MED/AEC sites and characterize their radiological conditions. As a result, in 1977, DOE formalized FUSRAP, and a generic plan was drafted with the following objectives:[13]

- Effect appropriate remedial action and/or controls, as required, consistent with authorization and appropriation by Congress;
- Develop acceptable storage/disposal sites in consultation with the affected states; and
- Certify the acceptability of the sites for future use.

Initially, formerly utilized MED/AEC sites were identified and selected as candidates for remedial action through a historical records search. Later, other sites (not necessarily formerly utilized in support of MED/AEC) were designated by Congress for remedial action under FUSRAP. During the organizational changes made during 1990, the Niagara Falls Storage Site (NFSS) was transferred from the SFMP to the FUSRAP and the New Brunswick Laboratory from the former Defense D&D Program to FUSRAP.[14] The Baker and Williams Warehouse in New York City was added to FUSRAP[15] and the Palos Park Forest Preserve site was removed from FUSRAP.[16] The 33 sites authorized to receive remedial action are given in Table 6.6.[17] Approximately one-half of these sites are in the northeastern part of the country, as can be seen in Fig. 6.10.

Initial remedial action activities have been completed at 9 of the 33 sites and partially completed at 9 additional sites, as shown in Table 6.6. Table 6.7 gives the estimated volumes of waste from FUSRAP activities remaining to be completed. Only waste having low radioactivity is anticipated from cleanup activities. Although very small amounts of some transuranic nuclides may be present, no TRU waste is expected from FUSRAP activities. Most waste material will be contaminated soil and building rubble, and the total volume of LLW is estimated to be about 1,587,000 m^3, including waste that has already been placed in storage. Site radiological surveys have developed considerable detailed information, and comprehensive site-by-site data are given in a number of reports listed in ref. 18.

6.3 REFERENCES

1. Gale Turi, DOE Headquarters (EM-431), Germantown, Maryland, memo to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update to the Integrated Data Base from Remedial Action and Decontamination and Decommissioning Activities," dated May 29, 1991.

2. U.S. Congress, Resource Conservation and Recovery Act of 1976, Pub. L. 94-580, Oct. 21, 1976, as amended by the Hazardous and Solid Waste Amendments Acts of 1984, Pub. L. 98-616, Nov. 9, 1984.

3. U.S. Congress, Comprehensive Environmental Response, Compensation, and Liability Act of 1980, Pub. L. 96-510, Dec. 1980, as amended.

4. U.S. Congress, National Environmental Policy Act of 1969, Pub. L. 91-190, Jan. 1, 1970.

5. U.S. Department of Energy, Environmental Restoration and Waste Management Five-Year Plan — Fiscal Years 1993-1997, FYP-DOE/S-0089P, Washington, D.C. (June 1991).

6. U.S. Congress, Atomic Energy Act of 1954, Pub. L. 83-703, Aug. 1954, as amended.

7. U.S. Nuclear Regulatory Commission, "Standards for Cleanups of Land and Buildings Contaminated with Residential Radioactive Materials from Inactive Uranium Processing Sites," Code of Federal Regulations, 40 CFR Part 192, Sect. 10 (July 1, 1987).

8. U.S. Department of Energy, Integrated Data Base for 1986: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 2, Table 6.2, p. 182, Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 1986).

9. Mark L. Matthews, U.S. Department of Energy, Uranium Mill Tailings Project Office, Albuquerque, New Mexico, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update of the Integrated Data Base for the Uranium Mill Tailings Remedial Action Project," dated Apr. 18, 1991.

10. U.S. Environmental Protection Agency, Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192), EPA 520/4-82-013-1 and EPA 520/4-82-013-2, Washington, D.C. (October 1982).

11. U.S. Department of Energy, DOE Field Office, Oak Ridge, Description of the Formerly Utilized Sites Remedial Action Programs, ORO-777, Oak Ridge, Tennessee (September 1980).

12. W. R. Voight, DOE Headquarters, memo to J. W. LaGrone, DOE Field Office, Oak Ridge, concerning designation of sites for remedial action, dated Dec. 17, 1985.

13. U.S. Department of Energy, A Background Report for the Formerly Utilized Manhattan Engineer District/Atomic Energy Commission Sites Program, DOE/EV-0097, Washington, D.C. (September 1980).

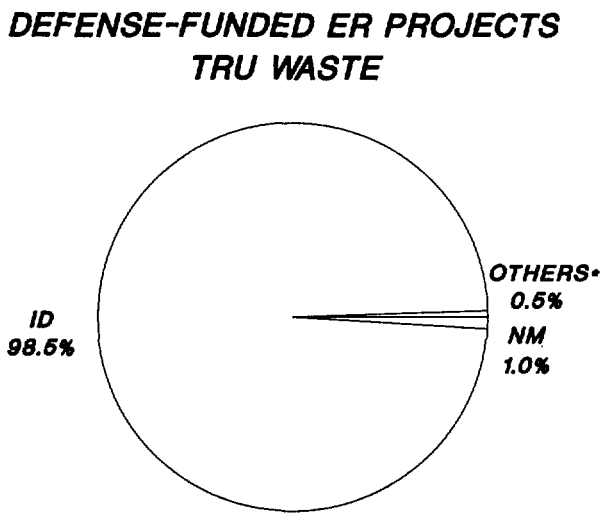
14. James J. Fiore, DOE Headquarters (EM-42), letter to Donald C. Fulmer, DOE Headquarters (EM-422), "Transfer of Sites to FUSRAP," dated July 23, 1990.

15. Addition of Baker and Williams Warehouse to FUSRAP, BNI CCN 71551 (August 1990).

16. James W. Wagoner, DOE Headquarters (EM-421), letter to James J. Fiore, DOE Headquarters (EM-42), "Transfer of Accountability for Palos Park Site," dated Oct. 11, 1990.

17. Lester K. Price, U.S. Department of Energy, DOE Field Office, Oak Ridge, Tennessee, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update to Data for Inclusion in Integrated Data Base for 1991," dated Apr. 5, 1991.

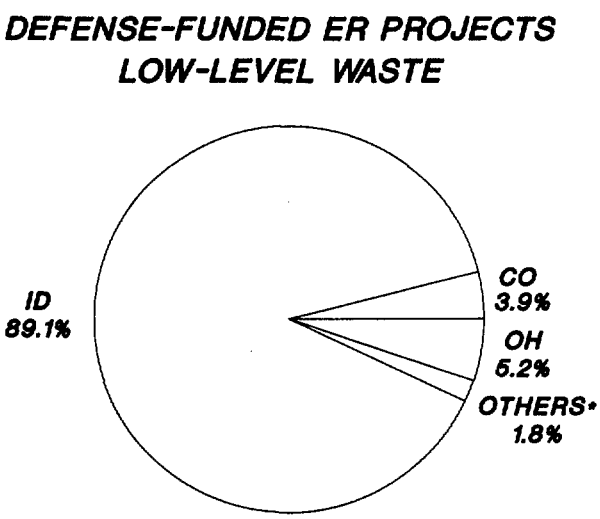
18. U.S. Department of Energy, Integrated Data Base for 1986: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 2, Table 6.3, p. 187, Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 1986).



ORNL DWG 91-8677

STATE	CUBIC METERS
CO*	2.10E+01
ID	4.33E+05
NM	4.51E+03
OH*	2.83E+02
WA*	1.92E+03
TOTAL	4.40E+05

Fig. 6.1. Projected total volumes of remaining TRU wastes from DOE defense-funded environmental restoration projects in various states.



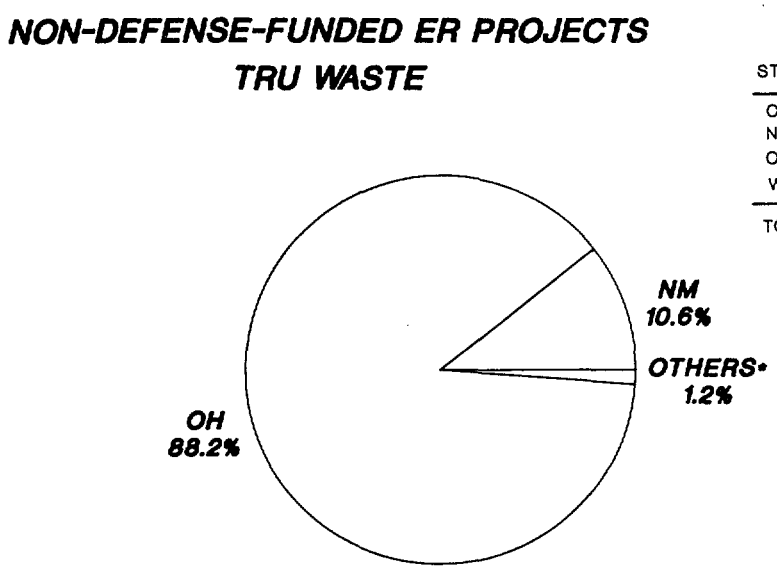
ORNL DWG 91-8678

STATE	CUBIC METERS
CA*	7.28E+02
CO	8.34E+04
ID	1.90E+06
NM*	1.50E+04
OH	1.12E+05
WA*	2.19E+06
TOTAL	2.13E+06

Fig. 6.2. Projected total volumes of remaining low-level wastes from DOE defense-funded environmental restoration projects in various states.

Fig. 6.3. Locations of DOE defense-funded environmental restoration projects.

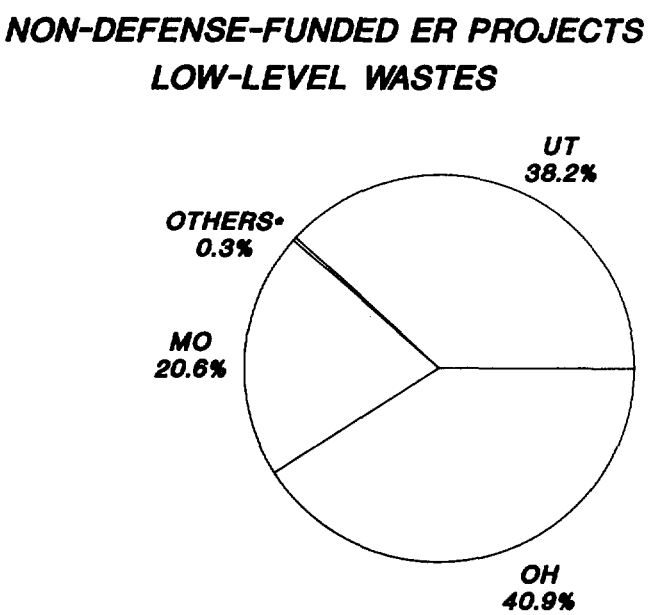
ORNL DWG 91-8680



STATE	CUBIC METERS
CA*	1.80E+01
NM	2.25E+02
OH	1.87E+03
WA*	6.00E+00
TOTAL	2.12E+03

Fig. 6.4. Projected total volumes of remaining TRU wastes from DOE non-defense-funded environmental restoration projects in various states.

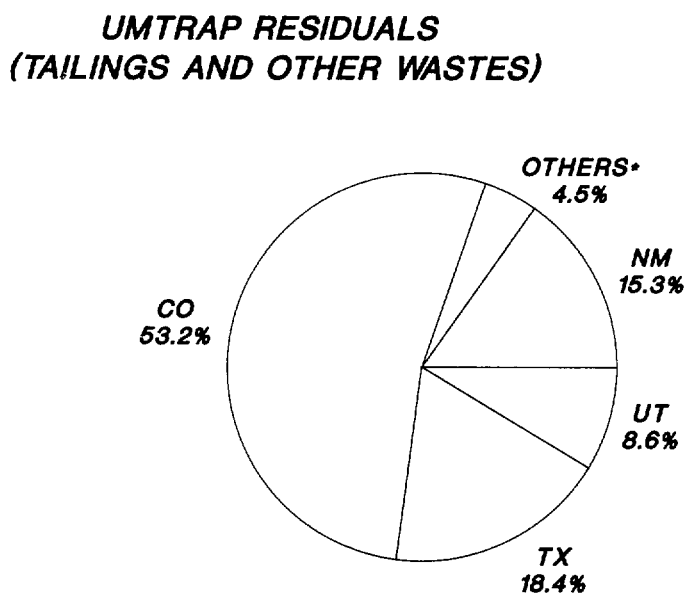
ORNL DWG 91-8681



STATE	CUBIC METERS
CA*	8.22E+03
ID*	1.08E+03
IL*	6.79E+02
MO	7.86E+05
NM*	9.13E+02
OH	1.56E+06
UT	1.45E+06
WA*	4.42E+02
TOTAL	3.81E+06

Fig. 6.5. Projected total volumes of remaining low-level wastes from DOE non-defense-funded environmental restoration projects in various states.

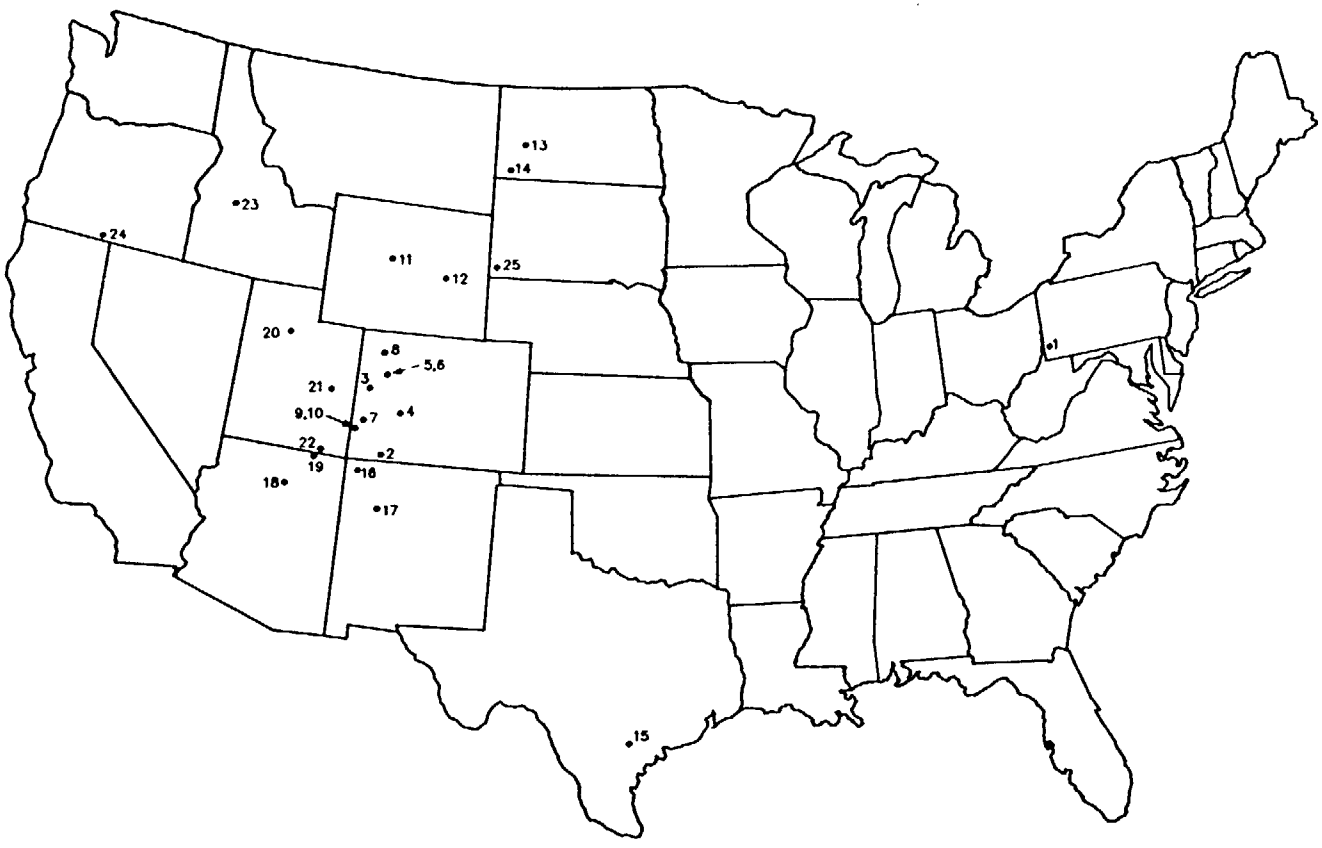
Fig. 6.6. Locations of DOE non-defense-funded environmental restoration projects.



STATE	CUBIC METERS
AZ*	1.06E+06
CO	1.58E+07
ID*	1.20E+05
ND*	1.58E+05
NM	4.54E+06
TX	5.45E+06
UT	2.56E+06
TOTAL	2.97E+07

Fig. 6.7. Projected total volumes of remaining residual radioactive materials from UMTRAP activities in various states.

ORNL DWG 91A-641R

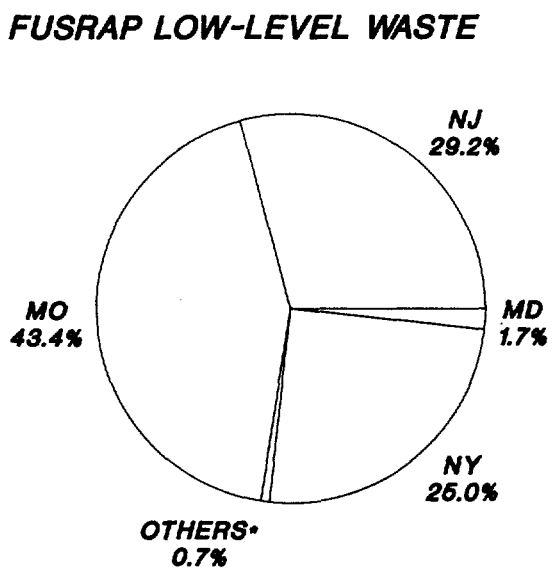


1 CANONSBURG, PA*
2 DURANGO, CO*
3 GRAND JUNCTION, CO
4 GUNNISON, CO
5 NEW RIFLE, CO
6 OLD RIFLE, CO
7 NATURITA, CO
8 MAYBELL, CO
9 SLICK ROCK (NC), CO**
10 SLICK ROCK (UC), CO***
11 RIVERTON, WY*
12 CONVERSE COUNTY, WY*
13 BELFIELD, ND
14 BOWMAN, ND
15 FALLS CITY, TX
16 SHIPROCK, NM*
17 AMBROSIA LAKE, NM
18 TUBA CITY, AZ*
19 MONUMENT VALLEY, AZ
20 SALT LAKE CITY, UT*
21 GREEN RIVER, UT*
22 MEXICAN HAT, UT
23 LOWMAN, ID
24 LAKEVIEW, OR*
25 EDGEMONT, SD*

* SITE WORK COMPLETED
** NORTH CONTINENT SITE
*** UNION CARBIDE SITE

Fig. 6.8. Locations of UMTRAP sites.

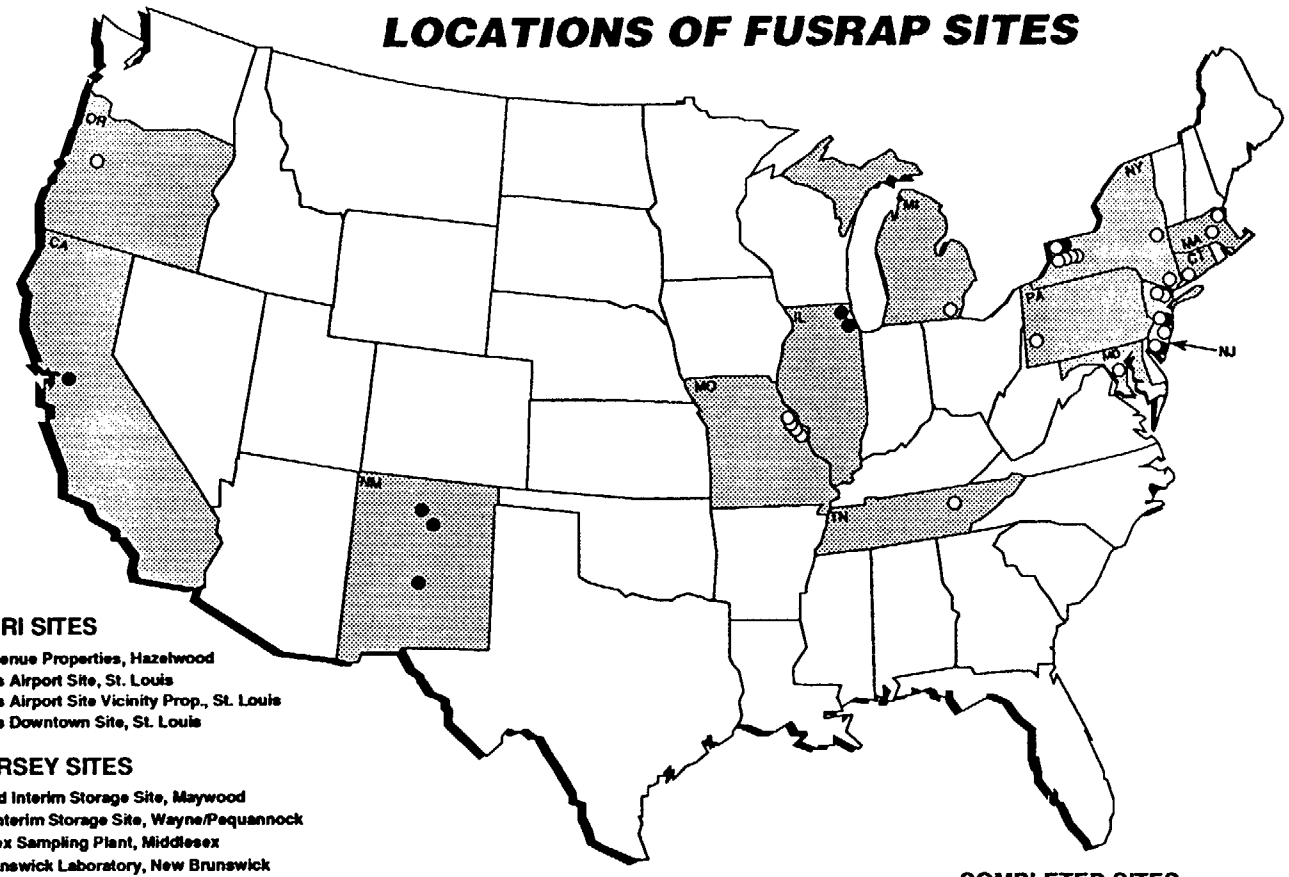
ORNL DWG 91-8684



STATE	CUBIC METERS
CT*	1.90E+01
MA*	5.48E+03
MD	2.75E+04
MI*	1.53E+02
MO	6.85E+05
NJ	4.62E+05
NY	3.95E+05
ORE*	8.00E+01
PA*	2.90E+01
TN*	6.80E+03
TOTAL	1.58E+06

Fig. 6.9. Projected total volumes of remaining low-level wastes from FUSRAP activities in various states.

ORNL DWG 91-577



MISSOURI SITES

* † Latty Avenue Properties, Hazelwood
* St. Louis Airport Site, St. Louis
* St. Louis Airport Site Vicinity Prop., St. Louis
  St. Louis Downtown Site, St. Louis

NEW JERSEY SITES

* † Maywood Interim Storage Site, Maywood
* † Wayne Interim Storage Site, Wayne/Pequannock
  † Middlesex Sampling Plant, Middlesex
  † New Brunswick Laboratory, New Brunswick
  Du Pont & Company, Deepwater

NEW YORK SITES

† Niagara Falls Storage Site, Lewiston
† Colonie Interim Storage Site, Colonie
Ashland 1, Tonawanda
Ashland 2, Tonawanda
Linde Center, Tonawanda
Seaway Industrial Park, Tonawanda
Baker and Williams Warehouses, New York City

ADDITIONAL SITES

Albany Research Center, Albany, OR
Aliquippa Forge, Aliquippa, PA
Elza Gate Site, Oak Ridge, TN
General Motors, Adrian, MI
Seymour Specialty Wire, Seymour, CT
* Shpack Landfill, Norton, MA
Ventron Corporation, Beverly, MA
W.R. Grace & Company, Curtis Bay, MD

COMPLETED SITES

Acid/Pueblo Canyon, Los Alamos, NM
Bayo Canyon, Los Alamos, NM
Chupadera Mesa, White Sands Missile Range, NM
Kellex/Pierpont, Jersey City, NJ
Middlesex Municipal Landfill, Middlesex, NJ
National Guard Armory, Chicago, IL
Niagara Falls Storage Site Vicinity Prop., Lewiston, NY
University of California, Berkeley, CA
University of Chicago, Chicago, IL

○ REMEDIAL ACTION ONGOING OR PLANNED
● REMEDIAL ACTION COMPLETED
† DOE-OWNED OR -LEASED SITE
* NPL SITE
▩ STATE WITH FUSRAP SITE(S)

4.45 3437.1A

Fig. 6.10. Locations of FUSRAP sites.

Table 6.1. Summary of waste volumes from environmental restoration activities

Program	Waste volume, 10^3 m^3		
	TRU	LLW	Residual radioactive material[a]
		A. Permanent storage[b,c]	
UMTRAP			9,765.2
FUSRAP		4.6	
GJRAP			52.07[d]
Total		4.6	9,817.27
		B. Interim storage[c]	
FUSRAP		327.2	
		C. Estimated remaining inventory[e]	
DFERP[f]	440.2	2,131.1	
N-DFERP[g]	2.1	3,808.8	
UMTRAP			29,653.0
FUSRAP		1,255.5	
Total	442.3	7,195.4	29,653.0

[a]Includes mill tailings and all contaminated material outside the immediate tailings pile. Once the cover is placed, all permanently stored material is considered to be tailings.

[b]As of December 31, 1990.

[c]Past inventories of wastes from former D&D Program and SFMP activities are included in the inventories reported for DOE activities in Chapters 3 and 4.

[d]GJRAP completed in 1988.

[e]See Tables 6.2, 6.3, 6.4, and 6.6 for estimated project completion dates.

[f]Defense-funded environmental restoration projects.

[g]Non-defense-funded environmental restoration projects.

Table 6.2. Projected remaining volumes (m^3) of low-level and transuranic wastes, status, and schedule for completion of defense-funded environmental restoration projects, as of December 31, 1990[a]

State and site	Soil		Rubble		Metal		Miscellaneous		Total		Disposal site	Environmental restoration status	Scheduled FY of completion
	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU			
California													
GA[b]	728	0							728	0	NTS	Under way	1992
LLNL[c]													
SNLL[c]													
SSFL[c]													
Colorado													
GJ[d]	81,090	0	796	0	344	0	0	0	82,230	0	Cheney	Under way	1992
RFP	900	0	150	8	70	0	20	5	1,140	21	RFP	Under way	2030
Florida													
Pinellas[c]													
Idaho													
INEL	1,762,304	284,184	11,393	84,181	8,882	14,170	115,751	50,943	1,898,330	433,478	INEL	Under way	2019
Kentucky													
PAD[c]													
Missouri													
KCP[c]													
Nevada													
NTS[c]													
New Mexico													
LANL	100	0	5,089	1,502	4,989	3,005	4,839	0	15,017	4,507	LANL	Planned	1997
SNLA[c]													
Ohio													
FMPC	0	0	0	0	28,000	0	2,200	0	30,200	0	FMPC/NTS	Under way	2020
MOUND	67,345	142	4,871	28	3,115	113	6,259	0	81,590	283	NTS	Under way	2003
PORTS[c]													
South Carolina													
SRS[c]													
Tennessee													
K-25[c]													
ORNL[c]													
ORAU[c]													
Y-12[c]													

Table 6.2 (continued)

State and site	Soil		Rubble		Metal		Miscellaneous		Total		Disposal site	Environmental restoration status	Scheduled FY of completion
	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU			
Texas													
PANT[c]													
Washington													
Hanford	11,219	809	2,357	209	4,482	451	3,870	451	21,927	1,920	Hanford	Under way	2021
Total									2,131,162	440,209			

[a]Data from ref. 1.
[b]General Atomics, San Diego, California.
[c]Information not available.
[d]Grand Junction, Colorado.

Table 6.3. Projected remaining volumes (m^3) of low-level and transuranic wastes, status, and schedule for completion of non-defense-funded environmental restoration projects, as of December 31, 1990[a]

State and site	Soil		Rubble		Metal		Miscellaneous		Total		Disposal site	Environmental restoration status	Scheduled FY of completion
	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU			
California													
GA[b]	0	0	909	0	0	0	0	1	909	1	Hanford	Under way	1996
GE[c]	0	0	0	17	0	0	0	0	0	17	Hanford	Planned	1997
LEHR[d]	3,068	0	70	0	50	0	100	0	3,288	0	Hanford	Under way	1997
LLNL[e]													
SLAC[e]													
SSFL[f]	1,355	0	1,621	0	581	0	495	0	4,025	0	Hanford	Under way	1998
Idaho													
ANL-W[e]													
INEL	2	0	768	0	295	0	15		1,080	0	INEL	Under way	1995
Illinois													
ANL-E	0	0	240	0	439	0	0	0	679	0	INEL	Under way	1995
FNAL[e]													
Missouri													
Weldon Spring	344,452	0	131,673	0	39,289	0	270,109	0	785,523	0	On-site	Under way	2002
New Jersey													
PPPL[e]													
New Mexico													
ITRI[e]													
LANL	40	0	305	25	518	200	50	0	913	225	LANL	Planned	1997
New York													
BNL[e]													
Ohio													
Battelle	899	94	1,571	1,118	524	559	262	94	3,256	1,864	Hanford	Under way	1997
Fernald (FMPC)	940,000	0	2,300	0	13,000	0	600,000	0	1,555,300	0	FMPC/NTS	Under way	2020
Mound Plant	28	0	198	3	85	0	85	0	396	3	NTS	Under way	1995
South Carolina													
SRS[e]													
Tennessee													
ORNL[e]													

Table 6.3 (continued)

State and site	Soil		Rubble		Metal		Miscellaneous		Total		Disposal site	Environmental restoration status	Scheduled FY of completion
	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU			
Utah													
Monticello	1,453,000	0	0	0	0	0	0	0	1,453,000	0	Monticello	Design	1996
Washington													
Hanford Site	0	0	0	0	221	3	221	3	442	6	Hanford	Under way	1995
Total									3,808,811	2,116			

[a]Data from ref. 1.
[b]General Atomics, San Diego, California.
[c]General Electric Vallecitos Nuclear Center, Vallecitos, California.
[d]Laboratory for Energy-Related Health Research, University of California-Davis.
[e]Information not available.
[f]Santa Susana Field Laboratory, Canoga Park, California.

Table 6.4. UMTRAP site descriptions, status, scheduled duration, and volume of permanently stored residual radioactive material[a]

State and site (last operation)	Site area (ha)	Remedial action status and scheduled duration as of Dec. 31, 1990	Permanently stored residual radioactive material[b] (m^3)
Arizona			
Monument Valley (1968)	11.0;[c] 11.5[d]	Pending (38% complete); project will restart in July 1992/24 months	
Tuba City (Sept. 1966)	8.9;[c] 128.3[d]	Completed in 1990	1,246,950
Colorado			
Durango (Mar. 1963)	51	Completed in 1990[e]	1,912,500
Grand Junction (Mar. 1970)	23.9;[c] 26.3[d]		
Phase I[f]		Completed	
Phase II[g]		In progress (24% complete)	
Gunnison (Apr. 1962)	14.2;[c] 15[d]	Planned; Apr. 1992/28 months	
Maybell (Nov. 1964)	29.7;[c] 69.2[d]	Planned; Apr. 1993/18 months	
Naturita (1963)	h; 20.2[d]	Planned; Apr. 1993/17 months	
New Rifle (Dec. 1972)	12.9;[c] 29.9[d]		
Phase I[f]		Completed	
Phase II[g]		Pending; Apr. 1991/38 months	
Old Rifle (1958)	5.5;[c] 18.8[d]		
Phase I[f]		Completed	
Phase II[g]		Pending; Apr. 1991/38 months	
Slick Rock – NC site (1957)	2.4;[c] 7.6[d]	Planned; Apr. 1993/17 months	
Slick Rock – UC site (1961)	7.7;[c] 26.3[d]	Planned; Apr. 1993/17 months	
Idaho			
Lowman (1960)	5.0;[c] 7.0[d]	Planned; Apr. 1991/6 months	
New Mexico			
Ambrosia Lake (Apr. 1963)	44.9;[c] 230.7[d]		
Phase I[f]		Completed	
Phase II[g]		Pending; Aug. 1991/29 months	
Shiprock (Aug. 1968)	29.1[c]	Completed in 1986	2,142,000
North Dakota			
Belfield (Oct. 1965)[i]	h; 14[d]	Planned; Apr. 1993/6 months	
Bowman (Feb. 1967)[i]	h; 26[d]	Planned; Apr. 1993/6 months	
Oregon			
Lakeview (1961)	16.2[c]	Completed in 1987	719,100
Pennsylvania			
Canonsburg (1957)	11.6[c]	Completed in 1985	130,050
South Dakota			
Edgemont[j]	NA[k]	Completed in 1988	34,400[l]
Texas			
Falls City (Aug. 1973)	59.1;[c] 123.4[d]	Planned; Aug. 1991/36 months	
Utah			
Green River (Jan. 1961)	3.6;[c] 16.3[d]	Completed in 1989	160,650
Mexican Hat (1965)	28.3;[c] 73.4[d]	Pending; July 1992/24 months	
Salt Lake City (Feb. 1964/July 1968)	24.3[c]	Completed in 1987	2,073,150[m]

Table 6.4 (continued)

State and site (last operation)	Site area (ha)	Remedial action status and scheduled duration as of Dec. 31, 1990	Permanently stored residual radioactive material[b] (m^3)
Wyoming			
Converse County (June 1965)	2.0;[c] 6.3[d]	Completed in 1989	122,400
Riverton (mid-year 1963)	29.1;[c] 56.7[d]	Completed in 1989	1,224,000
Total			9,765,200

[a]Data from ref. 9.
[b]Tailings and other wastes combined with radon barrier in place. Other components of the cover and site drainage features may not be completed.
[c]Tailings site area.
[d]Other wastes site area.
[e]Tailings have been stabilized; rock cover will be finalized in summer of 1991.
[f]Preparatory work (road construction and/or structure demolition).
[g]Storage of mill tailings or other waste.
[h]Tailings moved from site during 1977-1979; only contaminated soil remains. Mill area susceptible to flooding.
[i]No tailings; uraniferous lignite ashing plant; ore roasted and shipped away.
[j]Vicinity properties only.
[k]Not applicable.
[l]Buried in a permanently capped cell repository a few miles south of Edgemont.
[m]Tailings were relocated 80 miles southwest of Salt Lake City at Clive, Utah.

Table 6.5. Projected waste characteristics at uncompleted UMTRAP sites as of December 31, 1990[a]

State and site	Estimated waste volume (m^3)	Radioactivity ^{226}Ra (pCi/g)
Arizona		
Monument Valley	1,059,000	49
Colorado		
Grand Junction	5,664,000	665
Gunnison	762,000	314
Maybell	3,174,000	187
Naturita	615,000[b]	46
Rifle	4,151,000	750
Slick Rock	1,401,000	200
Subtotal	15,767,000	
Idaho		
Lowman	120,000	133
New Mexico		
Ambrosia Lake	4,536,000	455
North Dakota		
Belfield/Bowman	158,400[c]	45
Texas		
Falls City	5,450,000	200
Utah		
Mexican Hat	2,563,000	700
Total	29,653,000	

[a]Data from ref. 9.
[b]Contaminated soil only.
[c]No tailings, uraniferous lignite ashing plant; ore roasted and shipped away.

Table 6.6. FUSRAP site descriptions, status, schedule, and volume of stored wastes[a]

State and site	Site area (ha)	Remedial action status and schedule as of Dec. 31, 1990	Permanently stored waste, m^3		Interim stored waste (m^3)
			LLW	Stabilized	
California					
Gilman Hall, Univ. of California, Berkeley	b	Completed in FY 1982	23		
Connecticut					
Seymour Specialty Wire	b	Planned in FY 1994			
Illinois					
Laboratories at Univ. of Chicago, Chicago	b	Completed in FY 1987	35		
National Guard Armory, Chicago	b	Completed in 1987	15		
Maryland					
W. R. Grace and Company, Curtis Bay	1.6	Planned in FY 2003-2004			
Massachusetts					
Shpack Landfill, Norton	3.2	Planned in FY 1995			
Ventron, Beverly	1.2	Partially completed; to be completed in FY 1993-1994	176		
Missouri					
St. Louis Airport, St. Louis	8.8	Planned in FY 1995			
St. Louis Airport (Vicinity Properties), St. Louis	b	Planned in FY 1997-1998			
Latty Avenue Properties, Hazelwood	b	Partially completed; to be continued through 2000			24,200[c]
St. Louis Downtown Site, St. Louis	18.2	Planned in FY 1998-2002			
Michigan					
General Motors, Adrian	b	Planned in FY 1994			
New Jersey					
E. I. du Pont de Nemours and Co., Deepwater	283	Planned in FY 2000			
Kellex Research Facility, Jersey City	6.2	Completed in FY 1981	209		
Middlesex Municipal Landfill, Middlesex	1.2	Completed in 1986			23,900[d]
Middlesex Sampling Plant, Middlesex	3.9	Partially completed; to be completed in FY 2003-2005			26,900[e]
W. R. Grace/Sheffield Brook/other properties, Wayne and Pequannock	b	Partially completed; to be continued through FY 2007			29,400[f]
Stepan Chemical Co., Ballod property and private properties on Latham St. and Davidson Ave., Maywood	b	Partially completed; to be continued through FY 2009			26,700[g]
New Brunswick Laboratory, New Brunswick	b	Planned in FY 2007-2008			
New Mexico					
Acid/Pueblo/Los Alamos Canyons, Los Alamos	51.6	Completed in FY 1982	298		
Bayo Canyon, Los Alamos	137	Completed in FY 1982		1,160	

Table 6.6 (continued)

State and site	Site area (ha)	Remedial action status and schedule as of Dec. 31, 1990	Permanently stored waste, m^3		Interim stored waste (m^3)
			LLW	Stabilized	
New Mexico (contd.)					
Chupadera Mesa, White Sands Missile Range	b	None required[h]			
New York					
Linde Air Products Div., Tonawanda	22.2	Planned in FY 1995-1996			
Colonie Interim Storage Site, Colonie	b	Partially completed; to be continued through FY 1994			918[i]
Niagara Falls Storage Site (Vicinity Properties), Lewiston	b	Completed in FY 1986			38,200[j]
Niagara Falls Storage Site, Lewiston	77	Partially completed; to be completed in FY 1993-1995			157,000[k]
Ashland Oil Co. (No. 1), Tonawanda	3	Planned in FY 1995			
Ashland Oil Co. (No. 2), Tonawanda	1	Planned in FY 1996			
Seaway Industrial Park, Tonawanda	4.8[l]	None planned/required			
Baker and Williams Warehouses, New york	b	Planned in FY 1991			
Oregon					
Albany Metallurgical Research Center, Albany	b	Partially completed; to be completed in FY 1991	2,650		
Pennsylvania					
Aliquippa Forge, Aliquippa	0.34[m]	Partially completed; to be completed in FY 1993			
Tennessee					
Elza Gate, Oak Ridge	8.9	Planned in FY 1990-1992			
Total (all sites)			3,406	1,160	327,218

[a]Data from ref. 17.
[b]Not determined.
[c]24,200 m^3 of waste in interim storage on-site.
[d]23,900 m^3 of waste transferred to Middlesex Sampling Plant for interim storage.
[e]26,900 m^3 of waste in interim storage on-site. Does not include 23,900 m^3 of Middlesex Municipal Landfill waste which is stored on-site.
[f]29,400 m^3 of off-site property waste transferred to interim storage on-site.
[g]26,700 m^3 of waste in interim storage on-site.
[h]Based on a radiological survey, it was determined that this site does not require any remedial action.
[i]918 m^3 of off-site property waste transferred to interim storage on-site.
[j]38,200 m^3 of off-site property waste transferred to interim storage on-site.
[k]Construction of the final cap is dependent upon final resolution concerning disposal of certain residues currently contained in the waste containment structure.
[l]Existing waste in the Seaway Landfill will remain in place based on pathway analysis findings.
[m]Total floor area that was surveyed; only isolated patches of radioactive contamination were found.

Table 6.7. Projected waste characteristics at uncompleted FUSRAP sites[a]

State and site	Estimated waste volume (m^3)	Principal constituents	Identified contaminants
Connecticut			
Seymour Specialty Wire	19	Rubble, metal	^{238}U
Maryland			
W. R. Grace and Company, Curtis Bay	27,500	Soil	^{232}Th
Massachusetts			
Shpack Landfill, Norton	306	Soil, concrete, metal, and rubble	^{238}U, ^{235}U, ^{226}Ra, ^{210}Pb
Ventron, Beverly	5,170	Soil, concrete, rubble, metal, and building material	^{238}U
Subtotal	5,476		
Missouri			
St. Louis Airport	191,000	Soil	^{238}U, ^{230}Th, ^{226}Ra
St. Louis Airport (Vicinity Properties), St. Louis	145,000	Soil	^{238}U, ^{226}Ra
Latty Avenue Properties, Hazelwood	137,000	Soil, rubble	^{238}U, ^{231}Pa, ^{230}Th, ^{227}Ac, ^{226}Ra
St. Louis Downtown Site, St. Louis	188,000	Soil, building material, and rubble	^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{222}Rn
Subtotal	661,000		
Michigan			
General Motors, Adrian	153	Soil, building material, and metal	^{238}U
New Jersey			
E. I. du Pont de Nemours and Co., Deepwater	6,320	Soil, building material, rubble, and, road material	^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb
Middlesex Sampling Plant, Middlesex	16,800	Soil, building material, and rubble	^{238}U, ^{232}Th, ^{226}Ra
W. R. Grace/Sheffield Brook/other properties, Wayne and Pequannock	53,900	Soil, rubble	^{238}U, ^{232}Th, ^{228}Th, ^{226}Ra
Stepan Chemical Co., Ballod property and private properties on Latham St. and Davidson Ave., Maywood	275,000	Soil, rubble	^{235}U, ^{238}U, ^{232}Th, ^{226}Ra, ^{40}K
New Brunswick Laboratory, New Brunswick	3,440	Soil, rubble	^{241}Am, ^{239}Pu, ^{238}U, ^{235}U, ^{226}Ra
Subtotal	355,460		

Table 6.7 (continued)

State and site	Estimated waste volume (m^3)	Principal constituents	Identified contaminants
New York			
Linde Air Products Div., Tonawanda	20,500	Soil, building material, and equipment	^{238}U, ^{232}Th, ^{230}Th, ^{226}Ra
NL Bearings Plant and private properties on Central, Palmer, and Yardboro Avenues, Albany/Colonie	9,940	Soil, building material, equipment, and rubble	^{238}U, ^{226}Ra
Ashland Oil Co. (No. 1), Tonawanda	64,200	Soil	^{238}U, ^{232}Th, ^{226}Ra
Ashland Oil Co. (No. 2), Tonawanda	14,800	Soil	^{238}U, ^{232}Th, ^{226}Ra
Seaway Industrial Park, Tonawanda	89,500	Soil	^{226}Ra
Baker and Williams Warehouses, New York City	21	Building material	^{238}U
Subtotal	198,961		
Oregon			
Albany Metallurgical Research Center, Albany	80	Soil, building material, and plumbing	^{238}U, ^{232}Th
Pennsylvania			
Aliquippa Forge, Aliquippa	29	Soil, concrete, metal	^{238}U, alpha, beta-gamma
Tennessee			
Elza Gate, Oak Ridge	6,800	Soil, concrete, building material, and plumbing	^{238}U, ^{226}Ra
Total (all sites)	1,255,478		

[a]Data from ref. 17.

ORNL PHOTO 7876-91

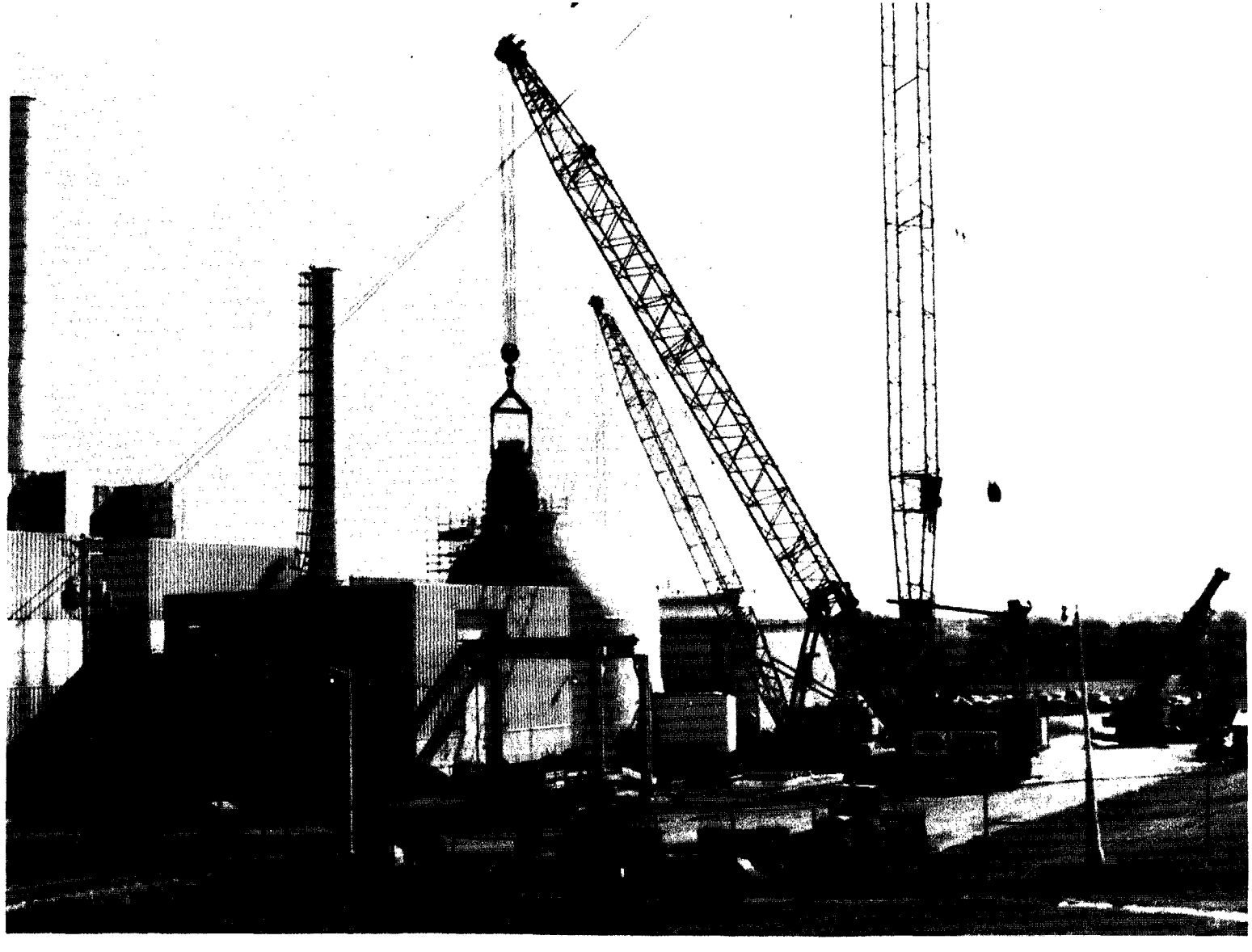


Photo 7.1. Removal from containment of the 245-ton Pathfinder boiling-water reactor pressure vessel on May 14, 1991. (Courtesy of the Northern States Power Company, Minneapolis, Minnesota.)

7. COMMERCIAL DECOMMISSIONING WASTES

7.1 INTRODUCTION

At the end of their useful life, commercial nuclear facilities must be shut down and decommissioned. A schedule of historical and projected commercial LWR shutdowns, based on refs. 1 and 2, is given in Table 7.1. The projected volume, radioactivity, and thermal power of various types of waste generated from future commercial power LWR decommissioning activities are reported in Table 7.2. These waste projections are in addition to those previously reported in Chapter 4 (for LLW) and in Chapter 6 (for environmental restoration activities). This approach is taken mainly because the timing associated with future decontamination and decommissioning (D&D) activities at commercial power reactor sites is uncertain. The projected data shown in Table 7.2 are based on refs. 3–9 and assume a 4-year period for decommissioning, beginning 2 years after reactor shutdown to allow sufficient preparation time for D&D operations. For these projections, it was further assumed that D&D wastes will be sent to disposal sites in four equal volumes during the 4 years of facility decommissioning. The power reactor shutdown schedule presented in Table 7.1 is based on utility estimates of reactor lifetime. Actual decommissioning schedules may be significantly different from those used herein if any of the following are implemented:

- reactors are upgraded to extend their operating lifetimes,
- significant radioactivity decay time is allowed before decommissioning operations begin, or
- the last core of spent fuel must remain on site for at least 5 years prior to shipment.

Estimates of wastes from decommissioning reference commercial LWRs and supporting fuel cycle facilities (for uranium conversion, enrichment, and fuel fabrication) are given in Table 7.3 (data from refs. 3–12). These estimates assume a 40-year facility operating life. (In practice, the operating lifetime can vary significantly, depending on the extent to which facility equipment is periodically upgraded or retrofitted.) On a relative basis, it is estimated that the volume of decommissioning wastes from conversion, enrichment, and fuel fabrication facilities is less than 2% of the waste volume from decommissioning a PWR (Table 7.3, col. 6). Table 7.3 also shows that, for conversion and fabrication facilities, the volume of wastes from decommissioning will be significantly less than the volume of wastes produced from normal lifetime operations. Not shown in this table are the additional wastes that will result from decommissioning of research, training, and test reactors.[13,14] However, the total volumes of these wastes are not significant, since such reactors are much smaller than commercial power reactors.

7.2 WASTE CHARACTERIZATION

The LWR decommissioning wastes can be grouped into three major categories:[5,8] (1) neutron-activated wastes, (2) surface-contaminated wastes, and (3) miscellaneous radioactive wastes.

Neutron-activated materials generally include the reactor vessel and its internal components (e.g., core support assemblies, control rod guide tubes). Contaminated materials include much of the piping and equipment in the reactor containment and auxiliary control buildings. In addition, some of the concrete surfaces of these buildings are expected to be radioactive and will require removal. The miscellaneous radioactive waste category consists of a small, but significant, group of materials that includes both "wet" and "dry" solid wastes. Wet radioactive wastes result from the processing of chemical decontamination solutions and contaminated water. These wastes include spent ion-exchange resins, cartridge filters, and evaporator and concentrator bottoms. Dry radioactive wastes include discarded contaminated items, such as rags and wipes, tools, and protective clothing. Many reactor items with surface contamination can be decontaminated,[15] rendering most of the material nonradioactive and producing a smaller, more concentrated volume of waste containing the radioactivity. Waste decontamination requires the appropriate technology and a defined level of radioactivity at which a waste is below an acceptable level of contamination. Establishing such criteria is complicated because there are varying levels of natural radioactivity. Minimum regulatory levels have already been defined in Europe;[16] the EPA, which has responsibility for defining such levels in the United States, began a review of criteria in 1984. Currently, the NRC handles requests to declare a waste below regulatory

concern on a case-by-case basis. Depending on the level of technology and the minimum regulatory level definition, actual decommissioning waste volumes could vary somewhat from the estimates reported in Table 7.3. However, the total radioactivity in the D&D waste from a particular facility is not expected to change significantly from that projected.

A list of the larger commercial power reactors that have undergone some mode of decommissioning to date is provided in Table 7.4 (data from refs. 2 and 17). (A comprehensive listing of all types of domestic reactors that have been shut down or dismantled is given in ref. 2.) As described in ref. 18, the NRC has defined the three major alternative classifications for decommissioning of nuclear facilities:

- DECON. This is defined as ". . . the alternative in which the equipment, structures and portions of a facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations."

- SAFSTOR. This is defined as ". . . the alternative in which the nuclear facility is placed and maintained in such condition that the nuclear facility can be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use."

- ENTOMB. This is defined as ". . . the alternative in which radioactive contaminants are encased in a structurally long-lived material, such as concrete. The entombment structure is appropriately maintained, and continued surveillance is carried out until the radioactivity decays to a level permitting unrestricted release of the property." (This alternative would be allowable for nuclear facilities contaminated with relatively short-lived radionuclides such that all contaminants would decay to levels permissible for unrestricted use within a period on the order of 100 years.)

Decommissioning operations collect LLW plus a small volume of high-activity wastes from certain reactor core internal parts. These high-activity wastes are often referred to as "high-activity activation wastes." Under NRC rules, many of these wastes would be classified as greater-than-Class-C (GTCC) LLW. Some GTCC wastes contain significant concentrations of long-lived, nontransuranic radioisotopes, such as ^{59}Ni, ^{63}Ni, and ^{94}Nb. These isotopes are generated by long-term irradiation of stainless steel and some other alloys used for reactor core structural components. Because the method of waste disposal for these reactor internals is different from LLW disposal, GTCC wastes are reported separately. Under current NRC regulations,[19-20] these wastes are considered not generally acceptable for shallow-land disposal. Such wastes must be put into a federal geologic repository unless the NRC approves an alternative disposal in a licensed site. High-activity activation wastes from the immediate decommissioning of LWRs are estimated to make up less than 1% of the total waste volume, but they contain more than 95% of the radioactivity.[5,8] Such reactor wastes are comprised of many long-lived radionuclides. Most of this radioactivity is in a single reactor component, the stainless steel core shroud that surrounds the reactor fuel.

As reported in ref. 21, a study of reactor decommissioning wastes is being made by the Pacific Northwest Laboratory for the NRC. This study includes an analysis of wastes from the Shippingport Station decommissioning and an analysis of neutron-activated metal components (GTCC materials) from the internals of other reactors. Thus far, the waste characterization assessments from this study have indicated the following:

- All reactor decommissioning materials, except the pressure vessel internals, have the potential for being disposed of as Class-A LLW;
- Fission products and TRU radionuclides are absent; and
- Most radioactivity results from neutron-activation products, of which ^{60}Co is the principal contributor.

Additional updated information on the radioactive characteristics of commercial reactor D&D wastes (in particular, spent LWR control rod assemblies) will be documented in future supplements to ref. 21.

7.3 INVENTORIES AND PROJECTIONS

Of the reactors listed in Table 7.4, only three, the Elk River station, the Santa Susana sodium reactor, and the Shippingport station (discussed later), have been completely dismantled. A summary of the wastes from decommissioning the Elk River station is provided in Table 7.5 (data from refs. 22–24). Types and volumes of wastes from decommissioning the Santa Susana reactor are reported in Table 7.6 (data from ref. 25).

For the projections listed in Table 7.2, a 6-year period for decommissioning activities is assumed: 2 years for planning and preparation and 4 for actual decommissioning, with wastes generated equally over the final 4 years. The option does exist, however, to delay decommissioning for 10 to 60 years after reactor shutdown to allow significant radioactive decay.[18] For example, radioactivity levels in PWR piping have been estimated to decrease, in 10 years, to 8.7% and, in 30 years, to 0.63% of the radioactivity levels at the time of reactor shutdown. At PWR shutdown and for about 4 years thereafter, ^{55}Fe and ^{60}Co control the radiation levels; from 4 to about 100 years, ^{60}Co and ^{63}Ni control radiation levels; and well beyond 100 years, ^{59}Ni and ^{94}Nb control radiation levels.[8] The choice between immediate or delayed

decommissioning involves cost trade-offs between the costs of storage with delayed decommissioning versus the higher costs resulting from the higher radiation levels associated with rapid decommissioning.[26] Therefore, the start of actual decommissioning may be much later than the shutdown date (Table 7.1) to allow plant radiation levels to decay to lower levels. Another consideration is that the last core of discharged spent fuel may need to remain at the reactor site for at least 5 years prior to shipment. Table 7.7 shows the effects of various decommissioning alternatives on the volumes and radioactivities of D&D wastes from a reference BWR[4-6] and a reference PWR.[7-9] For cases involving deferred D&D activities, it is evident that both the volumes and activities of wastes significantly decline after a safe storage period of 50 years.

Inventories and projections of wastes from three major DOE decommissioning programs are summarized in Tables 7.8, 7.9, and 7.10 (data from refs. 27–29). The first of these tables lists waste inventory and projection data for decommissioning activities at the Shippingport Station Decommissioning Project. This is the site of the first domestic commercial power reactor and is currently part of the civilian SFMP. The facility was shut down in 1982, and physical dismantling began in September 1985. During April 1989, the decommissioned reactor pressure vessel from the Shippingport Station was received for disposal at the Hanford site after an 8000-mile water journey. The pressure vessel was the last major reactor component to be shipped from the facility. Shippingport decommissioning activities were completed in 1990.[27]

Table 7.9 (data from ref. 28) presents a summary of the West Valley Demonstration Project (WVDP), formerly a commercial fuel reprocessing facility. Since startup of the project in 1982, more than 70% of the original process building's cell surface areas have been decontaminated and released for project reuse.

Inventories and projections of wastes from decontamination activities at the damaged Three Mile Island–Unit 2 reactor are summarized in Table 7.10. Removal of core debris from the damaged reactor started in January 1986 and was completed in 1990. By the end of 1990, 155.9 t of core debris had been shipped to INEL for R&D testing and storage.[29]

Decommissioning waste projections are being compiled on several other reactors and a fuel fabrication plant. The reactors include Dresden Unit 1, La Crosse, Saxton, Humboldt Bay Unit 3, Diablo Canyon Units 1 and 2, Rancho Seco, Fort St. Vrain, Peach Bottom (HTGR and BWR units), Pathfinder, and Shoreham.

The Commonwealth Edison Company has issued a decommissioning plan and environmental report[30] for the Dresden Unit 1 nuclear power station. Commonwealth Edison plans to decommission this reactor by first placing the facility in a SAFSTOR condition until Dresden Units 2 and 3 are ready for decommissioning. If an extended life program for Units 2 and 3 is not initiated, all three Dresden units will be decommissioned by dismantling, beginning in 2017. A summary of projected radioactive materials from the SAFSTOR decommissioning of the Dresden Unit 1 station is given in Table 7.11 (data from refs. 30 and 31).

The La Crosse BWR was shut down in 1987 and placed in SAFSTOR in 1988. Current plans are to dismantle the reactor after a SAFSTOR period of 25 years. Projected volumes and associated activities of annual waste shipments from this reactor during this period are given in Table 7.12 (data from ref. 32).

The Saxton Nuclear Experimental Reactor is a 3-MW(e) PWR that was placed in SAFSTOR following its shutdown in 1972. Work on dismantling the reactor site (DECON) started in 1986. To date, decontamination activities have been completed of the control room and radwaste building. The reactor containment building is not scheduled for dismantling until the mid-1990s. A summary of projected waste characteristics from dismantling the Saxton site is provided in Table 7.13 (data from ref. 33).

Projections of decommissioning wastes from reactors owned and operated by the Pacific Gas and Electric Company are provided in Tables 7.14 and 7.15. The waste data reported in these tables are based on a decommissioning study[34] made of the 65-MW(e) Humboldt Bay Unit 3 BWR and the 1100-MW(e) Diablo Canyon PWR Units 1 and 2. Projections for the Humboldt Bay BWR in Table 7.14 include wastes from completely dismantling the reactor following a SAFSTOR period of about 30 years. Projections for the Diablo Canyon units in Table 7.15 reflect wastes from immediate dismantlement (DECON) of these reactors following a 30-year period of operation. Units 1 and 2 were started up in 1985 and 1986, respectively.

The Rancho Seco reactor is a 918-MW(e) PWR that was shut down in 1989. Table 7.16 (data from ref. 35) lists projected volumes of wastes from the dismantlement of this reactor following a SAFSTOR period of about 20 years.

Projections of wastes from DECON (dismantling) of the 330-MW(e) Fort St. Vrain HTGR are reported in Table 7.17 (data from refs. 36 and 37). This reactor was shut down in August 1989.

The 40-MW(e) Peach Bottom HTGR (Unit 1) was shut down in 1974 and placed in SAFSTOR. To put the reactor in this mode of decommissioning, 490 containers of solid radioactive waste were packaged and shipped. This solid waste represented a total volume of nearly 400 m^3 and an activity level of 380 Ci. In addition, about 1.14 m^3 (300 gal) of liquid waste, consisting of contaminated oil, were processed or solidified.[38]

Projections of decommissioning wastes have been made for the 1065-MW(e) Peach Bottom BWRs (Units 2 and 3). These are reported in Table 7.18 (data from ref. 39) for a case involving prompt removal and reactor dismantling (DECON).

The 66-MW(e) Pathfinder BWR was placed in the SAFSTOR mode following its shutdown in 1967. Work on

dismantling the reactor (DECON) began in July 1990. The scope of this phase of decommissioning includes the reactor building, the fuel handling building, the fuel transfer tube and vault, and the surrounding areas. By May 1991, most of the piping, pumps, tanks, wiring, ventilation, and miscellaneous systems were removed and disposed of. The reactor vessel was lifted out of containment on May 14, 1991. The decommissioning team is preparing to ship the vessel via rail later in 1991. Upon completion of this phase of decommissioning in 1992, only trace amounts of residual contamination will remain in the operating, converted fossil plant. Waste inventories and projections from D&D activities at the Pathfinder Reactor site are given in Table 7.19 (data from ref. 40).

The 820-MW(e) Shoreham BWR underwent low-power tests until 1989, when the plant's owner, Long Island Lighting Company, agreed to sell the plant to the state of New York for decommissioning. A proposed decommissioning plan (ref. 41) for the Shoreham plant has been prepared and is being reviewed by the NRC. Estimates of decommissioning wastes reported in the Shoreham decommissioning plan are presented in Table 7.20. The volume estimates in this table are conservative because they do not take credit for any volume reduction techniques and, further, because they assume no systems or structures will be decontaminated below the release criteria in place. It is also assumed that even with decontamination, all contaminated systems and the reactor pressure vessel and its internals will need to be dismantled and disposed of off-site.[41]

Inventories and projections of wastes from decommissioning activities at the Cimarron (Oklahoma) Fuel Fabrication Facility are provided in Table 7.21 (data from ref. 42). Decontamination work at this fabrication plant is scheduled to be completed during 1991.

Currently, the total impact of wastes from D&D activities at commercial reactor and fuel cycle sites has been small. However, this will become more significant after the year 2000, when more of the older reactors complete their campaign of operation.

In addition to wastes from the decommissioning of commercial reactor and fuel cycle facilities, there will be some resulting from Department of Defense power plant decommissioning operations. Over the next 20 to 30 years, approximately 100 nuclear-powered submarines of the U.S. Navy may be taken out of service and consigned to permanent disposal after removal of spent fuel. Current plans are to dispose of the submarine reactor compartments by land burial at government-owned LLW burial sites. Each reactor compartment contains about 1000 t of metal, and it is estimated that 100 reactor compartments can be buried on 4 ha (10 acres) of land.[43] As of the end of 1990, 37 submarines had been taken out of active service. In 14 of these submarines, the reactor compartment was first defueled, then later removed and disposed of at a government burial site. (LLW disposed from these activities is included in the DOE site inventories reported in Chapter 4.) The remaining 23 submarines with reactor compartments were being held in protective storage.[2]

7.4 REFERENCES

1. U.S. Department of Energy, Richland Field Office, Spent Fuel Storage Requirements 1990–2040, DOE/RL-90-44, Richland, Washington (November 1990).

2. U.S. Department of Energy, Office of Scientific and Technical Information, Nuclear Reactors Built, Being Built, or Planned: 1990, DOE/OSTI-8200-R54, Oak Ridge, Tennessee (July 1991).

3. C. W. Forsberg, W. L. Carter, and A. H. Kibbey, Flowsheets and Source Terms for Radioactive Waste Projections, ORNL/TM-8462, Oak Ridge National Laboratory, Oak Ridge, Tennessee (March 1985).

4. H. D. Oak et al., Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station, NUREG/CR-0672, Vols. 1 and 2, U.S. Nuclear Regulatory Commission, Washington, D.C. (June 1980).

5. E. S. Murphy, Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station — Classification of Decommissioning Wastes, NUREG/CR-0672, Addendum 2, U.S. Nuclear Regulatory Commission, Washington, D.C. (September 1984).

6. G. J. Konzek and R. I. Smith, Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station — Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule, NUREG/CR-0672, Addendum 3, U.S. Nuclear Regulatory Commission, Washington, D.C. (July 1988).

7. R. I. Smith et al., Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station, NUREG/CR-0130, Vols. 1 and 2, U.S. Nuclear Regulatory Commission, Washington, D.C. (June 1978).

8. E. S. Murphy, Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station — Classification of Decommissioning Wastes, NUREG/CR-0130, Addendum 3, U.S. Nuclear Regulatory Commission, Washington, D.C. (September 1984).

9. G. J. Konzek and R. I. Smith, Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station — Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule, NUREG/CR-0130, Addendum 4, U.S. Nuclear Regulatory Commission, Washington, D.C. (July 1988).

10. H. K. Elder, Technology, Safety and Costs of Decommissioning a Reference Uranium Hexafluoride Conversion Plant, NUREG/CR-1757, U.S. Nuclear Regulatory Commission, Washington, D.C. (October 1981).

11. U.S. Energy Research and Development Administration, Final Environmental Statement, Portsmouth Gaseous Diffusion Plant Expansion, Piketon, Ohio, ERDA-1549, Vols. 1 and 2, Washington, D.C. (September 1977).

12. H. K. Elder and D. E. Blahnik, Technology, Safety and Costs of Decommissioning a Reference Uranium Fuel Fabrication Plant, NUREG/CR-1266, Vols. 1 and 2, U.S. Nuclear Regulatory Commission, Washington, D.C. (October 1980).

13. G. J. Konzek et al., Technology, Safety and Costs of Decommissioning Reference Nuclear Research and Test Reactors, NUREG/CR-1756, Vols. 1 and 2, U.S. Nuclear Regulatory Commission, Washington, D.C. (March 1982).

14. G. J. Konzek et al., Technology, Safety and Costs of Decommissioning Reference Nuclear Research and Test Reactors, NUREG/CR-1756, Addendum, U.S. Nuclear Regulatory Commission, Washington, D.C. (July 1983).

15. W. Manion and T. S. LaGuardia, Decommissioning Handbook, DOE/EV/10128-1, U.S. Department of Energy, Remedial Actions Program Office, Washington, D.C. (November 1980).

16. G. V. P. Watzel and I. Auler, "Decommissioning of Large Power Plants with LWRs in the Federal Republic of Germany," Nucl. Technol. 63(1), 90 (October 1983).

17. J. T. A. Roberts et al., "Decommissioning of Commercial Nuclear Power Plants," Annual Reviews of Energy, Vol. 10, pp. 251–84 (1985).

18. U.S. Nuclear Regulatory Commission, "General Requirements for Decommissioning Nuclear Facilities," Fed. Regist. 53(123), 24018–24056 (June 27, 1988).

19. U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Wastes: 'Greater-than-Class-C' Low-Level Radioactive Wastes," Fed. Regist. 54(100), 22578–83 (May 25, 1989).

20. U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Wastes," Code of Federal Regulations, 10 CFR Part 61.55(a)(2)(iv) (May 19, 1989).

21. D. E. Robertson et al., Radionuclide Characterization of Reactor Decommissioning Waste and Spent Fuel Assembly Hardware — Progress Report, NUREG/CR-5343, PNL-6806, prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, Washington, D.C. (January 1991).

22. United Power Association, AEC — Elk River Reactor — Final Program Report, COO-651-93, Elk River, Minnesota (November 1974).

23. J. P. Indusi and D. Majumdar, Nuclear Wastes from Decommissioning and Dismantling of Nuclear Reactors, BNL-NUREG-29244R, Brookhaven National Laboratory, Upton, New York (May 1981).

24. J. F. Nemec, "Decommissioning of Nuclear Power Plants," pp. 303–19 in Nuclear Power Waste Technology, ed. A. A. Moghissi et al., American Society of Mechanical Engineers, New York, New York (1978).

25. J. W. Carroll et al., Sodium Reactor Experiment Decommissioning, ESG-DOE-13403, Rockwell International Corporation, Canoga Park, California (Aug. 15, 1983).

26. D. F. Greenwood et al., "Analysis of Decommissioning Costs for Nuclear Reactors," Nucl. Technol. 62(2), 190–206 (August 1983).

27. U.S. Department of Energy, Richland Field Office, Shippingport Station Decommissioning Project Office, Final Project Report — Shippingport Station Decommissioning Project, prepared by Westinghouse Hanford Company, DOE/SSDP-0081, Richland, Washington (Dec. 22, 1989).

28. T. J. Rowland, DOE-West Valley Demonstration Project Office, West Valley, New York, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update to the DOE 1991 Integrated Data Base Report," dated Apr. 15, 1991.

29. W. T. Conaway, GPU Nuclear Corporation, Three Mile Island Site Office, Middletown, Pennsylvania, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 4230-91-031-WTC, transmitting updated summary of wastes from TMI Unit 2 cleanup activities, dated Apr. 17, 1991.

30. Commonwealth Edison Company, Decommissioning Program Plan for the Dresden Nuclear Power Station Unit 1, Rev. 2, Chicago, Illinois (March 1988).

31. W. E. Morgan, Commonwealth Edison Company, Chicago, Illinois, memo to Nuclear Regulatory Commission, Document Control Desk, "Dresden Nuclear Power Station Unit 1 Response to Request for Additional Information: Decommissioning Plan, Technical Specifications and Emergency Plans NRC Docket No. 50-010," dated Mar. 27, 1989.

32. S. J. Raffety, Dairyland Power Cooperative, La Crosse, Wisconsin, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, transmitting summary of updated waste inventories and projections from decommissioning the La Crosse BWR (LAC-13061), dated May 17, 1991.

33. S. A. Molello, Saxton Nuclear Experimental Corporation, General Public Utilities System, Forked River, New Jersey, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, transmitting summary of waste projections from decommissioning the Saxton Nuclear Station, dated July 17, 1989.

34. Pacific Gas and Electric Company, 1990 Test Year General Rate Case Exhibit 12, "Nuclear Decommissioning Costs," Documents P01-25-002 and P01-25-003, San Francisco, California (1989).

35. M. J. Bua, Sacramento Municipal Utility District, Rancho Seco Nuclear Generating Station, Herald, California, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, RPM 91-112, transmitting data on wastes from decommissioning the Rancho Seco PWR, dated July 24, 1991.

36. M. J. Fisher, Public Service Company of Colorado, Denver, Colorado, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, DDO-90-0068, transmitting summary of projected wastes from dismantling the Fort St. Vrain Reactor, dated June 4, 1990.

37. F. J. Novachek, Public Service Company of Colorado, Denver, Colorado, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, DDO-91-0097, "1991 Integrated Data Base Comments," dated July 30, 1991.

38. E. J. Kohler, Philadelphia Electric Company, Philadelphia, Pennsylvania, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, transmitting summary of wastes from decommissioning the Peach Bottom Unit 1 reactor, dated Mar. 27, 1989.

39. Decommissioning Cost Study for Peach Bottom, prepared by TLG Engineering, Inc., for Public Service Electric & Gas Company, P07-25A-003, Bridgewater, Connecticut (March 1988).

40. J. W. Closs, Northern States Power Company, Minneapolis, Minnesota, memo to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, transmitting summary of wastes from dismantling the Pathfinder reactor, dated June 13, 1991.

41. Long Island Power Authority, Shoreham Nuclear Power Station Decommissioning Plan, NRC Docket No. 50-322, December 1990.

42. A. W. Norwood, Standby Operations Manager, Cimarron Facility, Cimarron Corporation, Crescent, Oklahoma, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, transmitting summary of wastes from decommissioning the Cimarron (fuel fabrication) Facility, dated Mar. 6, 1989; updated transmittal submitted by Cimarron Corporation on Apr. 5, 1991.

43. U.S. Department of the Navy, Final Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants, Vols. 1-3, Washington, D.C. (May 1984).

Table 7.1. Schedule of final shutdown dates for commercial light-water reactors[a,b]

Calendar year of shutdown	BWR		PWR		Total LWR	
	No.	MW(e)	No.	MW(e)	No.	MW(e)
1963	1	5			1	5
1967	1	66	1	17	2	83
1968	2	39			2	39
1972			1	3	1	3
1974			1	265	1	265
1976	1	65			1	65
1978	1	200			1	200
1979			1	926[c]	1	926
1982			1	72	1	72
1987	1	48			1	48
1989	1	820	1	918	2	1,738
Totals through 1990	8	1,243	6	2,201	14	3,444
2000			1	175	1	175
2003	1	72			1	72
2007			2	1,018	2	1,018
2009	3	2,064	1	490	4	2,554
2010	1	660	2	1,197	3	1,857
2011	3	2,128	3	2,175	6	4,303
2012	3	1,958	3	2,306	6	4,264
2013	2	2,130	9	6,976	11	9,106
2014	7	5,865	6	4,960	13	10,825
2015			3	2,965	3	2,965
2016	2	1,886	5	4,532	7	6,418
2017			4	3,660	4	3,660
2018	1	784	1	912	2	1,696
2020			4	3,999	4	3,999
Projected totals (1991-2020)	23	17,547	44	35,365	67	52,912

[a]Data from refs. 1 and 2.

[b]Projected reactor shutdown dates are based on DOE/EIA No New Orders Case. Years in which no reactor shutdown is expected are eliminated.

[c]Shutdown of Three Mile Island-Unit 2 nuclear power plant due to an accident. Upon completion of the present cleanup campaign, the plant will be placed in a monitored storage mode for an indefinite period.

Table 7.2. Projections of cumulative volume, radioactivity, and thermal power of wastes from decommissioning commercial light-water reactors shut down during 1991-2020[a,b,c]

Waste type	Volume (m^3)	Activity (Ci)	Thermal power (W)
Boiling-water reactors			
Class-A LLW	281,238	30,116	246
Class-B LLW	5,667	93,679	773
Class-C LLW	805	304,067	1,261
Subtotals	287,710	427,862	2,280
Greater-than-Class-C LLW[d]	714	7,923,504	33,348
Totals for D&D of BWRs	288,424	8,351,366	35,628
Pressurized-water reactors			
Class-A LLW	540,579	153,029	816
Class-B LLW	6,441	215,552	1,900
Class-C LLW	512	172,789	1,391
Subtotals	547,532	541,370	4,107
Greater-than-Class-C LLW[e]	4,003	23,921,279	187,688
Totals for D&D of PWRs	551,535	24,462,649	191,795
Total light-water reactors			
Total LLW	835,242	969,232	6,387
Greater-than-Class-C LLW	4,717	31,844,783	221,036
Totals for D&D of LWRs	839,959	32,814,015	227,423

[a]The projections of this table are based on a decommissioning scenario which assumes that upon reactor shutdown, there will be a 2-year planning period followed by a 4-year decontamination campaign, with wastes being collected equally over each of the 4 years. In terms of numerical significance, the number of digits used to report these projections is greater than justified. However, this procedure is used for bookkeeping purposes to ensure consistency in the numerical totals reported. Since these projections are based on the reactor shutdown dates reported in ref. 1 and the source terms developed from refs. 3-9 (see Appendix A), each reported number is significant to no more than three figures.

[b]This table refers only to reactors yet to be decommissioned. Historical reactor D&D wastes are included in the institutional/industrial (I/I) waste inventories reported in Chapter 4.

[c]The projections in this table are cumulative levels for year 2026, the last year in which wastes are collected from reactors shut down in year 2020.

[d]Contribution from the core shroud (see refs. 4 and 5).

[e]Contributions from the lower core barrel, thermal shields, lower grid plate, and core shroud (see refs. 7 and 8).

Table 7.3. Projections of wastes from decommissioning of reference commercial fuel cycle facilities and power reactors[a]

Fuel cycle facility	Typical capacity	Number of equivalent 1-GW(e) PWRs annually supported by typical facility[b]	40-year waste generation[c] (m^3)	Decommissioning wastes[d] (m^3)	Relative decommissioning waste volumes[e]
Uranium conversion plant (solvent extraction process)	10,000 MTIHM/year	50	23,800[f]	1,260[f]	0.0016
Uranium enrichment plant (gaseous diffusion process)	8,750,000 kg SWU/year	73	8,000[f]	12,740[f]	0.0112
Fuel fabrication plant	1,000 MTIHM/year	40	98,800[f]	1,090[f]	0.0017
Boiling-water reactor	1 GW(e)	1	15,460[f] 640[g]	16,400[f] 41[g]	1.0540
Pressurized-water reactor	1 GW(e)	1	6,200[f] 150[g]	15,480[f] 113[g]	1.0000

[a]Based on information reported in refs. 3-12. A 40-year operating lifetime is assumed for all facilities.
[b]Assuming a 75% reactor capacity factor and the fuel cycle requirements of Table A.2 in Appendix A.
[c]Packaged LLW volumes generated during a 40-year operating lifetime.
[d]Assumes decommissioning immediately after shutdown.
[e]These relative values are calculated by $\frac{[(\text{total decommissioning waste volume})/(\text{number of PWRs supported})]}{[\text{total decommissioning waste volume of 1-GW(e) PWR}]}$.
[f]Class-A, Class-B, and Class-C LLW.
[g]Greater-than-Class-C LLW.

Table 7.4. List of U.S. civilian reactors shut down or dismantled as of December 31, 1990[a]

[Reactors of 10-MW(th) capacity or greater]

Reactor facility	Location	Reactor type	Capacity rating		Year of shutdown	Decommissioning alternative selected	Present status of decommissioning alternative
			MW(e)	MW(th)			
Boiling Nuclear Superheater Power Station (BONUS)	Punta Higuera, PR	Boiling-water	17	50	1968	ENTOMB	ENTOMB
Carolinas-Virginia Tube Reactor (CVTR)	Parr, SC	Pressure-tube, heavy-water	17	64	1967	SAFSTOR	SAFSTOR
Dresden Nuclear Power Station, Unit 1	Morris, IL	Boiling-water	200	700	1978	SAFSTOR	SAFSTOR preparation[b]
Elk River Power Station	Elk River, MN	Boiling-water	22	58	1968	DECON	DECON completed[c]
Enrico Fermi, Unit 1	Lagoona Beach, MI	Sodium-cooled, fast	61	200	1972	SAFSTOR	SAFSTOR
ESADA/GE Vallecitos Experimental Superheat Reactor (Empire States Atomic Development Associates and General Electric Company)	Pleasanton, CA	Light-water, moderated	NE[d]	17	1967	SAFSTOR	SAFSTOR
Fort St. Vrain Reactor	Platteville, CO	High-temperature, gas-cooled	330	842	1989	TBD[e]	TBD
General Electric Testing Reactor	Pleasanton, CA	Tank	NE	50	1977	SAFSTOR	SAFSTOR
Hallam Nuclear Power Facility	Hallam, NE	Sodium-cooled, graphite-moderated	75	240	1964	ENTOMB	ENTOMB
Humboldt Bay Power Plant, Unit 3	Eureka, CA	Boiling-water	65	242	1976	SAFSTOR	SAFSTOR[f]
Indian Point Station, Unit 1	Buchanan, NY	Pressurized-water	265	615	1974	TBD[g]	TBD
La Crosse Nuclear Generating Station	Genoa, WI	Boiling-water	48	165	1987	SAFSTOR	SAFSTOR[h]
Pathfinder Atomic Plant	Sioux Falls, SD	Boiling-water	66	203	1967	DECON	DECON[i]
Peach Bottom Power Station, Unit 1	Peach Bottom, PA	High-temperature, gas-cooled	40	115	1974	SAFSTOR	SAFSTOR
Piqua Nuclear Power Facility	Piqua, OH	Organic-cooled and moderated	11	46	1966	ENTOMB	ENTOMB

Table 7.4 (continued)

Reactor facility	Location	Reactor type	Capacity rating MW(e)	Capacity rating MW(th)	Year of shutdown	Decommissioning alternative selected	Present status of decommissioning alternative
Plum Brook Reactor	Sandusky, OH	Tank	NE	60	1974	SAFSTOR	SAFSTOR
Rancho Seco	Clay Station, CA	Pressurized-water	918	2,915	1989	SAFSTOR	SAFSTOR preparation[j]
Saxton Nuclear Experimental Reactor Project	Saxton, PA	Pressurized-water	3	24	1972	SAFSTOR	DECON in progress[k]
Shippingport Power Station	Shippingport, PA	Pressurized-water	72	236	1982	DECON	DECON completed[l]
Shoreham Reactor	Brookhaven, NY	Boiling-water	820	2,436	1989	DECON	DECON preparation[m]
Sodium Reactor Experiment	Santa Susana, CA	Sodium-cooled, graphite-moderated	10	30	1964	DECON	DECON completed[n]
Southwest Experimental Fast Oxide Reactor (SEFOR)	Strickler, AR	Sodium-cooled, fast	NE	20	1972	SAFSTOR	SAFSTOR
Three Mile Island-Unit 2 Reactor	Londonderry Township, PA	Pressurized-water	926	2,770	1979	o	o
Vallecitos Boiling-Water Reactor (VBWR)	Pleasanton, CA	Boiling-water	5	33	1963	SAFSTOR	SAFSTOR
Westinghouse Testing Reactor (WTR)	Waltz Mill, PA	Tank	NE	60	1962	SAFSTOR	SAFSTOR

[a]Based on refs. 2 and 17.
[b]Estimates of decommissioning wastes are reported in Table 7.11.
[c]Decommissioning wastes are reported in Table 7.5.
[d]NE = no electricity generated by reactor before it was shut down.
[e]TBD = to be determined. Decommissioning wastes for the DECON option are reported in Table 7.17.
[f]Estimates of decommissioning wastes are reported in Table 7.14.
[g]Indian Point Unit 1 has been placed in a mothballed state (a mode of SAFSTOR). Presently, this reactor's condition is being reviewed for approval by the NRC.
[h]Estimates of decommissioning wastes are reported in Table 7.12.
[i]Estimates of decommissioning wastes are reported in Table 7.19.
[j]Decommissioning wastes are reported in Table 7.16.
[k]DECON of the Saxton facility started in 1986. Estimates of decommissioning wastes are given in Table 7.13.
[l]Decommissioning wastes are reported in Table 7.8.
[m]A proposed decommissioning plan on the Shoreham reactor is undergoing review by the NRC. Estimates of decommissioning wastes are reported in Table 7.20.
[n]Decommissioning wastes are reported in Table 7.6.
[o]TMI-Unit 2 has completed defueling and decontamination in selected areas. The plant is being placed in a monitored storage mode for an indefinite period. Inventories of decontamination wastes are reported in Table 7.10.

Table 7.5. Types and quantities of wastes from decommissioning the Elk River reactor site[a,b]

Reactor component or waste type[c]	Volume (m^3)	Mass (t)	Radioactivity[d] (Ci)
Reactor pressure vessel	4.6	36.0	1,110
Reactor internals			
Upper shroud	e	e	770
Lower shroud	e	e	35
Core and shroud plate	e	e	2,370
Core support stand	e	e	100
Inner thermal shield	e	e	3,090
Shadow shields	e	e	2,330
Feedwater distribution ring	e	e	75
Subtotals (internals)	1.1	8.1	8,770
Externals	5.3	54.0	440[f]
Biological shield	5.9	39.0	5.8
Miscellaneous radioactive contaminated materials (excluding concrete)	1,350	1,090	e
Contaminated concrete	2,010	2,680	e
Totals	3,377	3,907	>10,325

[a]Based on information reported in COO-651-93 (ref. 22), BNL-NUREG-29244R (ref. 23), and ref. 24.

[b]The Elk River BWR operated from 1963 to 1968 and generated 58.29 MW(e)-years of (gross) electrical energy. The plant was decommissioned from 1971 to 1974. During this time, the reactor was completely dismantled.

[c]All decommissioning wastes were shipped to Sheffield, Illinois.

[d]Estimated at the start of decommissioning.

[e]Information not available.

[f]Includes 75 Ci estimated for the outer thermal shield of the reactor.

Table 7.6. Types and volumes of wastes from decommissioning the Santa Susana Sodium Reactor Experiment site[a,b]

Type of waste[c]	Shipping container volume, m^3					
	King-Pac[d]	Boxes[e]	Casks	Drums	Unboxed	Totals
Activated vessel components		301	20		18	339
Contaminated components		1,458	49	29	17	1,553
Contaminated soil and concrete	1,752			42		1,794
Absorbed alcohol and other solidified liquids				141		141
Disposed liquid				36		36
Totals	1,752	1,759	69	248	35	3,863

[a]Based on information reported in ESG-DOE-13403 (ref. 25). Activity data were not available.

[b]This sodium-cooled, graphite-moderated reactor operated from 1957 to 1964 and generated 4.244 MW(e)-years of (gross) electrical energy. The plant was decommissioned from 1974 to 1983. During this time, the reactor was completely dismantled.

[c]Initially, these wastes were shipped to Beatty, Nevada. Later in the decommissioning program, they were shipped to Hanford, Washington.

[d]This is a registered trademark for tri-walled cardboard containers used for packaging low-specific-activity nonmetallic wastes (e.g., contaminated soil, bedrock, and concrete rubble).

[e]Wooden boxes used for packaging low-specific-activity wood or steel.

Table 7.7. Estimated volumes and activities of wastes from decommissioning alternatives considered for reference LWRs[a,b]

Decommissioning alternative	Totals		Class-A LLW		Class-B LLW		Class-C LLW		Exceeds Class-C LLW limits	
	Volume (m^3)	Activity (10^3 Ci)	Volume (m^3)	Activity (10^3 Ci)	Volume (m^3)	Activity (10^3 Ci)	Volume (m^3)	Activity (10^3 Ci)	Volume (m^3)	Activity (10^3 Ci)
Reference boiling-water reactor [1,155 MW(e)]										
Immediate decontamination following shutdown	18,985	6,595.8	18,512	13.9	373	42.8	53	239.1	47[c]	6,300.0
Deferred decontamination after a safe storage period of:										
30 years[d]	18,985	180.4	18,652	1.4	233	1.1	53	6.5	47[c]	171.4
50 years[d]	1,783	141.4	1,450	0.2	247	1.0	39	4.7	47[c]	135.5
100 years[d]	1,673	97.2	1,340	0.1	247	0.6	39	3.3	47[c]	93.2
Entombment[e]	8,078	6,586.6	7,605	4.7	373	42.8	53	239.1	47[c]	6,300.0
Reference pressurized-water reactor [1,175 MW(e)]										
Immediate decontamination following shutdown	18,325	4,906.2	17,961	37.3	214	53.1	17	34.3	133[f]	4,781.5
Deferred decontamination after a safe storage period of:										
30 years[d]	18,328	209.1	18,055	1.5	123	0.6	17	1.5	133[f]	205.5
50 years[d]	1,833	159.4	1,568	0.3	115	0.2	17	1.1	133[f]	157.8
100 years[d]	1,783	106.2	1,533	0.2	100	<0.1	17	0.8	133[f]	105.2
Entombment[e]	3,500	4,908.0	3,136	39.1	214	53.1	17	34.3	133[f]	4,781.5

[a]From refs. 4-9. Activities were calculated from data reported in refs. 4-9. Data for each reactor are based on 40 years of operation and a capacity factor of 0.75.

[b]Based on limiting concentration of long- and short-lived radionuclides given in Tables 1 and 2 of 10 CFR 61.55.

[c]Contribution from the core shroud (see refs. 4 and 5).

[d]Includes radioactive wastes from both preparations for safe storage and deferred decontamination.

[e]Involves the removal of reactor spent fuel (shipped to repository) followed by the encasement of the rest of the radioactive portion of the reactor facility.

[f]Contributions from the lower core barrel, thermal shields, lower grid plate, and core shroud (see refs. 7 and 8).

Table 7.8. Characteristics of wastes from decommissioning activities at the Shippingport Station Decommissioning Project[a,b]

Type of waste	Total waste removed from the Shippingport reactor facility		
	Volume (m^3)	Mass (kg)	Activity (Ci)
Liquid	2,187	INA[c]	0.64
Solid[d]			
Reactor pressure vessel package	283	815,560	16,467
Spent resins	101	56,429	40.82
Asbestos	1,072	138,205	2.49
Compacted trash	24	12,412	0.04
Metallic waste	1,801	1,117,113	41.59
Large, one-piece components	326	455,230	24.27
Concrete	52	52,470	0.08
Lead	57	62,302	0.17
Soil	53	31,493	1.44
Solidified sludge	164	198,066	4.30
Other solids	2,123	833,976	26.54
Total solid waste	6,056	3,773,256	16,608.75

[a]Based on ref. 27.

[b]The Shippingport reactor operated from 1957 to 1982, generating 841.8 MW(e)-years of (gross) electrical energy. During its history, the reactor operated with three different cores. Two of these were light-water cooled, seed-blanket, PWR-type cores. The third and last core in the reactor was a seed-blanket LWBR-type. Physical dismantling began in September 1985 and was completed in July 1989.

[c]INA = information not available.

[d]Solid waste volume and mass include total volume and total mass as packaged.

Table 7.9. Inventories and projections of wastes from various activities at the West Valley Demonstration Project[a,b]

Waste description	Total wastes as of December 31, 1990	Projected total wastes upon completion of the project[c]
Spent fuel remaining[d]		
Mass, MTIHM	27	27
Number of fuel assemblies	125	125
High-level waste generated from reprocessing operations (1966-1972)[e]		
Volume, m^3 (waste form)	1,231 (liquid, sludge, and zeolite)	210 (glass)
Activity, Ci[f]	27,250,000	23,590,000[g]
Transuranic waste generated from presolidification activities and HLW vitrification		
Volume, m^3	42	300
Activity, Ci[f]	66	350
Low-level waste generated from presolidification activities and HLW vitrification		
Buried waste (1982-86) volume, m^3	5,786	15,000
Buried waste (1982-86) activity, Ci[f]	625	58,600
Stored waste volume, m^3	5,400[h]	
Stored waste activity, Ci[f]	433[i]	
Low-level waste incorporated in cement by radwaste treatment system[j]		
Stored waste volume, m^3	3,002	
Stored waste activity, Ci[f]	295	
Low-level waste from post-solidification D&D after HLW vitrification		
Volume, m^3	0	4,300
Activity, Ci[f]	0	1,400
Total low-level summary (buried and stored wastes)		
Volume, m^3	14,188	
Activity, Ci[f]	1,353	

[a]Based on data reported in ref. 28.

[b]At the West Valley Demonstration Project (WVDP) site, Nuclear Fuel Services, Inc., operated a reprocessing plant with a rated capacity of 300 MTIHM/year. During its operation from 1966 to 1972, 640 t of spent fuel were reprocessed.

[c]Wastes generated after 1987 are regarded as stored, not buried or disposed.

[d]At the end of 1990, 125 fuel assemblies (representing 27 t of spent fuel) still remained in storage at the WVDP. These assemblies are owned by DOE. The return shipment of all commercially owned spent fuel (625 fuel assemblies) to the owner utilities was completed by the end of 1986.

[e]Currently, about 2,031 m^3 of HLW is stored at the WVDP site in two underground steel tanks. Eventually, this waste will be vitrified and about 300 canisters of glass will be produced. This assumes each canister contains 0.70 m^3 of glass.

[f]Principal nuclides include ^{241}Am, ^{241}Pu, ^{137}Cs, ^{99}Tc, ^{90}Sr, and ^{63}Ni.

[g]Decayed activity for 1997.

[h]Comprised of Class A (89.5%), Class B (8.5%), and Class C (2.0%) LLW.

[i]Comprised of Class A (24.7%), Class B (64.1%), and Class C (11.2%) LLW.

[j]Comprised of Class A and Class C LLW (see Table A.10 of Appendix A).

Table 7.10. Characteristics of wastes from decontamination activities at the Three Mile Island-Unit 2 reactor site[a,b]

Type of waste	Mass shipped (t)	Total waste shipped from TMI (August 1979 through December 1989)	
		Packaged volume (m^3)	Shipment activity[c] (Ci)
Spent fuel/core debris[d]	155.9	123.9	6,911,513
Low-level and other wastes[e]			
Dry activated waste (DAW)[f]	-	5,562.1	698.8
Wet and solidified waste[g]	-	272.6	7,414.1
Submerged demineralizer system (SDS)[h]	-	56.02	673,876.7
EPICOR II system liners[i]			
First generation	-	125.7	77,750
Second generation	-	743.2	3,642.6
Defueling water cleanup system (DWCS)[j]	-	8.45	5,886.3
Off-site deconable scrap	-	138.9	4
Totals	155.9	7,030.9	7,680,785.5

[a]Three Mile Island (TMI)-Unit 2 is a PWR reactor with the following characteristics: rated capacity – 926 MW(e); mass of fuel in core before accident – 82 MTIHM; and number of fuel assemblies before accident – 177. The reactor began operation in 1978 and generated 231.6 MW(e)-years of (gross) electrical energy before being permanently shut down by an accident in March 1979.

[b]Based on information reported in ref. 29.

[c]These activities represent the cumulative sum of curies reported at the time of waste shipment. The values reported are not corrected for decay after the time of shipment.

[d]Defueling of the reactor started in January 1986.

[e]Other wastes include those regarded as "abnormal" because their classification is presently uncertain.

[f]Dry activated wastes are dry wastes packaged in drums, boxes, and high-integrity containers.

[g]Includes solidified miscellaneous liquids and miscellaneous resin liners and filters from TMI-Unit 2 systems.

[h]Resin liners and filters from the SDS (for water treatment).

[i]Resin liners and filters from the EPICOR II system that use organic ion-exchange resins and inorganic zeolite media. These include processing high-integrity containers (HICs).

[j]Resin liners and filters from the DWCS that use inorganic zeolite media. These are primarily processing HICs.

Table 7.11. Projected characteristics of radioactive wastes from Dresden Unit 1 decommissioning activities[a,b,c]

Waste category	Reactor component(s)	Volume (m^3)
Radioactive materials	Reactor vessel and internals:[d]	
	Reactor vessel	11
	Bioshield sand and concrete	239
	Thermal shield	2
	Instrumentation support tubes	1
	Bottom core support structure	1
	Other[e]	5
	Subtotal	259
	Solidified decontamination solvents	655
	Reactor station components and materials[f]	6,214
	Total	7,128
Radioactive hazardous materials	Asbestos insulation on contaminated piping and components	409
	Grand total	7,537

[a]Based on refs. 30 and 31.

[b]The 200-MW(e) Dresden BWR began operation in 1960 and generated about 1,800 MW(e)-years of (gross) electrical energy before it was shut down in 1978. The projections of this table pertain to wastes from the dismantlement of the reactor following a SAFSTOR period of about 30 years.

[c]These projections do not include 32 m^3 of LLW from SAFSTOR preparation activities (e.g., materials from cleaning spent fuel pool surfaces, miscellaneous sumps, and other contaminated areas; filters from chemical cleaning system; and miscellaneous dry active trash).

[d]The greatest source of radioactivity in the Dresden containment building is in the reactor vessel and internals. This activity results from neutron activation products in the vessel and shield materials. Reference 28 reports an estimated activity of 4,029,000 Ci for the vessel and internals when the reactor was shut down in 1978. By the year 2017, when dismantling of the reactor is to begin, this activity is projected to drop to a level of about 16,000 Ci.

[e]Other reactor internal components include steam deflector support, top grid assembly, bottom support grid, control rod guide tubes, and reactor vessel cladding.

[f]Reactor station components and materials include piping, valves, pumps, heat exchangers, building concrete, and structural steel.

Table 7.12. Inventories and projections of low-level radioactive wastes from La Crosse BWR decommissioning activities[a,b]

Calendar year(s)	Decommissioning mode	Average annual quantity of waste shipped from reactor site[c,d]	
		Volume (m^3/year)	Activity (Ci/year)
1988	SAFSTOR	4.62	70.3
1989[e]	SAFSTOR	6.74	32.12
1990[e]	SAFSTOR	4.59	0.74
1991-1993	SAFSTOR	9.7	20
1994-1998	SAFSTOR	7.0	23
1999-2003	SAFSTOR	6.5	13
2004-2008	SAFSTOR	4.9	7
2009-2013	SAFSTOR	3.6	5
2014-2018	DECON	103.0	>280

[a]Based on the information reported in ref. 32.

[b]The 48-MW(e) La Crosse BWR began operation in 1968 and generated 462 MW(e)-years of (gross) electrical energy until it was shut down in April 1987. The reactor was placed in SAFSTOR in 1988. The data in this table are based on a SAFSTOR period of 25 years.

[c]During the SAFSTOR period, the principal types of radioactive solid waste which will be processed and shipped to a suitable disposal facility will be low-level radioactive wastes principally with radioactivity content less than Class C (10 CFR 61) wastes. These wastes will include (1) dry active wastes (DAW), normally Class A, unstable; (2) dewatered spent demineralizer resins and filtration media, normally Class A or B, stable; and (3) contaminated or irradiated plant system components, normally Class B or C, stable.

[d]Contributions from activated core components and structural materials are not included. Volume estimates of these materials are currently not available; however, a preliminary activity estimate of 12,620 Ci has been made for these activated materials for year 2014, when the reactor will be ready for dismantlement.

[e]Waste shipments for this year contained DAW and contaminated metal, which were either decontaminated, supercompacted, or both by two Oak Ridge waste treatment companies (Quadrex Recycle Center and SEG).

Table 7.13. Projected volumes of wastes from Saxton PWR decommissioning activities[a,b,c]

Reactor component(s)/waste	Volume (m^3)
Reactor vessel, head, and internals	39.64
Pressurizer	3.12
Primary coolant pump	2.83
Steam generator	24.07
Demineralizers	4.25
Shutdown cooling pumps	0.85
Relief valve discharge tank	4.25
Purification system surge tank	9.91
Safety injection pumps	1.42
Cooling heat exchanger	16.99
Containment vessel sump pumps	0.85
Discharge tank drain pumps	0.85
Containment ventilation equipment	16.99
Primary piping	5.66
Auxiliary system piping and valves	28.32
Contaminated and activated concrete of containment vessel	229.37
General valves, controllers, and instrumentation	42.48
Low-level waste from disposal operations	33.98
Westinghouse supercritical test loop	42.48
Total volume	508.31

[a]Based on the information reported in ref. 33.

[b]The 3-MW(e) Saxton PWR was shut down in 1972 and placed in SAFSTOR. Work on dismantling the reactor site started in 1986. This facility operated from 1962 until 1971, generating 10.4 MW(e)-years of (gross) electrical energy.

[c]Activity data are unknown at this time. Saxton reactor decommissioning waste characteristics are still being reviewed, and additional information will be provided in this table in future reports.

Table 7.14. Projected volumes of radioactive wastes from SAFSTOR (mothballing/delayed dismantling) of Humboldt Bay Unit 3[a,b,c]

D&D activity/reactor component	Volume (m^3)
Spent fuel racks	63
Nuclear steam supply system removal	
Reactor vessel	67[d]
Reactor vessel internals	27[e]
Other components	17
Removal of major equipment	
Main turbine/generator	353
Main condensers	164
Asbestos removal	307
Disposal of contaminated plant systems	
Turbine system	437
Electrical system	386
High-pressure steam and feedwater systems	333
Condensate system	226
Radwaste collection and treatment systems	298
Other systems	449
Decontamination of site buildings	
Refueling	416
Other	30
Disposal of contaminated solid waste	149
Process liquid waste	105
Total	3,827

[a]Based on the information reported in ref. 34.

[b]The 65-MW(e) Humboldt Bay Unit 3 BWR operated from 1963 until 1976, generating 545 MW(e)-years of (net) electrical energy. The plant was placed in a SAFSTOR mode in 1985. The projections in this table and in ref. 34 assume delayed dismantling of the reactor begins in 2015, after the current inventory of spent fuel at the site has been shipped to a federal repository.

[c]Except where noted, the volumes reported represent estimates for packaged Class A LLW.

[d]Includes 48 m^3 of Class C LLW.

[e]Includes 23 m^3 of Class C LLW and 4 m^3 of GTCC waste.

Table 7.15. Projected volumes of radioactive wastes from DECON (prompt removal/dismantling) of Diablo Canyon Power Plant Units 1 and 2[a,b,c]

D&D activity/reactor component	Volume, m^3	
	Unit 1	Unit 2
Spent fuel racks	440	440
Nuclear steam supply system removal		
Steam generators	1,911	1,912
Reactor vessel	256[d]	256[d]
Reactor vessel internals	300[e]	284[f]
Other components	448	448
Disposal of plant systems		
Electrical (contaminated) system	4,120	3,890
Other systems	2,476	1,991
Decontamination of site buildings		
Fuel handling	96	96
Containment and penetration area	958	958
Other	~1	158
Disposal of contaminated solid waste	2,755	2,816
Process liquid waste	586	554
Total	14,347	13,803

[a]Based on information reported in ref. 34. This reference recommends the DECON option on the basis of technical and financial considerations. Projections for the SAFSTOR and ENTOMB decommissioning options are also reported in ref. 34.

[b]Commercial operation of the Diablo Canyon units began in May 1985 for Unit 1 and in March 1986 for Unit 2. For the study of ref. 34, shutdown dates of these reactors are taken as 30 years following their startup dates.

[c]Except where noted, the volumes reported represent estimates for packaged Class A LLW.

[d]Includes 130 m^3 of Class C LLW.

[e]Includes 144 m^3 of Class C LLW and 156 m^3 of GTCC waste.

[f]Includes 128 m^3 of Class C LLW and 156 m^3 of GTCC waste.

[g]Includes wastes from auxiliary and radwaste storage buildings.

Table 7.16. Projected volumes of wastes from Rancho Seco PWR decommissioning activities[a,b,c]

Reactor component(s)/waste	Volume (m^3)
Spent fuel racks	359
Reactor vessel	212
Reactor vessel internals	156
Primary system components and piping	1,336
Total for reactor vessel and components	2,063
Secondary and radwaste systems	2,625
Contaminated structures	468
Processed liquid waste	98
Dry active waste	397
Grand total	5,651

[a]Based on ref. 35 (extracted from a 1991 decommissioning cost study prepared by TLG Engineering, Inc.).

[b]The 918-MW(e) Rancho Seco (Unit 1) PWR was shut down in 1989. The reactor operated from 1974 until 1989, generating 5,277.3 MW(e)-years of (gross) electrical energy.

[c]The projections in this table pertain to wastes from dismantlement of the reactor following a SAFSTOR period of about 20 years.

Table 7.17. Projected characteristics of wastes from DECON (dismantling) of the Fort St. Vrain HTGR[a,b]

Reactor component(s)/waste	Burial volume (m^3)	Projected LLW class
Prestressed concrete reactor vessel (PCRV) system		
PCRV concrete	1,174.94	A
Control rod drives (CRDs)	97.81	A
CRD absorber strings	18.81	C
CRD metal clad reflector	4.04	C
Boronated stainless steel rods	845.27	B
Top cover plates	1.59	A
Top head kaowool[c] and liner	13.32	A
Core barrel	21.97	A
Core support blocks	41.09	A
Core support floor kaowool, plates, and liner	6.94	A
Metal clad reflector blocks (non-CRD)	28.67	C
Dummy fuel blocks	168.28	A
Graphite reflector blocks	237.65	A, B
Silica insulation blocks	14.27	A
Large permeable reflectors	709.32	B
Reflector keys	0.57	A
Metal shell for large side reflector	0.58	A
Radial cover plate, kaowool, and PCRV liner	55.57	A
Region constraint devices	1.42	C
Helium purification and regeneration system	30.87	A
Helium circulators	4.01	A
Steam generators	269.02	A, B
PCRV system total	3,746.01	
Material handling, treatment, and storage (MHTS) systems		
Fuel handling machine	63.33	A
Fuel storage wells	28.48	A
Equipment storage wells	2.98	A
Auxiliary transfer cask	19.52	A
Hot service facility	10.98	A
MHTS systems total	125.29	
Decontamination and waste (DW) systems		
Decontamination system	9.57	A
Radioactive liquid waste	9.15	A
Radioactive gas waste	32.93	A
Dry activated and other wastes	153.34	A
DW systems total	204.99	
Fort St. Vrain HTGR total	4,076.29	

[a]Based on refs. 36 and 37. The case considered involves complete dismantlement of all radioactive systems at the reactor site after defueling of the reactor has been completed.

[b]The 330-MW(e) Fort St. Vrain HTGR operated from 1979 until 1989, generating about 490 MW(e)-years of (gross) electrical energy.

[c]Kaowool is an insulation material.

Table 7.18. Projected volumes of radioactive wastes from DECON (prompt removal/dismantling) of the Peach Bottom reactors[a]

Reactor [type, net MW(e)] and waste type	Projected LLW class	Disposal volume (m^3)
Peach Bottom, Unit 2 [BWR, 1065]		
LLW	A	23,980
LLW	C	504
LLW	GTCC	169
Subtotal		24,653
Peach Bottom, Unit 3 [BWR, 1065]		
LLW	A	24,913
LLW	C	504
LLW	GTCC	169
Subtotal		25,586
Total		50,239

[a]Peach Bottom data were adapted from ref. 39.

Table 7.19. Characteristics of radioactive wastes associated with decommissioning the Pathfinder reactor[a,b]

Reactor component(s)/waste	Volume (m^3)	Mass (t)	Activity (Ci)
Reactor vessel[c]	113	250	562
Bioshield	95[d]	150[d]	Unknown
Recirculation pumps and motors (3)	71	56	0.018
Contaminated concrete	60[d]	90[d]	Unknown
Dry active waste[e]	420[d]	450[d]	0.250[d]
Liquids	0	0	0
Asbestos	20[f]	17	0.0001
Total	779	1,013	563

[a]Based on ref. 40.
[b]All material is low-specific-activity LLW.
[c]Includes reactor pressure vessel, internal components, control rod drive blades, gravel, and grout.
[d]Estimated value.
[e]Includes piping, valves, conduit, cable, sand, wire, steel, shield blocks, grating, lights, and filters.
[f]Originally about 96 m^3 of asbestos was removed during D&D. Later this material was reduced in volume to 20 m^3.

Table 7.20. Projected characteristics of wastes from Shoreham BWR decommissioning activities[a,b]

(All wastes are projected to be LLW Class A)

Reactor component(s)/waste	Burial volume (m^3)	Activity[c,d] (Ci)
Reactor pressure vessel (RPV) and internals	467	6.01E+2
Reactor recirculation system	170	2.45E-4
Control rod drive system	14[e]	3.00E-4
Residual heat removal system	428	4.30E-4
Core spray system	45	7.19E-4
Reactor water cleanup system	260	6.16E-4
Fuel pool cleanup system	71	7.86E-4
Condensate and demineralizer system	57	2.62E-5
Process sampling system	9	2.29E-5
Spent fuel rack and accessories	235	5.65E-4
Process and dry activated wastes	218	f
Demineralizer system and resins/filters	91	f
Liquid radwaste system	170	1.60E-4
Mirror insulation	11	f
Total	2,246	6.01E+2

[a]Based on the Shoreham Nuclear Power Station Decommissioning Plan (ref. 41).

[b]The 820-MW(e) Shoreham BWR underwent low-power tests until 1989, when the Long Island Lighting Company agreed to sell the plant to the state of New York for decommissioning. A total of 865 MW(e)-hours of (gross) electrical energy were generated during the low power tests.

[c]Activity levels are as of March-April 1990, except for the RPV and internals, which reflect levels as of July 1990.

[d]The isotopic composition of Shoreham's anticipated wastes is assumed to be represented by two radionuclides: ^{60}Co (comprising one-third of the total activity) and ^{55}Fe (comprising the remaining two-thirds of the total activity).

[e]Excludes control blades and control rod drives.

[f]Negligible.

Table 7.21. Characteristics of wastes from decommissioning activities at the Cimarron Fuel Fabrication Facility[a]

Project area	Type of waste	Total waste removed from Cimarron through December 1990[b]		Projected waste volume remaining[c] (m^3)
		Volume (m^3)	Activity (Ci)	
Burial ground	LLW (LSA)[d]	1,833.10	5.37	0
Mixed oxide fuel plant	TRU	255.89	10.87	0
	LLW (LSA)	463.88	3.25	0
Uranium fuel plant	LLW (LSA)	2,158.62	3.63	500
Liquid process waste evaporation ponds				
a. Mixed oxide plant pond	LLW (LSA)	104.30	0.000009	0
b. Uranium plant pond	LLW (LSA)	183.73	0.23	0
Sanitary lagoons	LLW (LSA)	1,559.26	2.93	0
Project totals	TRU	255.89	10.87	0
	LLW (LSA)	6,302.89	15.41	500
Total waste		6,558.78	26.28	500

[a]Based on the information provided in ref. 42.
[b]The LLW inventories are included in the commercial disposal site inventories of Chapter 4.
[c]Decontamination work is scheduled to be completed during 1991. More than 95% of the estimated decontamination requirement has been completed.
[d]LSA = low-specific-activity waste.

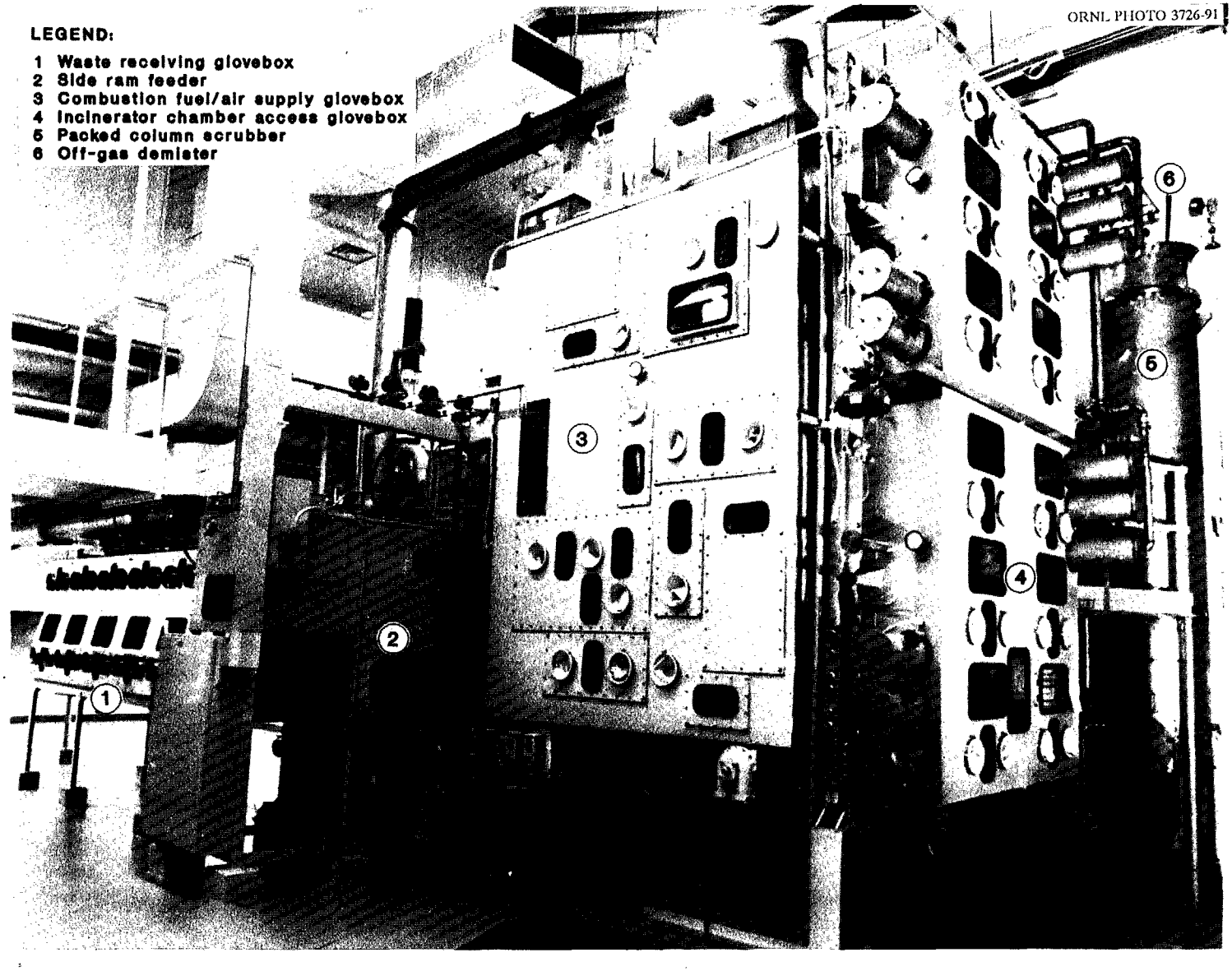


Photo 8.1. The Controlled Air Incinerator at Los Alamos National Laboratory, which is used to treat both radioactive and mixed waste. (Courtesy of the Los Alamos National Laboratory, Los Alamos, New Mexico, and the Hazardous Waste Remedial Actions Program, Oak Ridge, Tennessee.)

8. MIXED LOW-LEVEL WASTE

8.1 INTRODUCTION

This chapter reports estimated inventories and generation rates of mixed LLW from DOE site and commercial operations. Mixed LLW includes mixtures of low-level radioactive materials and (chemically and/or physically) hazardous wastes. Mixed high-level and TRU wastes are not included in this chapter but are included in the HLW and TRU waste inventories and projections of Chapters 2 and 3, respectively. This report does not consider the chemically hazardous features of mixed HLW or TRU wastes. Their dominating radioactive characteristics alone dictate the methods by which these materials need to be treated, handled, stored, and disposed. The radioactive components of mixed wastes are subject to the Atomic Energy Act (AEA), as amended,[1] which, for government sources, is administered by DOE, and, for commercial sources, by NRC (unless a state has obtained agreement state status). The hazardous components of all mixed wastes are subject to two federal statutes that are administered by the Environmental Protection Agency (EPA) (unless a state has obtained an authorization status). They are (1) the Resource Conservation and Recovery Act (RCRA), as amended,[2] and (2) the Toxic Substances Control Act (TSCA).[3] Thus, the treatment, handling, and disposal of mixed wastes are subject to the regulations of the EPA[4] and NRC (or the authorized and agreement states), or DOE. Table 8.1 (data from refs. 5 and 6) lists those states and territories designated by EPA as having mixed waste authorization.

In this report, mixed LLW is considered separately from the purely radioactive LLW discussed in Chapter 4. The information provided in the tables of this chapter is preliminary in nature and pertains only to hazardous wastes regulated by RCRA and polychlorinated biphenyls (PCBs) regulated by TSCA. Unless otherwise noted, the inventories and projections reported for mixed LLW are separate from those reported for radioactive LLW in Chapter 4. Inventories of mixed LLW presently stored at DOE sites are in the process of being thoroughly characterized. As a result, the waste at some sites could require reclassification, thereby causing significant changes in the inventories currently reported.

Typically, mixed LLW at DOE sites includes a variety of contaminated materials, such as air filters, cleaning solutions and cleanup materials, engine oils and grease, epoxies and resins, laser dyes, paint residues, photographic materials, soils, asphalt, roofing compounds and wall materials, water treatment chemicals, and decommissioned weapons manufacturing equipment.[7] To support the DOE Office of Environmental Restoration and Waste Management, the Hazardous Waste Remedial Actions Program (HAZWRAP) has developed the Waste Management Information System (WMIS), a data base containing treatment, storage, and disposal (T/S/D) unit capabilities and waste stream characteristics at DOE sites. Presently, WMIS contains mixed waste T/S/D units and waste streams. Information on hazardous, polychlorinated biphenyl (PCB), and radioactive T/S/D unit capabilities and waste stream characterization is scheduled to be available on WMIS in early FY 1992.

8.2 WASTE CHARACTERIZATION

Currently, generic characterization of mixed wastes is difficult for several reasons: (1) such wastes have different blends of hazardous (chemical and/or physical) and radioactive components that dictate precautionary measures, (2) several processes may be involved in generating these wastes, (3) various methods are used to prepare these wastes for storage, and (4) EPA has recently adopted new toxic characterization leaching procedures. Representative data on the chemical and radionuclide compositions of mixed wastes will be reported as more detailed site information is available.

In this chapter, inventories and annual generation rates of mixed LLW are expressed in terms of physical and chemical categories. Physical properties are classified in four categories: solid, liquid, gas, and sludge. Chemical properties are classified according to six categories defined by RCRA and TSCA.

8.3 DOE SITE INVENTORIES AND GENERATION RATES

Cumulative mass inventories and generation rates are reported in this chapter for most of the DOE sites listed in Table D.1 of Appendix D. The DOE site inventories and

generation rates reported are based on information compiled and processed by HAZWRAP (ref. 8). The levels reported do not reflect any treatment that may take place before interim storage. Thus, some generation rates may vary from current inventory additions. DOE site inventories and generation rates are given in both mass (kg) and volume (m^3) units. Until recently, many DOE sites tracked and reported their mixed waste streams in mass units. However, for disposal considerations, DOE is requiring these sites to report their mixed waste inventories and generation rates in units of disposal volume. A breakdown of DOE site mixed LLW inventories and generation rates by various physical categories is provided in Tables 8.2–8.5.

Chemical properties of mixed LLW are described by the following six categories of waste types: PCB, listed, ignitable, reactive, corrosive, and TCLP/EP (toxicity characteristic leaching procedure/extraction procedure) toxic. Table 8.6 (based on refs. 3, 9, and 10) gives a detailed description of the waste characteristics associated with each of the chemical categories. Tables 8.7 through 8.10 report DOE site mixed LLW inventories and generation rates for these categories. The columns in Tables 8.7 through 8.10 are ordered according to the potential hazard presented to humans and the environment, with PCBs accounting for the greatest hazard and TCLP/EP the least hazard. This ordering also reflects considerations given to waste handling. The methodology used in preparing Tables 8.7 through 8.10 assumes that if a waste stream composition falls into more than one category, then its inventory and generation rates are included in the most severe category. (For example, a waste stream containing both PCBs and corrosives would be included in the PCB column.)

A breakdown of the mixed LLW volume inventory by site is graphically described in Fig. 8.1, and a breakdown of the volume generation level by site is shown in Fig. 8.2. The current total volume inventory of mixed LLW at DOE sites is 106,800 m^3, most of which is located at seven sites (Hanford, INEL, K-25, Portsmouth, Rocky Flats, SRS, and Y-12). During 1990, about 22,160 m^3 of mixed LLW was generated at DOE sites. Tables 8.11 and 8.12 report projected mass and volume generation rates, respectively, of mixed LLW at DOE sites. Data reported in these tables are based on information currently available from HAZWRAP (ref. 8).

8.4 COMMERCIAL MIXED LOW-LEVEL WASTES

Recent projections of commercial mixed LLW are given in Table 8.13. These estimates are based on recently submitted State Governor's Certifications (reported in ref. 11), which are required by the 1985 LLRWPAA, discussed in Chapter 4. Presently, the NRC and EPA are cosponsoring a survey study to compile a national profile of the volumes, characteristics, and treatability of commercially generated mixed low-level wastes. Such a profile will serve to assist state and compact officials, federal agencies, and private developers in the planning and development of mixed waste treatment, storage, and disposal facilities. Results documented from this investigation will be issued next year and summarized in future updates of this report.

Several past studies (refs. 12–15) have been made to identify the types, sources, volumes, and radioactivity of mixed LLW generated from commercial facilities. The most notable of these investigations is a study (ref. 15) performed by the Rogers and Associates Engineering Corporation for the Office of Technology Assessment (OTA). For this study, the total community of commercial mixed LLW generators was divided into three groups: (1) industrial facilities (including pharmaceutical manufacturing, biotechnology manufacturing, spent fuel storage, and waste processing facilities); (2) medical/academic institutions; and (3) nuclear power (LWR) plants. As a result of examining various source studies and performing surveys and interviews, the OTA study identified 12 categories of mixed LLW from these commercial facilities, institutions, and plants:

- Liquid scintillation cocktails or fluids from laboratory counting activities.
- Organic chemicals, including residues from research and manufacturing activities, spent reagents from experiments, residues from cleaning laboratory and process equipment, and expired products.
- Trash with organic chemicals, including used research equipment.
- Lead, including residues and contaminated materials.
- Lead solutions from lead shielding decontamination.
- Waste oil from contaminated equipment, systems, and work areas.
- Trash with oil from radioactive systems and work areas.
- Chlorinated fluorocarbon (CFC) solvents.
- CFC concentrates from laundry and tool decontamination.
- Aqueous corrosive liquids from cleaning spent fuel casks and resin filters.
- Chromate wastes from resin changeouts in LWRs.
- Cadmium wastes from spent LWR equipment and cleanup activities, including spent welding rods, weld cleaning, and equipment decontamination.

A summary of estimated annual generation characteristics of these wastes was determined in the OTA study for each of the three commercial groups investigated, and these are given in Tables 8.14–8.16. The OTA study emphasizes that, while its investigation was useful in identifying the types of commercial mixed LLW and associated management practices, it was not able to accurately determine how much of this waste is generated nationwide. Table 8.14 reports the OTA summary for mixed LLW from 35 industrial facilities (out of a potential

total of 563). OTA study results for mixed LLW from 39 medical/academic facilities (out of a potential total of 744) are given in Table 8.15. Summary generation characteristics of mixed LLW from 42 commercial LWRs (out of a total of 76) are reported in Table 8.16.

Last year, the Nuclear Management and Resources Council (NUMARC) completed a study (ref. 16) of mixed wastes in the commercial nuclear power industry. This investigation developed estimates of generation and disposal rates for mixed wastes from LWR operations (summarized in Table 8.17). Two case estimates were developed for the NUMARC study, one based on a set of conservative assumptions and the other based on reasonable changes made to those assumptions. The "reasonable assumptions" case indicates a lower bound LWR mixed waste generation rate of 82 m^3/year and a disposal rate of 21 m^3/year. These "reasonable assumptions" are based on the following:

- It is possible to segregate wastes containing certain hazardous (EPA code F003) spent solvents from other spent solvents.
- Characteristically hazardous wastes can be processed to render them nonhazardous.
- Procedures can be implemented to minimize radiological contamination.
- Cadmium content in welds and weld rods may be shown to not exhibit the TCLP/EP toxicity characteristics.
- Explicit account can be made of the timing of mixed waste generated on an infrequent basis.
- Scintillation cocktails may be shown to not exhibit the ignitability characteristic.
- Chromate-bearing ion-exchange resins may be shown to not exhibit the TCLP/EP toxicity characteristic.
- Decontamination resins may be shown to not exhibit the corrosivity characteristic.
- Individual plants may have design and operating features which do not produce the mixed waste streams assumed in this estimate.

Results of earlier studies on commercial mixed LLW, made by Brookhaven National Laboratory (refs. 12–14), indicated that about 3–10% of the total volume of commercial LLW may be mixed LLW. The upper bound of 10% could be realized if the EPA rules that waste oil should be treated as hazardous.[17] These studies also indicated that the mixed LLW portion was primarily composed of three types of hazardous materials: organic liquids, lead, and chromates. Based on the total accumulated commercial LLW disposal volume through 1990 of about 1,384,000 m^3 (see Chapter 4), a mixed waste component of 3–10% would result in about 41,500–138,400 m^3 of total mixed commercial LLW disposed nationwide. It should be cautioned that the lower bound of these estimates is probably low, in part, because it does not include contributions from materials such as waste oil (listed in Tables 8.14–8.16), which, in some regions of the country, are considered hazardous.

8.5 REFERENCES

1. U.S. Congress, Atomic Energy Act of 1954, Pub. L. 83-703, Aug. 15, 1954.

2. U.S. Congress, Resource Conservation and Recovery Act of 1976, Pub. L. 94-580, Oct. 21, 1976, as amended by the Hazardous and Solid Waste Amendments Acts of 1984, Pub. L. 98-616, Nov. 9, 1984.

3. U.S. Congress, Toxic Substances Control Act of 1976, Pub. L. 94-469, Oct. 11, 1976.

4. U.S. Environmental Protection Agency, "Identification and Listing of Hazardous Waste," Code of Federal Regulations, 40 CFR Parts 260–271 (1986).

5. T. T. Traceski, DOE/HQ Office of Environmental Guidance, memo to Office of the Assistant Secretary for Environment, Safety, and Health, Director of Environmental Guidance (EH-231), "Update of States with Mixed Waste Authorization," dated July 13, 1990.

6. Betty Shackleford, U.S. Department of Energy, Division of Program Support, Office of Waste Operations, Washington, D.C., facsimile to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, dated Aug. 19, 1991, containing updated EPA mixed waste authorization status for states and U.S. territories as of Dec. 31, 1990.

7. C. S. Fore et al., DOE Waste Information Network: DOE/DP Hazardous and Mixed Waste Data Base – A User's Guide, DOE/HP-15, Oak Ridge National Laboratory, Oak Ridge, Tennessee (August 1986).

8. U.S. Department of Energy, Waste Management Information System (WMIS), DOE site mixed LLW inventory and projection data summaries prepared by the Hazardous Waste Remedial Actions Program (HAZWRAP), submitted to the Integrated Data Base Program, Sept. 24, 1991.

9. S. M. DePaoli, A. L. Rivera, and B. M. Eisenhower, Hazardous and Mixed Waste Generation at the DOE/ORO Installations Operated by Martin Marietta Energy Systems, Inc., During Calendar Years 1987 and 1988, K/ESH-2, Oak Ridge, Tennessee (September 1990).

10. U.S. Environmental Protection Agency, Code of Federal Regulations, 40 CFR Parts 702-799 (1988).

11. U.S. Department of Energy, Office of Environmental Restoration and Waste Management, 1989 Annual Report on Low-Level Radioactive Waste Management Progress – Report to Congress in Response to Public Law 99-240, DOE/EM-0006P, Washington, D.C. (October 1990).

12. Brookhaven National Laboratory, An Analysis of Low-Level Wastes: Review of Hazardous Waste Regulations and Identification of Radioactive Mixed Wastes, NUREG/CR-4406 (December 1985).

13. Brookhaven National Laboratory, Document Review Regarding Hazardous Chemical Characteristics of Low-Level Waste, NUREG/CR-4433 (March 1986).

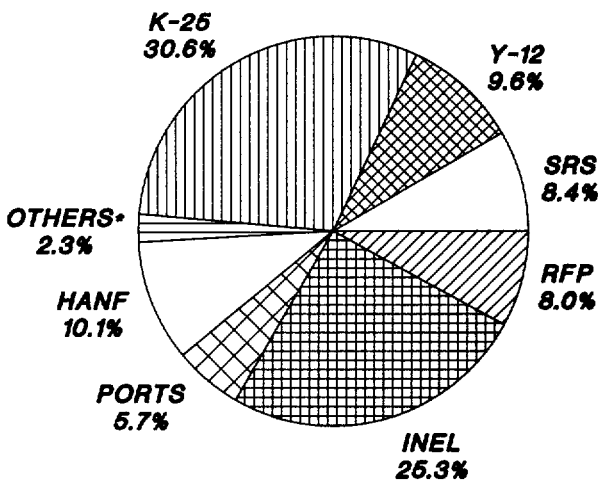
14. Brookhaven National Laboratory, Evaluation of Potential Mixed Wastes Containing Lead, Chromium, Used Oil, or Organic Liquids, NUREG/CR-4730 (January 1987).

15. Rogers and Associates Engineering Corporation, Management Practices and Disposal Concepts for Low-Level Radioactive Mixed Waste, RAE-8830-1, Salt Lake City, Utah, performed for the Office of Technology Assessment, U.S. Congress, Washington, D.C. (March 1989).

16. Nuclear Management and Resources Council, The Management of Mixed Low-Level Radioactive Waste in the Nuclear Power Industry, NUMARC/NESP-006, prepared by Rogers and Associates Engineering Corporation with Nuclear Waste Management, Inc., Washington, D.C. (January 1990).

17. U.S. Congress, Office of Technology Assessment, Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste, OTA-0-426, Washington, D.C. (November 1989).

ORNL DWG 91-8689

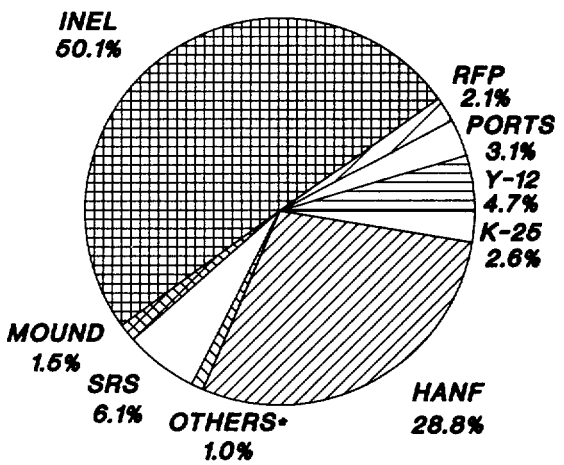


SITE	CUBIC METERS
HANF	1.08E+04
INEL	2.70E+04
K-25	3.27E+04
PORTS	6.09E+03
RFP	8.49E+03
SRS	8.96E+03
Y-12	1.03E+04
OTHERS*	2.48E+03
TOTAL	1.07E+05

*Includes contributions from 24 sites.

Fig. 8.1. Total volume inventory of DOE mixed LLW through 1990.

ORNL DWG 91-8690



SITE	CUBIC METERS
HANF	6.38E+03
INEL	1.11E+04
K-25	5.87E+02
MOUND	3.24E+02
PORTS	6.89E+02
RFP	4.62E+02
SRS	1.35E+03
Y-12	1.05E+03
OTHERS*	2.15E+02
TOTAL	2.22E+04

*Includes contributions from 23 sites.

Fig. 8.2. Volume generation of DOE mixed LLW during 1990.

Table 8.1. States and territories with EPA mixed waste authorization[a]

State/territory	Effective date	State/territory	Effective date
Arkansas	05/29/90	New Mexico	07/25/90
Colorado	11/07/86	New York	05/07/90
Connecticut	12/31/90	North Carolina	11/21/89
Georgia	09/26/88	North Dakota	08/24/90
Guam	10/10/89	Ohio	06/30/89
Idaho	04/09/90	Oklahoma	11/27/90
Illinois	04/30/90	Oregon	05/29/90
Kansas	06/25/90	South Carolina	09/13/87
Kentucky	12/19/88	Tennessee	08/11/87
Michigan	12/26/89	Texas	03/15/90
Minnesota	06/23/89	Washington	11/23/87
Nebraska	12/03/89	Utah	03/07/89
		(Total = 24 states/territories)	

[a]Based on refs. 5 and 6. Information as of December 31, 1990.

Table 8.2. Cumulative mass (kg) inventories of DOE site mixed LLW, by physical category, through 1990[a,b]

Site	Solid	Liquid	Gas[c]	Sludge	Total
Ames	450	0	0	0	450
ANL-E[d]					
ANL-W	17,596	177	0	0	17,773
BNL[d]					
FMPC[d]					
FNAL	45	1,090	0	0	1,135
HANF	11,811,734	8,783	0	0	11,820,517
INEL	22,934,771	136,142	0	2,610,803	25,681,716
ITRI[d]					
KCP	3,689	0	0	0	3,689
K-25	492,000	1,307,000	0	46,595,100	48,394,100
LANL	129,986	39,073	0	172,060	341,119
LBL	3,407	10,200	0	0	13,607
LLNL[d]					
MOUND	4,236	12,383	0	0	16,619
NR sites[e]	27,264	1,691	0	0	28,955
NTS[d]					
ORNL[f]	5,605	1,192,205	0	65,128	1,262,938
PAD[d]					
PANT	72,777	2,587	0	0	75,364
Pinellas	0	0	0	0	0
PORTS	505,612	232,735	0	5,795,481	6,533,828
PPPL	0	45	0	0	45
RAP sites[g]	211,471	51,650	0	4,974	268,095
RFP	893,462	20,238	0	52,295	965,995
RMI[d]					
SLAC	0	0	0	0	0
SNLA	282,424	1,000	0	0	283,424
SNLL	45	321	0	0	366
SRS	5,676,711	4,400,272	0	16,253	10,093,236
WVDP	8,655	2,311	0	0	10,966
Y-12	6,596,100	203,500	0	8,762,100	15,561,700
Total	49,678,040	7,623,403	0	64,074,194	121,375,637

[a]Based on ref. 8. Materials may be in interim storage awaiting treatment.

[b]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids and sludges were assumed to calculate masses when the site did not report mass data.

[c]Stored in cylinders.

[d]Updated information for 1990 was not available from this site.

[e]Includes contributions from Bettis (BAPL) and NRF (INEL).

[f]Includes a small contribution from Oak Ridge Associated Universities (ORAU).

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.3. Cumulative volume (m^3) inventories of DOE site mixed LLW, by physical category, through 1990[a,b]

Site	Solid	Liquid	Gas[c]	Sludge	Total
Ames	0.10	0	0	0	0.10
ANL-E[d]					
ANL-W	8.61	0.21	0	0	8.82
BNL[d]					
FMPC[d]					
FNAL	0.03	1.05	0	0	1.08
HANF	10,821.2	8.00	0	0	10,829.20
INEL	23,882.09	376.71	0	2,737.52	26,996.32
ITRI[d]					
KCP	4.93	0	0	0	4.93
K-25	328.00	1,307.00	0	31,063.40	32,698.40
LANL	76.89	62.04	0	185.00	323.93
LBL	2.42	10.20	0	0	12.62
LLNL[d]					
MOUND	5.06	44.88	0	0	49.94
NR sites[e]	6.29	2.53	0	0	8.82
NTS[d]					
ORNL[f]	5.60	1,200.20	0	62.40	1,268.20
PAD[d]					
PANT	175.85	3.95	0	0	179.80
Pinellas	0	0	0	0	0
PORTS	1,161.44	252.45	0	4,675.08	6,088.97
PPPL	0	0.02	0	0	0.02
RAP sites[g]	117.08	51.43		3.12	171.63
RFP	7,856.12	176.07	0	455.43	8,487.62
RMI[d]					
SLAC	0	0	0	0	0
SNLA	445.10	1.00	0	0	446.10
SNLL	0.22	0.63	0	0	0.85
SRS	4,162.16	4,779.95	0	15.40	8,957.51
WVDP	5.77	2.31	0	0	8.08
Y-12	4,108.40	203.5	0	5,944.40	10,256.30
Total	53,173.36	8,484.13	0	45,141.75	106,799.24

[a]Based on ref. 8. Materials may be in interim storage awaiting treatment.

[b]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids and sludges were assumed to calculate volumes when the site did not report volume data.

[c]Stored in cylinders.

[d]Updated information for 1990 was not available from this site.

[e]Includes contributions from Bettis (BAPL) and NRF (INEL).

[f]Includes a small contribution from Oak Ridge Associated Universities (ORAU).

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.4. Mass generation rates (kg/year) of DOE site mixed LLW, by physical category, for 1990[a,b]

Site	Solid	Liquid	Gas[c]	Sludge	Total
Ames	0	0	0	0	0
ANL-E[d]					
ANL-W	378	0	0	0	378
BNL[d]					
FMPC[d]					
FNAL	0	27	0	0	27
HANF	6,353,174	1,049	0	0	6,354,223
INEL	36,038	11,076,099	0	1,961	11,114,098
ITRI[d]					
KCP	218	0	0	0	218
K-25	253,328	208,768	0	115,553	577,649
LANL	90,633	13,434	0	67,025	171,092
LBL[d]					
LLNL[d]					
MOUND	0	396	0	0	396
NR sites[e]	939	0	0	0	939
NTS[d]					
ORNL[f]	787	6,784	0	0	7,571
PAD[d]					
PANT	2,909	1,634	0	0	4,543
Pinellas	0	0	0	0	0
PORTS	155,455	94,717	0	36,335	286,507
PPPL	0	45	0	0	45
RAP sites[g]	79,938	1,589	0	0	81,527
RFP	48,329	0	0	5,000	53,329
RMI[d]					
SLAC	0	0	0	0	0
SNLA[d]					
SNLL	0	161	0	0	161
SRS	85,793	1,208,126	0	0	1,293,919
WVDP	0	14	0	0	14
Y-12	247,293	30,000	0	863,500	1,140,793
Total	7,355,212	12,642,843	0	1,089,374	21,087,429

[a]Based on ref. 8. Values do not reflect any treatment that may, or will, occur prior to interim storage.

[b]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids and sludges were assumed to calculate masses when the site did not report mass data.

[c]Stored in cylinders.

[d]Updated information for 1990 was not available from this site.

[e]Includes contributions from Bettis (BAPL) and NRF (INEL).

[f]Includes a small contribution from Oak Ridge Associated Universities (ORAU).

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.5. Volume generation rates (m^3/year) of DOE site mixed LLW, by physical category, for 1990[a,b]

Site	Solid	Liquid	Gas[c]	Sludge	Total
Ames	0	0	0	0	0
ANL-E[d]					
ANL-W	0.31	0	0	0	0.31
BNL[d]					
FMPC[d]					
FNAL	0	0.01	0	0	0.01
HANF	6,372.00	4.50	0	0	6,376.50
INEL	25.93	11,076.50	0	3.46	11,105.89
ITRI[d]					
KCP	0.31	0	0	0	0.31
K-25	259.80	211.40	0	116.30	587.50
LANL	46.05	13.73	0	70.56	130.34
LBL[d]					
LLNL[d]					
MOUND	322.10	1.48	0	0	323.58
NR sites[e]	1.01	0	0	0	1.01
NTS[d]					
ORNL[f]	0.79	6.78	0	0	7.57
PAD[d]					
PANT	8.32	2.49	0	0	10.81
Pinellas	0	0	0	0	0
PORTS	532.40	104.00	0	52.50	688.90
PPPL	0	0.02	0	0	0.02
RAP sites[g]	62.92	1.79	0	0	64.71
RFP	418.26	0	0	44.00	462.26
RMI[d]					
SLAC	0	0	0	0	0
SNLA[d]					
SNLL	0.05	0.32	0	0	0.37
SRS	144.90	1,204.90	0	0	1,349.80
WVDP	0	0.01	0	0	0.01
Y-12	164.90	30.00	0	858.00	1,052.90
Total	8,360.05	12,657.93	0	1,144.82	22,162.80

[a]Based on ref. 8. Values do not reflect any treatment that may, or will, occur prior to interim storage.

[b]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids and sludges were assumed to calculate volumes when the site did not report volume data.

[c]Stored in cylinders.

[d]Updated information for 1990 was not available from this site.

[e]Includes contributions from Bettis (BAPL) and NRF (INEL).

[f]Includes a small contribution from Oak Ridge Associated Universities (ORAU).

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.6. Chemical categories used in this report for characterizing DOE site mixed LLW[a]

Waste category	EPA code(s)	Description
PCB	(none)	PCB wastes[b] contain any form of polychlorinated biphenyl (PCB)-containing wastes (liquid, solid, equipment, etc.)
Listed	F001-F015 F006-F028 P001-P123 U001-U359	A waste is regarded as listed if it is characterized by EPA as hazardous and published in 40 CFR Part 261. Examples: spent solvents (F001-F015), spent sludges (F006-F028), discarded commercial chemicals (P001-P123 and U001-U359), poisons, regulated medical wastes, and combustibles (materials that have a flash point[c] above 60°C)
Ignitable	D001	A waste exhibits ignitability if the waste has a flash point under 60°C, or if, as a solid, it is capable of causing fire through friction at standard temperature and pressure (see 40 CFR Part 261.21). Examples: acetone, toluene, and alcohols
Reactive	D003	A waste exhibits reactivity if it is normally unstable, reacts violently with water, is capable of detonation, or generates toxic gases under certain conditions (see 40 CFR Part 261.23). Examples: poisons and carcinogens
Corrosive	D002	A waste exhibits corrosivity if the pH is <2 or >12.5, or if it corrodes steel at a specified rate (see 40 CFR Part 261.22). Examples: acids, bases, and crystalline solids (e.g., sodium hydroxide)
TCLP/EP toxic	D004-D017	A waste exhibits this toxicity if the leachate contains certain constituents (such as arsenic, lead, mercury, and silver) at concentrations equal to or higher than those given in 40 CFR Part 261.24

[a]Adapted from ref. 9.

[b]PCB wastes with PCB content ≥50 ppm are regulated by the Toxic Substances Control Act (TSCA) (ref. 3) under 40 CFR Parts 702-799 (ref. 10).

[c]The flash point is the lowest temperature at which the vapor of a combustible liquid can be made to ignite momentarily in air.

Table 8.7. Cumulative mass (kg) inventories of DOE site mixed LLW, by chemical category, through 1990[a,b]

Site	PCB	Listed	Ignitable	Reactive	Corrosive	TCLP/EP toxic	Total
Ames	0	0	0	0	0	450	450
ANL-E[c]							
ANL-W	0	770	5,891	0	0	11,112	17,773
BNL[c]							
FMPC[c]							
FNAL	90	30	1,000	0	0	15	1,135
HANF[d]	11,896	1,986,035	1,032,425	3,756,956	22,093	5,011,112	11,820,517
INEL	2,315,347	22,473,903	312,827	0	3,312	576,327	25,681,716
ITRI[c]							
KCP	0	2,345	0	0	0	1,344	3,689
K-25	290,100	47,678,900	0	0	18,000	407,100	48,394,100
LANL	0	204,977	6,000	100	5,794	124,248	341,119
LBL	1,007	9,000	2,100	0	1,200	300	13,607
LLNL[c]							
MOUND	1,757	10,604	0	0	0	4,258	16,619
NR sites[e]	0	2,516	0	0	0	26,439	28,955
NTS[c]							
ORNL[f]	0	1,142,891	49,556	0	4,181	66,310	1,262,938
PAD[c]							
PANT	0	66,913	2,451	0	0	6,000	75,364
Pinellas	0	0	0	0	0	0	0
PORTS	2,508,551	3,817,659	9,100	0	28,668	169,850	6,533,828
PPPL	0	45	0	0	0	0	45
RAP sites[g]	111,545	64,219	10,630	717	5,075	75,909	268,095
RFP	1,182	960,339	120	0	0	4,354	965,995
RMI[c]							
SLAC	0	0	0	0	0	0	0
SNLA	10,000	141,180	0	102,900	0	29,344	283,424
SNLL	0	321	0	0	0	45	366
SRS	0	9,822,738	3,129	0	96,800	170,569	10,093,236
WVDP	4,290	75	216	0	1,992	4,393	10,966
Y-12	5,835,800	9,471,550	0	0	0	254,350	15,561,700
Total	11,091,565	97,857,010	1,435,445	3,860,673	187,115	6,943,829	121,375,637

[a]Based on ref. 8. Material may be in interim storage awaiting treatment.

[b]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids and sludges were assumed to calculate masses when the site did not report mass data.

[c]Updated information for 1990 was not available from this site.

[d]Hanford applied a different hazardous ordering scheme for wastes with two or more chemical categories: listed (highest), ignitable, corrosive, TCLP/EP toxic, reactives and other, and PCB (lowest).

[e]Includes contributions from Bettis (BAPL) and NRF (INEL).

[f]Includes a small contribution from ORAU.

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.8. Cumulative volume (m^3) inventories of DOE site mixed LLW, by chemical category, through 1990[a,b]

Site	PCB	Listed	Ignitable	Reactive	Corrosive	TCLP/EP toxic	Total
Ames	0	0	0	0	0	0.10	0.10
ANL-E[c]							
ANL-W	0	0.52	6.41	0	0	1.89	8.82
BNL[c]							
FMPC[c]							
FNAL	0.05	0.02	1.00	0	0	0.01	1.08
HANF[d]	32.40	1,636.20	739.20	3,745.20	64.00	4,612.20	10,829.20
INEL	2,429.51	23,818.89	326.30	0	3.40	418.22	26,996.32
ITRI[c]							
KCP	0	2.81	0	0	0	2.12	4.93
K-25	237.40	32,171.60	0	0	18.00	271.40	32,698.40
LANL	0	239.74	12.48	0.11	6.88	64.72	323.93
LBL	0.82	9.00	1.40	0	1.20	0.20	12.62
LLNL[c]							
MOUND	5.10	39.70	0	0	0	5.14	49.94
NR sites[e]	0	2.89	0	0	0	5.93	8.82
NTS[c]							
ORNL[f]	0	1,150.89	49.55	0	4.18	63.58	1,268.20
PAD[c]							
PANT	0	172.06	3.74	0	0	4.00	179.80
Pinellas	0	0	0	0	0	0	0
PORTS	1,820.34	3,993.58	9.20	0	32.10	233.75	6,088.97
PPPL	0	0.02	0	0	0	0	0.02
RAP sites[g]	93.94	36.35	9.83	0.45	4.69	26.37	171.63
RFP	10.63	8,436.47	1.05	0	0	39.47	8,487.62
RMI[c]							
SLAC	0	0	0	0	0	0	0
SNLA	35.00	128.00	0	268.30	0	14.80	446.10
SNLL	0	0.63	0	0	0	0.22	0.85
SRS	0	8,556.54	4.64	0	96.70	299.63	8,957.51
WVDP	2.87	0.07	0.21	0	1.99	2.94	8.08
Y-12	3,739.20	6,359.20	0	0	0	157.90	10,256.30
Total	8,407.26	86,755.18	1,165.01	4,014.06	233.14	6,224.59	106,799.24

[a]Based on ref. 8. Values do not reflect any treatment that may, or will, occur prior to interim storage.

[b]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids and sludges were assumed to calculate volumes when the site did not report volume data.

[c]Updated information for 1990 was not available from this site.

[d]Hanford applied a different hazardous ordering scheme for wastes with two or more chemical categories: listed (highest), ignitable, corrosive, TCLP/EP toxic, reactives and other, and PCB (lowest).

[e]Includes contributions from Bettis (BAPL) and NRF (INEL).

[f]Includes a small contribution from ORAU.

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.9. Mass generation rates (kg/year) of DOE site mixed LLW, by chemical category, for 1990[a,b]

Site	PCB	Listed	Ignitable	Reactive	Corrosive	TCLP/EP toxic	Total
Ames	0	0	0	0	0	0	0
ANL-E[c]							
ANL-W	0	62	1	0	0	315	378
BNL[c]							
FMPC[c]							
FNAL	27	0	0	0	0	0	27
HANF[d]	5,647	971,991	1,589	1,816,000	2,694	3,556,302	6,354,223
INEL	0	11,074,230	370	0	0	39,498	11,114,098
ITRI[c]							
KCP	0	0	0	0	0	218	218
K-25	73,148	275,774	0	0	8,850	219,877	577,649
LANL	0	78,857	0	0	1,602	90,633	171,092
LBL	0	0	0	0	0	0	0
LLNL[c]							
MOUND	56	340	0	0	0	0	396
NR sites[e]	0	735	0	0	0	204	939
NTS[c]							
ORNL[f]	0	2	6,139	0	652	778	7,571
PAD[c]							
PANT	0	2,909	1,634	0	0	0	4,543
Pinellas	0	0	0	0	0	0	0
PORTS	191,936	45,464	8,000	0	0	41,107	286,507
PPPL	0	45	0	0	0	0	45
RAP sites[g]	77,168	107	461	0	1	3,790	81,527
RFP	0	52,495	0	0	0	834	53,329
RMI[c]							
SLAC	0	0	0	0	0	0	0
SNLA	0	0	0	0	0	0	0
SNLL	0	161	0	0	0	0	161
SRS	0	53,544	1,090	0	1,168,300	70,985	1,293,919
WVDP	0	0	4	0	10	0	14
Y-12	55,000	1,084,293	0	0	0	1,500	1,140,793
Total	402,982	13,641,009	19,288	1,816,000	1,182,109	4,026,041	21,087,429

[a]Based on ref. 8. Values do not reflect any treatment that may, or will, occur prior to interim storage.

[b]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids and sludges were assumed to calculate masses when the site did not report mass data.

[c]Updated information for 1990 was not available from this site.

[d]Hanford applied a different hazardous ordering scheme for wastes with two or more chemical categories: listed (highest), ignitable, corrosive, TCLP/EP toxic, reactives and other, and PCB (lowest).

[e]Includes contributions from Bettis (BAPL) and NRF (INEL).

[f]Includes a small contribution from ORAU.

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.10. Volume generation rates (m^3/year) of DOE site mixed LLW, by chemical category, for 1990[a,b]

Site	PCB	Listed	Ignitable	Reactive	Corrosive	TCLP/EP toxic	Total
Ames	0	0	0	0	0	0	0
ANL-E[c]							
ANL-W	0	0.10	0	0	0	0.21	0.31
BNL[c]							
FMPC[c]							
FNAL	0.01	0	0	0	0	0	0.01
HANF[d]	11.50	920.30	6.40	1,812.80	6.10	3,619.40	6,376.50
INEL	0	11,074.33	0.42	0	0	31.14	11,105.89
ITRI[c]							
KCP	0	0	0	0	0	0.31	0.31
K-25	66.60	282.60	0	0	6.10	232.20	587.50
LANL	0	82.60	0	0	1.69	46.05	130.34
LBL	0	0	0	0	0	0	0
LLNL[c]							
MOUND	0.21	1.27	0	0	0	322.10	323.58
NR sites[e]	0	0.80	0	0	0	0.21	1.01
NTS[c]							
ORNL[f]	0	0	6.14	0	0.65	0.78	7.57
PAD[c]							
PANT	0	8.32	2.49	0	0	0	10.81
Pinellas	0	0	0	0	0	0	0
PORTS	575.1	45.10	8.10	0	0	60.60	688.90
PPPL	0	0.02	0	0	0	0	0.02
RAP sites[g]	61.17	0.09	0.47	0	0	2.98	64.71
RFP	0	454.95	0	0	0	7.31	462.26
RMI[c]							
SLAC	0	0	0	0	0	0	0
SNLA	0	0	0	0	0	0	0
SNLL	0	0.32	0	0	0	0.05	0.37
SRS	0	52.90	1.50	0	1,168.30	127.10	1,349.80
WVDP	0	0	0	0	0.01	0	0.01
Y-12	50.00	1,001.90	0	0	0	1.00	1,052.90
Total	764.59	13,925.60	25.52	1,812.80	1,182.85	4,451.44	22,162.80

[a]Based on ref. 8. Material may be in interim storage awaiting treatment.

[b]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids and sludges were assumed to calculate volumes when the site did not report volume data.

[c]Updated information for 1990 was not available from this site.

[d]Hanford applied a different hazardous ordering scheme for wastes with two or more chemical categories: listed (highest), ignitable, corrosive, TCLP/EP toxic, reactives and other, and PCB (lowest).

[e]Includes contributions from Bettis (BAPL) and NRF (INEL).

[f]Includes a small contribution from ORAU.

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.11. Projected annual mixed LLW mass generation rates (kg/year) for various DOE sites[a]

Site	Calendar year(s)					
	1991	1992	1993	1994	1995	1996-2020[b]
Ames	10	10	10[c]	10	5	3
ANL-E[d]						
ANL-W	1,103	579	516	423	423	423
BNL[d]						
FMPC[d]						
FNAL	81	<1	<1	<1	<1	<1
HANF	829,400	7,138,000[e]	754,500	1,025,000	661,800	1,667,500
INEL[f]	11,142,611	8,415,000	120,000	120,000	120,000	120,000
ITRI[d]						
KCP	1,273	273	273	273	2,455	6,818
K-25	459,539	438,539	438,539	438,539	438,539	438,539
LANL	90,400	250,000	250,000	250,000	250,000	250,000
LBL	2,630	2,270	2,990	2,890	2,040	2,286
LLNL[d]						
MOUND	1,385	500	250	250	250	2,500
NR sites[g]	71	100	100	100	100	NA[h]
NTS[d]						
ORNL	16,267	12,000	12,000	12,000	12,000	12,000
PAD[d]						
PANT	12,982	6,982	6,982	6,982	6,982	6,982
Pinellas[d]						
PORTS	4,133,340	2,406,120[i]	441,710	441,710	386,000	386,000[j]
PPPL[k]	45	11,250	11,250	45,000	11,250	162,000
RAP sites[l]	8,306	230	230	460	230	230
RFP[m]	1,166,272	11,860,000	93,630	93,630	93,630	93,630
RMI[d]						
SLAC[d]						
SNLA	332,260	22,000	22,000	22,000	22,000	22,000
SNLL	161	161	161	161	161	150
SRS	1,412,523	707,950	184,000	184,000	184,000	184,000
WVDP	61	n	n	n	n	n
Y-12[j]	1,824,530	1,120,793	86,634	672,476	448,317	224,159
Total	21,435,250	32,392,758	2,425,776	3,315,905	2,640,183	3,579,221

[a]Based on ref. 8.

[b]Annual average for the period indicated.

[c]If a burial site at Ames is excavated in 1993, a potential generation of 80,000 kg/year could result.

[d]Information not reported by site.

[e]Includes contribution from Hanford's receipt of waste in 1992 that is currently being stored by off-site generators.

[f]Projections for INEL do not include contributions from environmental restoration activities planned at the site over the next 30 years. More waste characterization analyses and studies are needed to predict how much mixed LLW will result from these activities.

[g]Includes contributions from Bettis (BAPL) and NRF (INEL).

[h]NA = not available.

[i]Excludes contaminated soil (10,760 m^3) that may be generated if clean closure of X-701B area is required.

[j]Excludes contributions of wastes from environmental restoration activities.

[k]Mass generation rates for this site are based on an assumed density of 1,500 kg/m^3.

[l]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

[m]Projections for RFP assume completion of solar pond cleanout and the resumption of plant production by the end of 1992.

[n]Mixed LLW generation data for WVDP cannot be estimated for years 1992-2020 until programmatic and process uncertainties have been resolved in the development of a formal environmental impact statement.

Table 8.12. Projected annual mixed LLW volume generation rates (m^3/year) for various DOE sites[a]

Site	Calendar year(s)					
	1991	1992	1993	1994	1995	1996-2020[b]
Ames	0.001	0.001	0.001[c]	0.001	<0.0005	<0.0005
ANL-E[d]						
ANL-W	1	0.7	0.6	0.4	0.4	0.4
BNL[d]						
FMPC[d]						
FNAL	0.08	<0.001	<0.001	<0.001	<0.001	<0.001
HANF	754	6,489.4[e]	685.9	931.4	601.6	1,525
INEL[f]	11,126	8,345	50	50	50	50
ITRI[d]						
KCP	0.8	0.4	0.4	0.4	2.1	10.4
K-25	537	513.8	513.8	513.8	513.8	513.8
LANL	84.5	200	200	200	200	200
LBL	2.1	10	12	11	8	10
LLNL[d]						
MOUND	0.9	1.0	0.5	0.5	0.5	5
NR sites[g]	0.09	0.1	0.1	0.1	0.1	NA[h]
NTS[d]						
ORNL	16.3	12	12	12	12	12
PAD[d]						
PANT	24.0	20.0	20.0	20.0	20.0	20.0
Pinellas[d]						
PORTS	3,285.2	2,409[i]	866	866	782	782[j]
PPPL	0.02	7.5	7.5	30	7.5	108
RAP sites[k]	6.7	0.3	0.3	0.32	0.3	0.3
RFP[l]	9,912.8	10,360	817.8	817.8	817.8	817.8
RMI[d]						
SLAC[d]						
SNLA	221.8	140	140	140	140	140
SNLL	0.3	0.3	0.3	0.3	0.3	0.2
SRS	1,421	708	184.1	184.1	184.1	184.1
WVDP	0.06	m	m	m	m	m
Y-12[j]	1,801	934	747	560	374	187
Total	29,195.7	30,151.5	4,258.3	4,338.1	3,714.5	4,566.0

[a]Based on ref. 8.

[b]Annual average for the period indicated.

[c]If a burial site at Ames is excavated in 1993, a potential generation of 50 m^3/year could result.

[d]Information not reported by site.

[e]Includes contribution from Hanford's receipt of waste in 1992 that is currently being stored by off-site generators.

[f]Projections for INEL do not include contributions from environmental restoration activities planned at the site over the next 30 years. More waste characterization analyses and studies are needed to predict how much mixed LLW will result from these activities.

[g]Includes contributions from Bettis (BAPL) and NRF (INEL).

[h]NA = not available.

[i]Excludes contaminated soil (10,760 m^3) that may be generated if clean closure of X-701B area is required.

[j]Excludes contributions of wastes from environmental restoration activities.

[k]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

[l]Projections for RFP assume completion of solar pond cleanout and the resumption of plant production by the end of 1992.

[m]Mixed LLW generation data for WVDP cannot be estimated for years 1992-2020 until programmatic and process uncertainties have been resolved in the development of a formal environmental impact statement.

Table 8.13. Projections of commercial mixed LLW volumes after 1992[a]

Compact/states	Projected volume (m^3)[b]			
	1993	1994	1995	Total
Appalachian	31	35	38	104
Central[c]	-	-	-	-
Central-Midwest	(51)	(51)	(51)	(153)
District of Columbia	(117)	-	-	(117)
Maine	-	-	-	-
Massachusetts[d]	(142)	(142)	(142)	(426)
Midwest	(86)	(86)	(86)	(258)
New Hampshire	-	-	-	-
New York[e]	-	-	-	-
Northeast				
New Jersey	(1)	(1)	(1)	(3)
Connecticut	(174)	(174)	-	(348)
Northwest[f]	-	-	-	-
Puerto Rico	-	-	-	-
Rhode Island	-	-	-	-
Rocky Mountain[f]	-	-	-	-
Southwestern[f]	173	173	173	519
Texas	-	-	-	-
Vermont	-	-	-	-
Western[f]	-	-	-	-
Total[g]	775	662	491	1928

[a]Based on a summary of State Governor's Certifications reported in ref. 11.

[b]Volumes without parentheses reflect waste that has undergone some form of volume reduction; volumes in parentheses reflect waste that has not undergone volume reduction.

[c]The Central Compact did not distinguish between LLW and mixed LLW volumes, but indicated that access to disposal will be provided by January 1, 1993.

[d]Based on 1989 mixed LLW inventory.

[e]New York did not report mixed LLW data projections.

[f]These compacts/states did not need to submit a State Governor's Certification because they were either already sited or their license application had been submitted.

[g]Includes contributions from both treated and untreated wastes.

Table 8.14. Summary of OTA-estimated characteristics of annually generated mixed LLW from industrial facilities[a]

(Information for 35 out of a potential 563 industrial facilities)[b]

Type of mixed LLW	Volume (m^3/year)	Specific activity (Ci/m^3)	Radionuclides identified in waste(s)
Liquid scintillation cocktails or fluids	17.0[c]	0.00071-0.092	^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{45}Ca, ^{51}Cr, ^{125}I, and ^{131}I
Organic chemicals	93[d]	0.035-110	^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{60}Co, ^{90}Sr, ^{125}I, ^{137}Cs, and ^{241}Am
Trash contaminated with organic chemicals	0.6	0.007	^{3}H, ^{14}C, ^{32}P, and ^{125}I
Lead	0[e]	f	Mixed fission products[f]
Lead decontamination solutions	3	f	Mixed fission products[f]
CFC concentrates	6	0.000011	f
Aqueous corrosive liquid	91[g]	99	Mixed activation products[f]
Waste oil	4.87	0.00007	^{3}H, ^{14}C, ^{60}Co, ^{99}Tc, ^{134}Cs, and ^{137}Cs
Reactive chemicals (uranyl nitrate and thorium nitrate)	6.68	0.0019	Uranium and thorium radionuclides
Other[h]	77.9	0.-53	f
Total (35 facilities)	300		

[a]Based on the information reported in ref. 15.

[b]The information reported should be considered rough estimates because of possible double-counting (duplication of data) and provision of incomplete facility data in the surveys taken for this study.

[c]Waste processors report a total scintillation fluid volume of 2920 m^3 from all types of generators.

[d]Does not include 25 m^3 in storage.

[e]Does not include 2.6 to 3.5 m^3 in storage. Most of this waste has very low activity, although about 0.5 m^3 may be GTCC waste.

[f]Detailed information not available.

[g]Does not include 1100 m^3 in storage.

[h]Waste reported as mixed but lacking sufficient information to determine type.

Table 8.15. Summary of OTA-estimated characteristics of annually generated mixed LLW from medical/academic facilities[a]

(Information for 39 out of a potential 744 medical/academic facilities)[b]

Type of mixed LLW	Volume (m^3/year)	Specific activity (Ci/m^3)	Radionuclides identified in waste(s)
Liquid scintillation cocktails or fluids	516.08[c]	0.0003-0.0042	^{14}C, ^{22}Na, ^{32}P, ^{35}S, ^{36}Cl, ^{45}Ca, ^{46}Sc, ^{51}Cr, ^{57}Co, ^{63}Ni, ^{85}Sr, ^{86}Rb, ^{111}In, ^{125}I, ^{131}I, ^{141}Ce, ^{153}Gd, and ^{203}Pb
Organic chemicals	15.9-16.4[d]	0.000007-1.3	^{3}H, ^{14}C, and ^{35}S
Lead	0.6[e]	0.053	Radium radionuclides and standard radionuclides used by medical facilities and universities
Waste oil	0[f]	>0.00004	^{3}H
Reactive chemicals	0.003	0.13	Uranium and thorium radionuclides
Other[g]	41.54	0.004-0.1	h
Total (39 facilities)	574.1-574.6		

[a]Based on the information reported in ref. 15.

[b]The information reported should be considered rough estimates because of possible double-counting (duplication of data) and provision of incomplete facility data in the surveys taken for this study.

[c]Waste processors report a total scintillation fluid volume of 2920 m^3 from all types of generators.

[d]Does not include 4.64 m^3 in storage.

[e]Does not include 6.85 m^3 in storage.

[f]Does not include 0.8 m^3 in storage.

[g]Waste reported as mixed but lacking sufficient information to determine type.

[h]Detailed information not available.

Table 8.16. Summary of OTA-estimated characteristics of annually generated mixed LLW from commercial LWR power plants[a]

(Information for 42 out of a potential 76 LWR power plants)[b]

Type of mixed LLW	Volume (m^3/year)	Specific activity (Ci/m^3)	Radionuclides identified in waste(s)
Liquid scintillation cocktails or fluids	3.28	0-0.046	c
Organic chemicals	5.86[d,e]	c	c
Waste oil	715.77[f]	0.007	^{3}H, ^{14}C, ^{54}Mn, ^{51}Cr, ^{55}Fe, ^{59}Fe, ^{58}Co, ^{60}Co, ^{63}Ni, ^{65}Zn, ^{90}Sr, ^{99}Tc, ^{125}Sb, ^{129}I, ^{134}Cs, and ^{137}Cs
CFC solvents and concentrates	204.8[g]	0-0.00039	c
Low-activity sludge	0[h]	c	c
Chromium/cadmium waste	1.3	0-0.46	c
Lead	1.5	0.14	c
Ignitable	0.54	0.002	c
Corrosive	0.2	0.004	c
Other[i]	38.2[j]	0.081	c
Total (42 facilities)	971.5		

[a]Based on the information reported in ref. 15.
[b]The information reported should be considered rough estimates because of possible double-counting (duplication of data) and provision of incomplete facility data in the surveys taken for this study.
[c]Detailed information not available.
[d]<0.03 m^3 reported in storage.
[e]May include some CFC solvents.
[f]Does not include 6.8 m^3 in storage.
[g]May include other halogenated solvents.
[h]Does not include 850 m^3 resulting from a one-time event.
[i]Includes either toxic waste or a combination of lead, CFC waste, liquid scintillation fluids, cleaning solvents, and other unspecified materials.
[j]Does not include 47.80 m^3 in storage.

Table 8.17. Summary of NUMARC-estimated characteristics of mixed LLW from commercial LWR operations[a]

Source	Annual waste volume (m^3/year)	
	Generated	Disposed
BWR operations	119	59.5
PWR operations	102	42.5
LWR total		
(Conservative base case)	221	102
(Reasonable assumptions case)	82.1	21.2

[a]Based on the NUMARC study of ref. 16.

APPENDIX A. WASTE FLOWSHEETS, SOURCE TERMS, AND CHARACTERISTICS

APPENDIX A. WASTE FLOWSHEETS, SOURCE TERMS, AND CHARACTERISTICS

A.1 DISCUSSION

In this report, a number of engineering estimates, assumptions, and ground rules are used to determine radioactive waste and spent fuel projections through the year 2020. Many of these involve parameters that characterize certain types of waste (e.g., see Table A.1). In other instances, estimates were made of the waste volume generated per unit of product throughput for each step in the fuel cycle. This appendix is a compilation of generic flowsheets and source terms used for making waste projections. Source terms are used to describe quantitative and qualitative characteristics of radioactive wastes. In general, the source term for a particular waste is comprised of two components unique to that waste: (1) the number of curies of radioactivity expressed either per unit of facility production or per unit of waste volume or mass and (2) a listing of the relative radioactivity contributions of component radioisotopes.

The source terms used in the analysis of this report are based on reported historical data, engineering estimates, calculations, and/or experimental data. Documentation of the source terms and key waste modeling parameters is provided in the following sets of figures and tables (based on refs. 1 through 11). Detailed information on how these source terms and modeling parameters were derived is available, mainly in ref. 1 and its update (ref. 2). Figures A.1 through A.9 were taken from refs. 1 and 2. Figure A.10 was adapted from information presented in ref. 3. Table A.2 lists some basic factors used for estimating waste projections (including HLW estimates reported in ref. 4). Using these requirements, the source terms of Figs. A.1–A.9, and the spent fuel activity levels based on refs. 5 and 6, estimates were made of the spent fuel and waste generation by a 1-GW(e) reference BWR and a 1-GW(e) PWR for a 40-year operating life. The results are reported in Table A.3. The mass, radioactivity, and thermal power of the nuclides contained in all stored domestic commercial LWR spent fuel as of December 31, 1990, are listed in Table A.4.

Representative DOE LLW radionuclide compositions are described in Table A.5 (based on ref. 1). Average concentrations for representative radionuclides in LLW disposed of at commercial sites are given in Table A.6, which is based on data available in ref. 1. Table A.7, which gives the radionuclide composition of saltstone at SRS, summarizes information obtained from ref. 3. The data on LLW produced from commercial LWR operations are based on the annual LWR waste shipments to commercial disposal sites (refs. 7 and 8) and the energy generation values reported in Table A.8, which is based on refs. 7, 9, and 10. Table A.9 gives a summary of major sources and estimated characteristics of commercial greater-than-Class-C LLW. Information on the LLW to be incorporated in cement as a result of future operations by the West Valley Demonstration Project Radwaste Treatment System is presented in Table A.10, which is taken from ref. 11.

Compositions (adapted from ref. 2) of I/I wastes are given in Table A.11. These wastes are categorized according to I/I activities (bioresearch, medical, and nonbioresearch).

A.2 REFERENCES

1. C. W. Forsberg, W. L. Carter, and A. H. Kibbey, Flowsheets and Source Terms for Radioactive Waste Projections, ORNL/TM-8462, Oak Ridge National Laboratory, Oak Ridge, Tennessee (March 1985).

2. A. H. Kibbey, H. W. Godbee, and S. M. DePaoli, An Update of the Source Terms and Rationale Used for Low-Level Radioactive Waste Projections in the 1988 Department of Energy Integrated Data Base, ORNL/TM-11710, Oak Ridge National Laboratory, Oak Ridge, Tennessee (in preparation).

3. R. G. Garvin, Westinghouse Savannah River Company, Savannah River Site, Aiken, South Carolina, memo to A. L. Watkins, U.S. Department of Energy, Savannah River Field Office, Aiken, South Carolina, "Data for Integrated Data Base," NMP-WMT-910376, dated Apr. 24, 1991.

4. U.S. Department of Energy, Integrated Data Base for 1990: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 6, Oak Ridge National Laboratory, Oak Ridge, Tennessee (October 1990).

5. C. W. Alexander and A. G. Croff, Decay Characteristics of Once-Through LWR and LMFBR Spent Fuels, High-Level Wastes, and Fuel-Assembly Structural Material Wastes, ORNL/TM-7431, Oak Ridge National Laboratory, Oak Ridge, Tennessee (November 1980).

6. A. G. Croff, ORIGEN2 – A Revised and Updated Version of the Oak Ridge Generation and Depletion Code, ORNL-5621, Oak Ridge National Laboratory, Oak Ridge, Tennessee (July 1980).

7. A. H. Kibbey and S. M. DePaoli, A Compilation of the Electricity Generated and Low-Level Radioactive Wastes Shipped for Disposal by U.S. Nuclear Power Plants, 1959–1985, ORNL/TM-10440, Oak Ridge National Laboratory, Oak Ridge, Tennessee (December 1987).

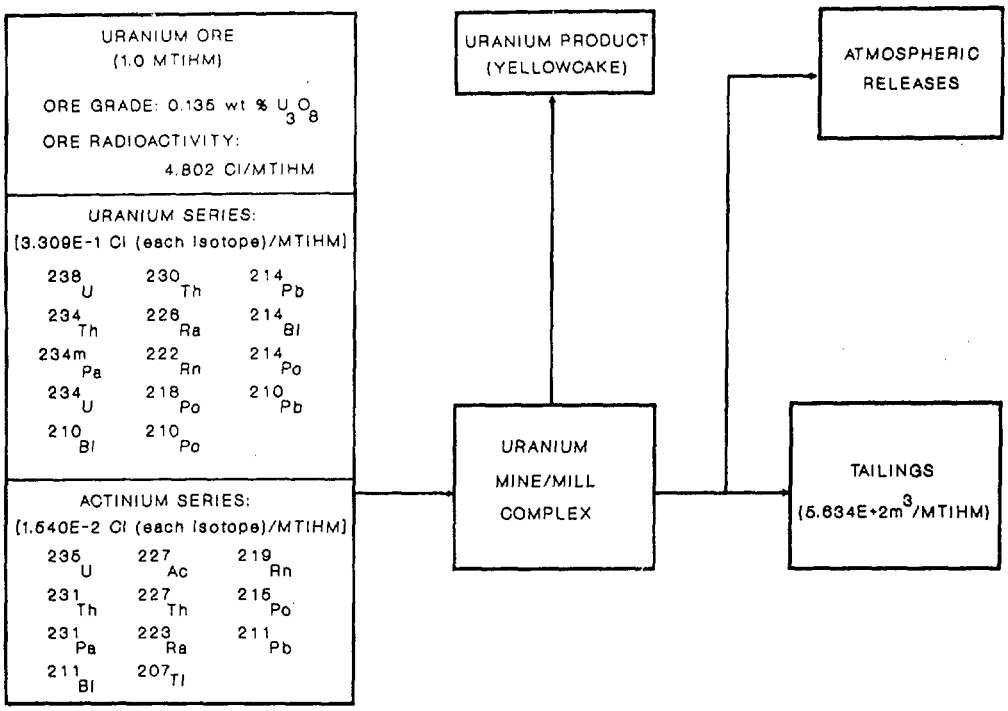
8. U.S. nuclear power plants, semiannual operating reports submitted to the NRC in 1986 through 1990.

9. U.S. Nuclear Regulatory Commission, The Licensed Operating Reactor Status Summary Report (Gray Book), Vols. 1–14, No. 1 for each year 1976–1989, usually published by the following February, U.S. Government Printing Office, Washington, D.C. 20402. Data are also available on magnetic tape from W. H. Lovelace, Office of Information Resources Management, Division of Computer and Telecommunications Services, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

10. U.S. Department of Energy, Energy Information Administration, Commercial Nuclear Power 1991: Prospects for the United States and the World, DOE/EIA-0438(91), Washington, D.C. (August 1991).

11. T. J. Rowland, DOE-West Valley Demonstration Project Office, West Valley, New York, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update to the DOE 1991 Integrated Data Base Report," dated Apr. 15, 1991.

ORNL DWG 89-7803



Fractions of elements from uranium ore in waste and product streams from a uranium mine/mill complex

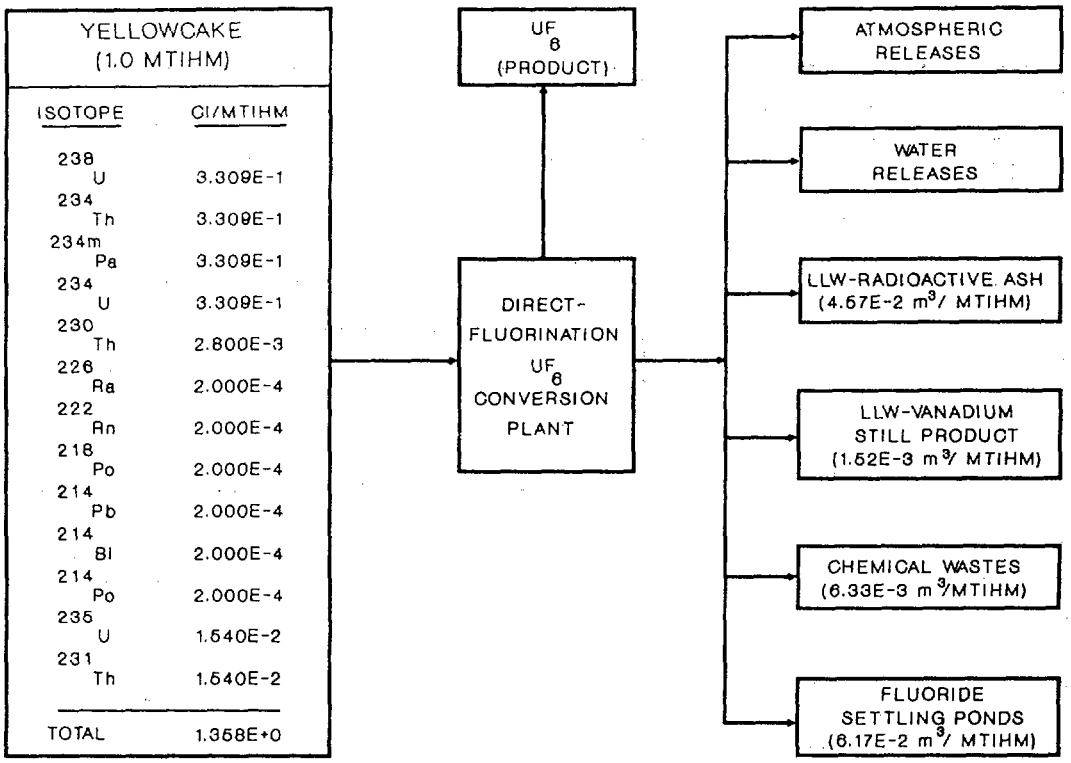
	Waste streams		Product stream[a]
Element	Atmospheric releases	Tailings[b]	Uranium (yellowcake)
Uranium	1.000E-3	6.800E-2	9.310E-1
Protactinium	0.000E+0	1.000E+0	0.000E+0
Thorium	8.000E-6	9.923E-1	7.692E-3
Actinium	0.000E+0	1.000E+0	0.000E+0
Radon	1.000E-1	9.000E-1	0.000E+0
Other	6.000E-7	9.994E-1	5.994E-4

[a] Also includes yellowcake from both solution mining and by-product U_3O_8.

[b] Assumed density = 1.6 t/m^3.

Fig. A.1. Principal waste and product streams from a uranium mine/mill complex.

ORNL DWG 89-7804

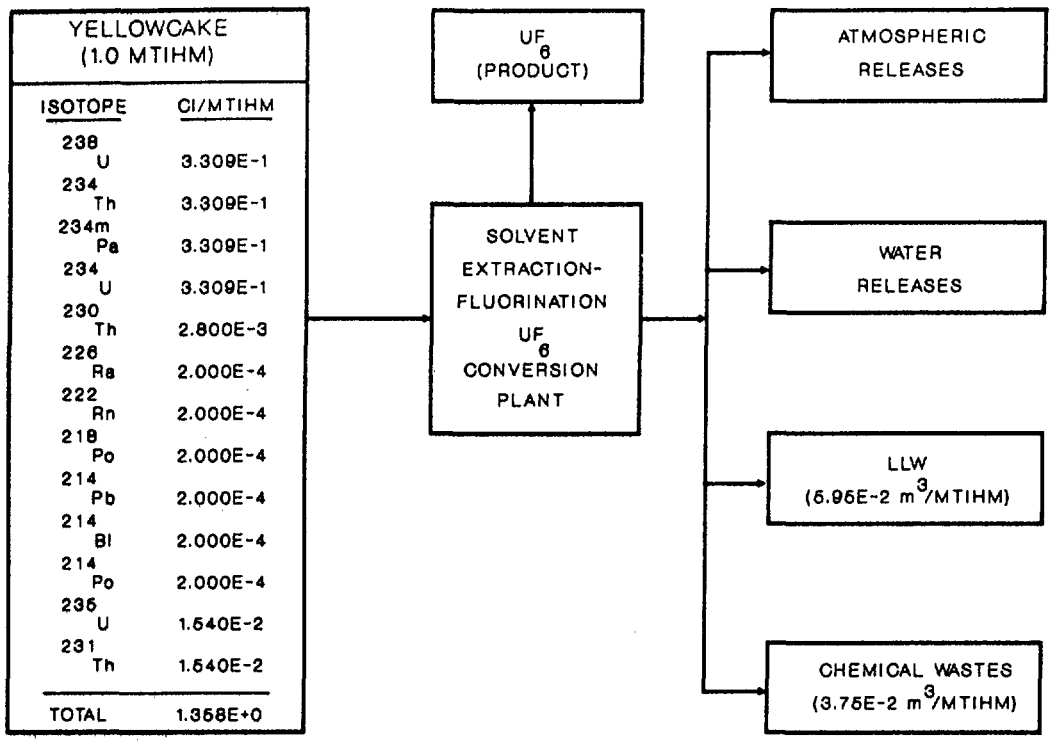


Fractions of elements from yellowcake in waste and product streams from a direct-fluorination UF_6 conversion plant

	Waste streams						
Element	Atmospheric releases	Water releases	Radioactive ash	Vanadium still product	Chemical wastes	Fluoride settling ponds	Product stream (UF_6)
Uranium	2.60E-5	7.66E-5	3.51E-5	5.01E-4	1.00E-6	3.63E-5	9.9932E-1
Thorium	3.22E-5	7.27E-6	1.00E+0	2.67E-5	1.00E-6	8.80E-7	0.00
Radium	3.36E-5	1.14E-3	9.99E-1	2.68E-5	1.00E-6	5.88E-6	0.00
Radon	8.21E-1	0.00	1.79E-1	4.84E-6	0.00	1.06E-6	0.00
Other	3.26E-5	7.25E-6	1.00E+0	2.67E-5	1.00E-6	3.80E-6	0.00

Fig. A.2. Principal waste and product streams from a direct-fluorination UF_6 conversion plant.

ORNL DWG 89-7805

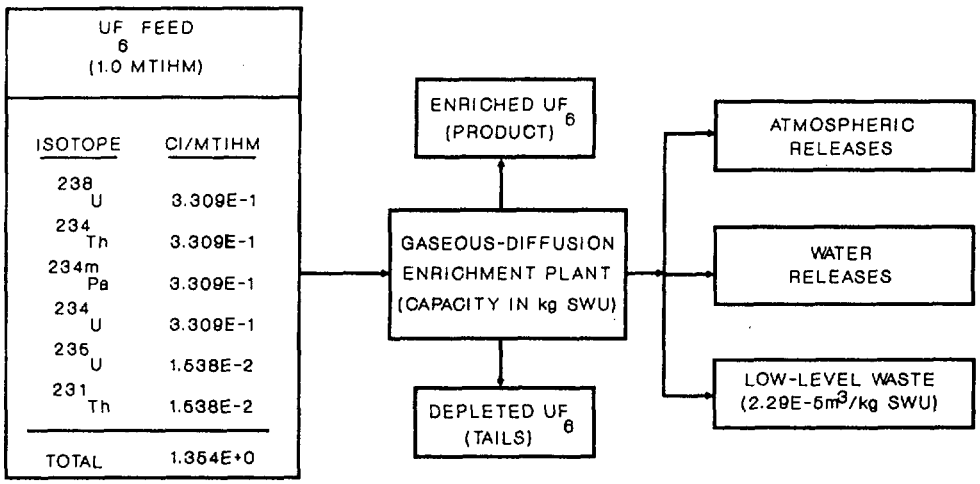


Fractions of elements from yellowcake in waste and product streams from a solvent extraction-fluorination UF_6 conversion plant

	Waste streams				
Element	Atmospheric releases	Water releases	Low-level wastes	Chemical wastes	Product stream (UF_6)
Uranium	1.35E-5	1.13E-9	2.54E-4	2.79E-5	9.997E-1
Protactinium	9.54E-6	6.54E-10	5.01E-1	2.79E-5	4.99E-1
Thorium	1.28E-5	1.15E-9	1.00E+0	2.50E-6	0.00
Other	5.35E-6	1.15E-11	1.00E+0	2.25E-6	0.00

Fig. A.3. Principal waste and product streams from a solvent extraction-fluorination UF_6 conversion plant.

ORNL DWG 89-7806



Separative work units required to produce 1.0 kg of enriched uranium from natural uranium by gaseous diffusion while generating tails containing 0.2 wt % ^{235}U

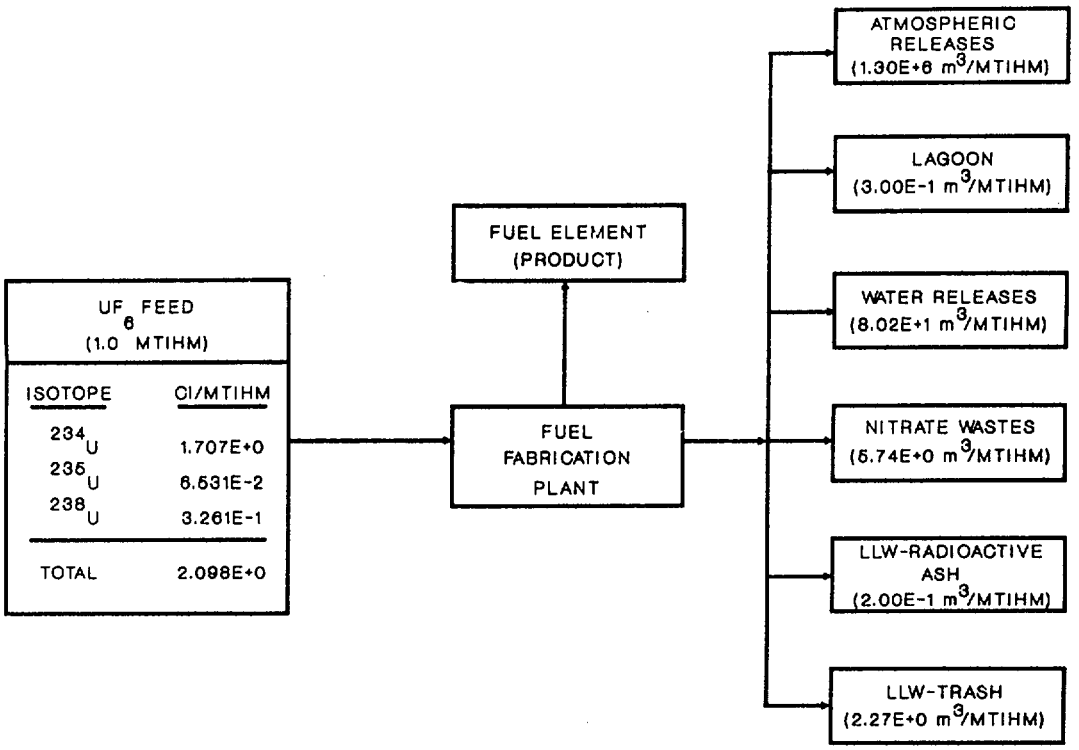
Product desired enrichment (wt % ^{235}U)	Feed natural (0.711 wt % ^{235}U) uranium (kg)	Separative work units (No. of kg SWU)
2	3.523	2.194
3	5.479	4.306
4	7.436	6.544

Fractions of elements from feed in waste and product streams from a gaseous-diffusion uranium enrichment plant

	Waste streams			
Element	Atmospheric releases	Water releases	LLW	Product and tails streams
Uranium	1.4E-6	6.1E-6	4.74E-5	9.9994E-1
Other	1.0E-3	2.0E-3	9.97E-1	0.0

Fig. A.4. Principal waste and product streams from a gaseous diffusion uranium enrichment plant.

ORNL DWG 89-7807

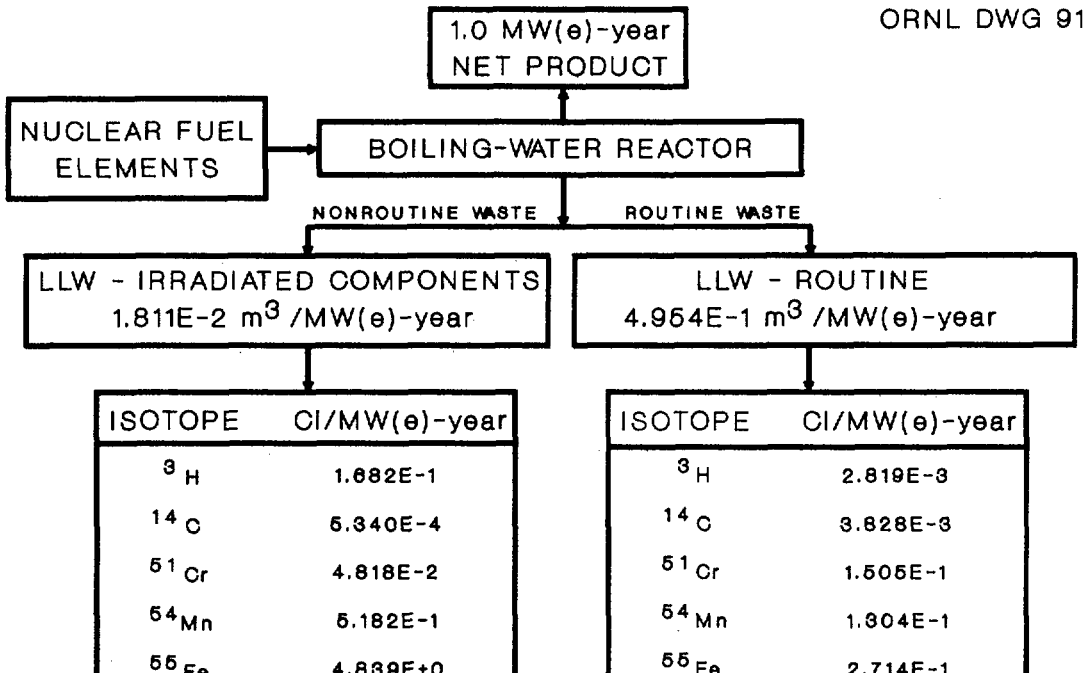


Fractions of uranium from feed in waste and product streams from a fuel fabrication plant

	Waste streams						
Element	Atmospheric releases	Lagoon	Water releases	Nitrate wastes	Radioactive ash	Trash	Product stream (fuel element)
Uranium	1.6E-6	9.6E-4	4.9E-4	1.1E-4	1.0E-6	2.8E-3	9.956E-1

Fig. A.5. Principal waste and product streams from a fuel fabrication plant.

ORNL DWG 91-8696



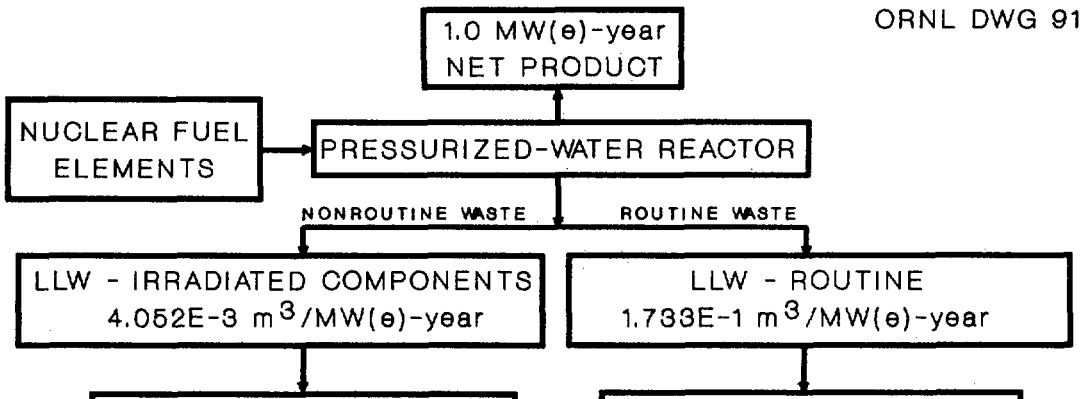
ISOTOPE	Ci/MW(e)-year
^{3}H	1.682E-1
^{14}C	5.340E-4
^{51}Cr	4.818E-2
^{54}Mn	5.182E-1
^{55}Fe	4.839E+0
^{58}Co	1.170E-1
^{59}Fe	8.492E-3
^{59}Ni	3.195E-2
^{60}Co	6.688E+0
^{63}Ni	5.061E-1
^{65}Zn	1.354E-1
^{90}Sr	1.989E-5
^{90}Y	1.989E-5
^{94}Nb	5.246E-6
^{99}Tc	1.081E-4
^{129}I	3.381E-5
^{134}Cs	2.230E-3
^{137}Cs	7.311E-2
^{137m}Ba	6.921E-2
^{241}Pu	1.121E-4
^{242}Cm	1.080E-4
TOTAL	1.321E+1

ISOTOPE	Ci/MW(e)-year
^{3}H	2.819E-3
^{14}C	3.828E-3
^{51}Cr	1.505E-1
^{54}Mn	1.304E-1
^{55}Fe	2.714E-1
^{58}Co	3.312E-2
^{59}Fe	8.218E-3
^{59}Ni	1.052E-4
^{60}Co	5.822E-1
^{63}Ni	1.338E-2
^{65}Zn	1.642E-1
^{90}Sr	6.816E-4
^{90}Y	6.816E-4
^{94}Nb	3.781E-6
^{99}Tc	4.316E-5
^{129}I	4.105E-4
^{134}Cs	7.333E-2
^{137}Cs	8.985E-2
^{137m}Ba	8.498E-2
^{144}Ce	3.664E-4
^{144}Pr	3.664E-4
^{241}Pu	6.751E-4
^{242}Cm	1.232E-5
TOTAL	1.612E+0

NOTE:
NET PRODUCT IS THE ELECTRICAL ENERGY LEAVING THE PLANT FOR DISTRIBUTION

Fig. A.6. Principal waste and product streams from a boiling-water reactor.

ORNL DWG 91-8697



ISOTOPE	Ci/MW(e)-year
^{3}H	6.307E-3
^{14}C	7.794E-5
^{51}Cr	2.103E-2
^{54}Mn	8.410E-2
^{55}Fe	7.550E-1
^{58}Co	1.795E-1
^{59}Fe	1.553E-3
^{59}Ni	5.512E-4
^{60}Co	1.112E-0
^{63}Ni	1.400E-1
^{65}Zn	1.920E-7
^{90}Sr	1.883E-5
^{90}Y	1.883E-5
^{94}Nb	2.463E-8
^{99}Tc	5.649E-8
^{134}Cs	2.462E-2
^{137}Cs	4.225E-2
^{137m}Ba	3.996E-2
^{144}Ce	9.799E-8
^{144}Pr	9.799E-8
^{241}Pu	1.991E-6
TOTAL	2.407E+0

ISOTOPE	Ci/MW(e)-year
^{3}H	1.159E-2
^{14}C	8.729E-4
^{51}Cr	1.942E-3
^{54}Mn	1.207E-2
^{55}Fe	3.784E-2
^{58}Co	9.451E-2
^{59}Fe	2.853E-4
^{59}Ni	1.806E-4
^{60}Co	1.423E-1
^{63}Ni	6.392E-2
^{65}Zn	6.836E-5
^{90}Sr	2.272E-2
^{90}Y	2.272E-2
^{94}Nb	1.240E-6
^{99}Tc	3.935E-5
^{129}I	8.469E-6
^{134}Cs	5.599E-2
^{137}Cs	7.179E-2
^{137m}Ba	6.788E-2
^{144}Ce	3.186E-4
^{144}Pr	3.186E-4
^{241}Pu	3.965E-4
^{242}Cm	6.155E-4
TOTAL	6.084E-1

NOTE:
NET PRODUCT IS THE ELECTRICAL ENERGY LEAVING THE PLANT FOR DISTRIBUTION.

Fig. A.7. Principal waste and product streams from a pressurized-water reactor.

ORNL DWG 89-7810

DECOMMISSIONING OF 1-MW(e) CAPACITY OF BOILING-WATER REACTOR (IMMEDIATE DECOMMISSIONING)

LOW-LEVEL WASTE

PACKAGED WASTE VOLUME = 1.64E+1 m^3/MW(e)

TOTAL ACTIVITY = 2.63E+2 Ci/MW(e)

	WASTE CLASS		
	A	B	C
Volume, m^3/MW(e)	1.60E+1	3.23E-1	4.59E-2
Activity, Ci/MW(e)	1.23E+1	3.88E+1	2.12E+2
Specific Activity, Ci/m^3			
^{14}C	3.97E-6	1.03E-3	1.68E-1
^{59}Ni	1.40E-5	6.31E-3	1.00E+0
^{94}Nb	2.15E-8	1.44E-5	2.39E-3
^{99}Tc	9.34E-8	3.15E-7	5.02E-5
^{60}Co	2.70E-1	4.29E+1	5.37E+2
^{63}Ni	1.97E-3	8.73E-1	1.37E+2
^{90}Sr	5.48E-4	5.07E-2	0.00E+0
^{90}Y	5.48E-4	5.07E-2	0.00E+0
^{137}Cs	2.54E-2	3.44E+0	0.00E+0
^{137m}Ba	2.40E-2	3.25E+0	0.00E+0
Half-Life <5 yr	4.47E-1	6.90E+1	3.93E+3
Total	7.69E-1	1.20E+2	4.61E+3

GREATER-THAN-CLASS-C LOW-LEVEL WASTE

PACKAGED WASTE VOLUME = 4.07E-2 m^3/MW(e)

TOTAL ACTIVITY = 5.29E+3 Ci/MW(e)

	GREATER THAN CLASS C
Volume, m^3/MW(e)	4.07E-2
Activity, Ci/MW(e)	5.29E+3
Specific Activity, Ci/m^3	
^{14}C	5.00E+0
^{59}Ni	3.00E+1
^{94}Nb	7.10E-2
^{99}Tc	1.50E-3
^{60}Co	1.60E+4
^{63}Ni	4.20E+3
Half-Life <5 yr	1.10E+5
Total	1.30E+5

Fig. A.8. Boiling-water reactor decommissioning wastes per 1-MW(e) capacity.

ORNL DWG 90-8312

DECOMMISSIONING OF 1-MW(e) CAPACITY OF PRESSURIZED WATER REACTOR (IMMEDIATE DECOMMISSIONING)

LOW-LEVEL WASTE

PACKAGED WASTE VOLUME = 1.55E+1 m^3/MW(e)

TOTAL ACTIVITY = 1.06E+2 Ci/MW(e)

	WASTE CLASS		
	A	B	C
Volume, m^3/MW(e)	1.53E+1	1.82E-1	1.45E-2
Activity, Ci/MW(e)	3.28E+1	4.40E+1	2.91E+1
Specific Activity, Ci/m^3			
^{14}C	0.00E+0	0.00E+0	0.00E+0
^{59}Ni	4.75E-5	7.23E-3	5.51E-1
^{94}Nb	2.41E-8	5.22E-5	4.06E-3
^{99}Tc	0.00E+0	0.00E+0	0.00E+0
^{60}Co	3.57E-1	7.83E+1	7.39E+2
^{63}Ni	5.66E-3	1.16E+0	8.99E+1
^{90}Sr	4.88E-5	1.73E-3	0.00E+0
^{90}Y	4.88E-5	1.73E-3	0.00E+0
^{137}Cs	5.39E-2	2.06E+0	0.00E+0
^{137m}Ba	5.10E-2	1.95E+0	0.00E+0
Half-Life <5 yr	1.68E+0	1.59E+2	1.18E+3
Total	2.15E+0	2.42E+2	2.01E+3

GREATER-THAN-CLASS-C LOW-LEVEL WASTE

PACKAGED WASTE VOLUME = 1.13E-1 m^3/MW(e)

TOTAL ACTIVITY = 4.07E+3 Ci/MW(e)

	GREATER THAN CLASS C
Volume, m^3/MW(e)	1.13E-1
Activity, Ci/MW(e)	4.07E+3
Specific Activity, Ci/m^3	
^{14}C	0.00E+0
^{59}Ni	1.00E+1
^{94}Nb	7.22E-2
^{99}Tc	0.00E+0
^{60}Co	1.28E+4
^{63}Ni	1.62E+3
Half-Life <5 yr	2.16E+4
Total	3.60E+4

Fig. A.9. Pressurized-water reactor decommissioning wastes per 1-MW(e) capacity.

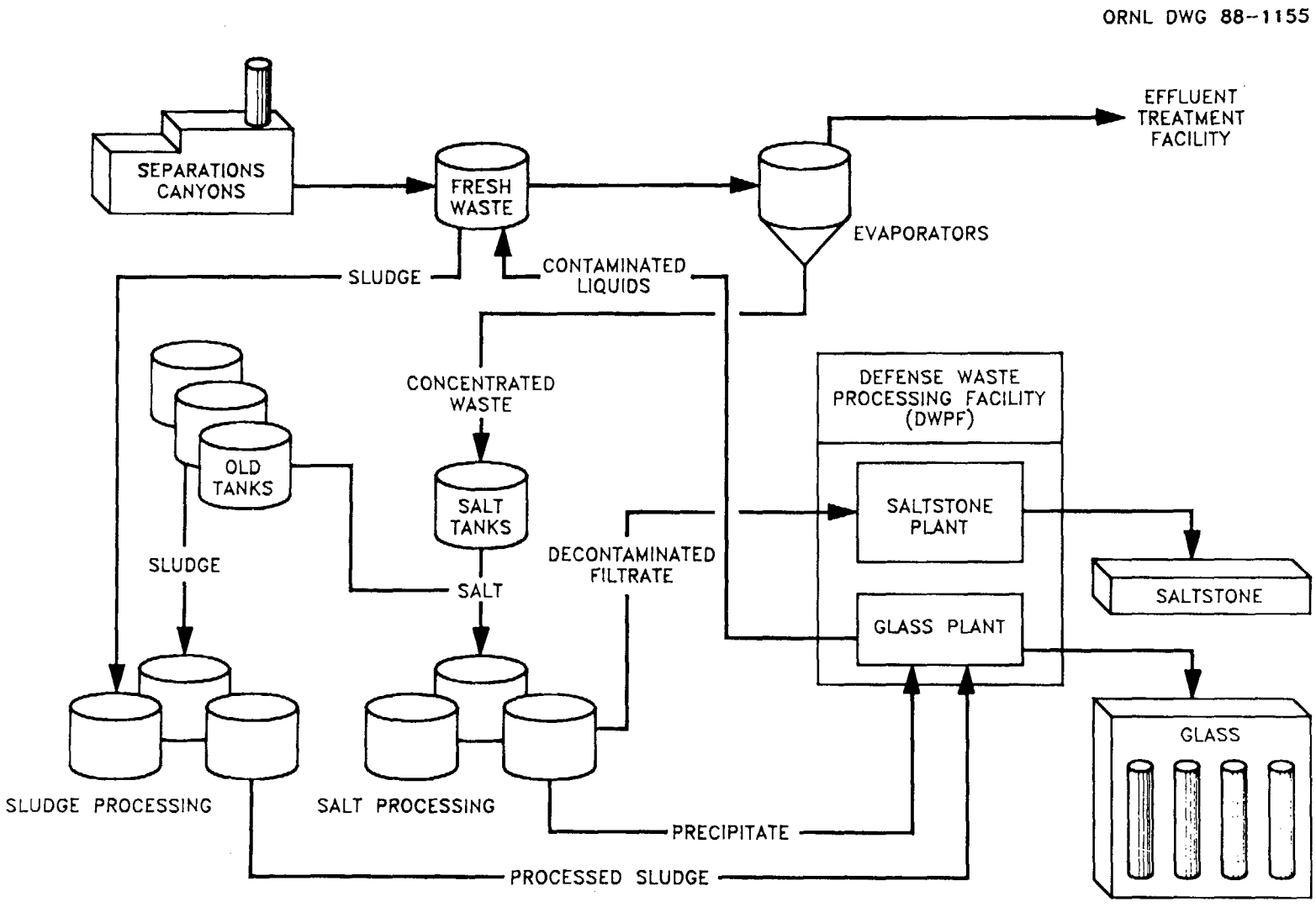


Fig. A.10. Waste flow diagram for the SRS Defense Waste Processing Facility.

Table A.1. Estimated representative unit activity and thermal power characteristics of various types of radioactive materials and wastes

Radioactive material/ waste type	Unit activity (Ci/m^3)	Unit thermal power (W/m^3)
Spent fuel[a]		
BWR	1,000,000-10,000,000	3,500-40,000
PWR	2,000,000-20,000,000	7,500-65,000
High-level waste	1,500-15,000	5-50
Transuranic waste		
Remote handled, stored	1,000	1-2
Contact handled, stored	25-50	0.5-1.5
Buried	0.25-0.50	0.005-0.010
Low-level waste[b]		
DOE sites	9-27	0.012-0.054
Commercial sites[c]	4.6-6.4	0.30-1.60
Class A	0.5-0.7	0.03-0.10
Class B	55-60	14-15
Class C	0.1->7,000[d]	0.003-115[d]
GTCC[e]	>0.1-No limit	>0.003-No limit
Uranium mill tailings	0.010	0.00020

[a]Lower-bound levels are based on cumulative spent fuel discharged; upper-bound levels are based on annual discharges.

[b]Based on 1986-1988 Solid Waste Information Management System (SWIMS) and the national Low-Level Waste Management Program (LLWMP) data access system, both of which were maintained by EG&G, Idaho, Inc., Idaho Falls, Idaho.

[c]Waste classification is defined by the NRC in 10 CFR 61.55 on the basis of concentration of certain long- and short-lived radionuclides. The classification system is designed to minimize potential exposures in both the short and long term. The gross Ci/m^3 shown above are representative of typical LLW shipped to commercial disposal sites. Most medical wastes are Class A. The nuclear power plant wastes account for most of the radioactivity, but some industrial wastes are in the Class B and C categories.

[d]Maximum for ^{63}Ni in activated metal or ^{90}Sr. There is no limit on concentration of ^{3}H, ^{60}Co, or nuclides with half-lives <5 years. The maximum thermal power shown is based on the highest reported gross Ci/m^3 analysis for irradiated core components (1986-1988) and assumes all the activity is due to ^{60}Co, which would yield the greatest heat output. If the activity is due to activation products, such as ^{54}Mn, ^{58}Co, etc., the Ci/m^3 could be much higher for individual shipments and the total W/m^3 could exceed the value shown.

[e]In temporary storage. The concentration of actinides and ^{129}I determine the lower activity boundary. There is no limit on concentration of ^{3}H, ^{60}Co, or nuclides with half-lives <5 years.

Table A.2. Basic factors used for fuel cycle, DOE waste, and I/I waste projections[a]

Activity/facility	Waste type	Annual waste volume generation rate
Electric power generation		Per unit energy generated [m^3/GW(e)-year]
Boiling-water reactor	LLW (routine)	495.4
	LLW (nonroutine)	18.11
Pressurized-water reactor	LLW (routine)	173.3
	LLW (nonroutine)	4.052
Nuclear fuel cycle support[b]		
Uranium mill	Mill tailings	118,000
Uranium conversion[c]	LLW	10.403
Uranium enrichment[d]	LLW	3.52
Fuel fabrication	LLW	87.36
DOE wastes		Annual increase in waste volume inventory during 1990 (m^3/year)
	LLW	54,500
	TRU	1,493
	HLW	18,500[e]
Industrial/institutional wastes		Annual increase in waste volume inventory during 1990 (m^3/year)
	LLW	14,160

[a]Volumes given are typical for each operation. Many fuel cycle operations occur years before or after electricity from the nuclear reactor is generated.

[b]Waste quantities for the case of no spent fuel recycle and based on a ratio of PWRs to BWRs of 2 to 1.

[c]Assumes one-half of conversion demand is met by direct fluorination and the remaining half of demand is met by solvent extraction-fluorination.

[d]Assumes enrichment demand is met by gaseous diffusion.

[e]This is the difference between the total HLW in storage through 1990 (reported in Table 2.5) and the total HLW in storage through 1989 (reported in Table 2.5 of ref. 4). Such a quantity represents the annual change to all forms of HLW in storage. The positive number listed represents a net annual volume increase that results from combined changes in both the annual rate of waste generation and waste management operations such as evaporation and calcination.

Table A.3. Lifetime radioactive waste generation by light-water reactors and supporting fuel cycle activities

Waste type	Reference BWR, 1 GW(e)		Reference PWR, 1 GW(e)	
	Volume (m^3)	Radioactivity (undecayed curies)	Volume (m^3)	Radioactivity (undecayed curies)
1. Fuel cycle wastes (no reprocessing)[a]				
A. Mill tailings	3.007E+06	2.353E+04	3.098E+06	2.424E+04
B. LLW from uranium conversion[b]	2.651E+02	2.975E+03	2.732E+02	3.066E+03
C. LLW from uranium enrichment[c]	8.502E+01	3.355E+03	9.479E+01	3.457E+03
D. LLW from fuel fabrication	2.511E+03	5.974E+00	2.151E+03	5.118E+00
2. LLW from reactor power generation[a]				
A. Routine wastes	1.288E+04	4.191E+04	4.506E+03	1.582E+04
B. Nonroutine wastes	4.709E+02	3.435E+05	1.054E+02	6.258E+04
3. Reactor spent fuel[a]	4.792E+02[d]	1.945E+09[e]	3.511E+02[d]	2.188E+09[e]
4. Decommissioning wastes				
A. LLW	1.640E+04	2.631E+05	1.548E+04	1.061E+05
B. Greater-than-Class-C LLW	4.070E+01	5.290E+06	1.130E+02	4.070E+06
Totals	3.040E+06	1.951E+09	3.121E+06	2.192E+09

[a]Waste generated from 40 years of reactor operation and 26 GW(e)-years of electric energy production.

[b]Assumes one-half of conversion demand will be met by direct fluorination and the remaining half by solvent extraction-fluorination.

[c]Applies to the gaseous diffusion process.

[d]Includes spacing between the stacked fuel rods of each assembly.

[e]Based on activity levels measured 1 year after reactor discharge, as reported in ref. 5 from using the ORIGEN2 code (ref. 6). Activity levels reported for the BWR are based on a burnup of 27,500 MWd/MTIHM. For the PWR, these levels are based on a burnup of 33,000 MWd/MTIHM.

Table A.4. Mass, radioactivity, and thermal power of nuclides in domestic commercial LWR spent fuel at the end of calendar year 1990[a]

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
1	Hydrogen	Stable[b]	9.71E+03	1.05E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Hydrogen	3	1.74E+02	1.13E+03	1.68E+06	1.09E+07	5.65E+01	3.68E+02
2	Helium	Stable	5.64E+03	4.84E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Lithium	Stable	2.38E+03	2.39E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Beryllium	Stable	2.15E+00	1.89E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Boron	Stable	2.19E+03	2.18E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Carbon	Stable	3.86E+05	3.92E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Carbon	14	9.01E+02	8.01E+03	4.02E+03	3.57E+04	1.18E+00	1.05E+01
7	Nitrogen	Stable	2.66E+05	2.71E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Oxygen	Stable	2.94E+08	2.95E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Fluorine	Stable	2.34E+04	2.34E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Neon	Stable	9.07E-01	7.99E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Sodium	Stable	3.27E+04	3.27E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Sodium	24	1.94E-04	1.94E-04	1.69E+03	1.69E+03	4.69E+01	4.69E+01
12	Magnesium	Stable	4.45E+03	4.44E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Aluminum	Stable	1.86E+05	1.77E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Silicon	Stable	1.04E+06	1.05E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Phosphorus	Stable	5.35E+05	4.86E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Phosphorus	32	3.57E-01	3.57E-01	1.02E+05	1.02E+05	1.03E+03	1.03E+03
16	Sulfur	Stable	5.63E+04	5.88E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Chlorine	Stable	1.08E+04	1.09E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Argon	Stable	8.65E+02	7.68E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Potassium	Stable	3.73E+00	3.29E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Calcium	Stable	4.36E+03	4.37E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Scandium	Stable	2.44E-01	2.15E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Titanium	Stable	1.93E+05	1.80E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Vanadium	Stable	3.77E+04	3.62E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Vanadium	50	1.22E+02	1.12E+03	2.17E-11	2.00E-10	2.40E-13	2.21E-12
24	Chromium	Stable	2.39E+07	2.39E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Chromium	51	8.78E+01	8.78E+01	8.12E+06	8.12E+06	1.74E+03	1.74E+03
25	Manganese	Stable	1.97E+06	2.00E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Manganese	54	1.90E+02	3.11E+02	1.47E+06	2.41E+06	7.34E+03	1.20E+04
26	Iron	Stable	7.20E+07	7.29E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Iron	55	4.99E+03	1.58E+04	1.25E+07	3.96E+07	4.22E+02	1.34E+03
	Iron	59	3.25E+00	3.26E+00	1.60E+05	1.60E+05	1.24E+03	1.24E+03
27	Cobalt	Stable	1.77E+05	1.73E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cobalt	58	1.03E+02	1.06E+02	3.28E+06	3.36E+06	1.97E+04	2.01E+04
	Cobalt	60	1.44E+04	6.55E+04	1.63E+07	7.41E+07	2.52E+05	1.14E+06
28	Nickel	Stable	2.31E+07	2.20E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Nickel	59	1.35E+05	1.10E+06	1.03E+04	8.33E+04	4.07E-01	3.31E+00
	Nickel	63	2.33E+04	1.80E+05	1.44E+06	1.11E+07	1.45E+02	1.12E+03
29	Copper	Stable	3.91E+04	3.85E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
30	Zinc	Stable	8.80E+04	8.80E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Zinc	65	2.31E+01	3.37E+01	1.91E+05	2.78E+05	6.67E+02	9.72E+02
31	Gallium	Stable	7.14E+01	6.32E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Germanium	Stable	1.30E+03	1.11E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Arsenic	Stable	4.10E+02	3.51E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Selenium	Stable	1.01E+05	8.61E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Selenium	79	1.21E+04	1.03E+05	8.43E+02	7.19E+03	2.10E-01	1.79E+00
35	Bromine	Stable	4.40E+04	3.77E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Krypton	Stable	6.90E+05	5.87E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Krypton	81	4.73E-02	3.91E-01	9.95E-04	8.23E-03	1.23E-07	1.02E-06
	Krypton	85	4.76E+04	2.90E+05	1.87E+07	1.14E+08	2.80E+04	1.71E+05
37	Rubidium	Stable	2.01E+05	1.71E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Rubidium	86	3.41E+00	3.41E+00	2.77E+05	2.77E+05	1.25E+03	1.25E+03
	Rubidium	87	4.99E+05	4.25E+06	4.37E-02	3.72E-01	3.65E-05	3.11E-04
38	Strontium	Stable	7.15E+05	6.08E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Strontium	89	1.13E+04	1.13E+04	3.28E+08	3.30E+08	1.13E+06	1.14E+06
	Strontium	90	1.08E+06	8.07E+06	1.48E+08	1.10E+09	1.71E+05	1.28E+06
39	Yttrium	Stable	8.77E+05	7.37E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Yttrium	90	2.75E+02	2.03E+03	1.50E+08	1.10E+09	8.29E+05	6.12E+06
	Yttrium	91	2.04E+04	2.07E+04	5.01E+08	5.07E+08	1.80E+06	1.82E+06
40	Zirconium	Stable	7.11E+08	7.71E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Zirconium	93	1.68E+06	1.46E+07	4.23E+03	3.66E+04	4.92E-01	4.25E+00
	Zirconium	95	3.82E+04	3.88E+04	8.20E+08	8.34E+08	4.15E+06	4.23E+06
41	Niobium	Stable	1.20E+06	1.11E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Niobium	93m	1.29E+00	3.78E+01	3.65E+02	1.07E+04	6.46E-02	1.89E+00
	Niobium	94	1.40E+04	1.13E+05	2.62E+03	2.11E+04	2.67E+01	2.15E+02
	Niobium	95	3.25E+04	3.33E+04	1.27E+09	1.30E+09	6.10E+06	6.25E+06
	Niobium	95m	1.66E+01	1.68E+01	6.31E+06	6.42E+06	8.77E+03	8.91E+03
42	Molybdenum	Stable	7.42E+06	6.35E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Technetium	99	1.60E+06	1.38E+07	2.71E+04	2.33E+05	1.36E+01	1.17E+02
44	Ruthenium	Stable	4.49E+06	3.81E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ruthenium	103	1.51E+04	1.51E+04	4.88E+08	4.89E+08	1.63E+06	1.64E+06
	Ruthenium	106	2.57E+05	4.59E+05	8.60E+08	1.54E+09	5.11E+04	9.14E+04
45	Rhodium	Stable	8.77E+05	7.66E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Rhodium	103m	1.35E+01	1.36E+01	4.41E+08	4.41E+08	1.01E+05	1.02E+05
	Rhodium	106	2.41E-01	4.32E-01	8.60E+08	1.54E+09	8.25E+06	1.47E+07
46	Palladium	Stable	2.09E+06	1.74E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Palladium	107	4.64E+05	3.95E+06	2.39E+02	2.03E+03	1.41E-02	1.20E-01
47	Silver	Stable	1.61E+05	1.39E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Silver	108	9.02E-10	1.48E-08	6.63E-01	1.08E+01	2.47E-03	4.04E-02
	Silver	108m	2.86E-01	4.67E+00	7.45E+00	1.22E+02	7.21E-02	1.18E+00
	Silver	110	1.81E-05	2.60E-05	7.54E+04	1.09E+05	5.42E+02	7.80E+02
	Silver	110m	1.19E+03	1.72E+03	5.67E+06	8.17E+06	9.47E+04	1.36E+05
	Silver	111	2.85E+01	2.85E+01	4.50E+06	4.50E+06	1.01E+04	1.01E+04

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
48	Cadmium	Stable	2.79E+05	2.43E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cadmium	109	8.03E-01	1.68E+00	2.07E+03	4.33E+03	2.41E-01	5.03E-01
	Cadmium	113m	5.28E+02	3.47E+03	1.14E+05	7.52E+05	1.93E+02	1.27E+03
	Cadmium	115m	2.58E+01	2.58E+01	6.56E+05	6.58E+05	2.45E+03	2.46E+03
49	Indium	Stable	2.32E+03	2.25E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Indium	114	6.90E-05	6.94E-05	9.51E+04	9.56E+04	4.53E+02	4.55E+02
	Indium	114m	4.29E+00	4.31E+00	9.93E+04	9.99E+04	1.40E+02	1.41E+02
	Indium	115	5.03E+03	4.88E+04	3.13E-08	3.04E-07	4.49E-11	4.36E-10
	Indium	115m	5.13E-02	5.13E-02	3.25E+05	3.25E+05	6.49E+02	6.49E+02
50	Tin	Stable	1.17E+07	1.26E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Tin	117m	1.60E+01	1.60E+01	1.28E+06	1.28E+06	2.37E+03	2.37E+03
	Tin	119m	3.19E+03	4.76E+03	1.43E+07	2.13E+07	7.39E+03	1.10E+04
	Tin	121m	4.53E+01	3.91E+02	2.68E+03	2.32E+04	5.37E+00	4.64E+01
	Tin	123	4.66E+02	5.33E+02	3.84E+06	4.38E+06	1.20E+04	1.37E+04
	Tin	125	1.21E+01	1.21E+01	1.31E+06	1.31E+06	8.69E+03	8.69E+03
	Tin	126	5.68E+04	4.87E+05	1.61E+03	1.38E+04	2.01E+00	1.72E+01
51	Antimony	Stable	4.33E+04	3.80E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Antimony	124	3.71E+01	3.75E+01	6.49E+05	6.57E+05	8.61E+03	8.72E+03
	Antimony	125	3.13E+04	1.04E+05	3.23E+07	1.08E+08	1.01E+05	3.37E+05
	Antimony	126	1.47E+00	1.47E+00	1.23E+05	1.23E+05	2.27E+03	2.27E+03
	Antimony	127	1.27E+01	1.27E+01	3.39E+06	3.39E+06	2.01E+04	2.01E+04
52	Tellurium	Stable	9.66E+05	8.24E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Tellurium	123	2.17E+01	1.89E+02	6.31E-09	5.50E-08	6.40E-13	5.57E-12
	Tellurium	123m	2.11E+00	2.34E+00	1.88E+04	2.08E+04	2.73E+01	3.02E+01
	Tellurium	125m	4.22E+02	1.44E+03	7.60E+06	2.60E+07	6.39E+03	2.19E+04
	Tellurium	127	5.72E+00	6.14E+00	1.51E+07	1.62E+07	2.04E+04	2.19E+04
	Tellurium	127m	1.28E+03	1.40E+03	1.21E+07	1.32E+07	6.51E+03	7.12E+03
	Tellurium	129	4.09E-01	4.09E-01	8.57E+06	8.58E+06	3.06E+04	3.06E+04
	Tellurium	129m	4.21E+02	4.21E+02	1.27E+07	1.27E+07	2.22E+04	2.22E+04
	Tellurium	132	1.14E+02	1.14E+02	3.48E+07	3.48E+07	6.89E+04	6.89E+04
53	Iodine	Stable	1.11E+05	9.54E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Iodine	129	3.73E+05	3.20E+06	6.58E+01	5.65E+02	3.04E-02	2.61E-01
	Iodine	131	5.06E+02	5.06E+02	6.28E+07	6.28E+07	2.13E+05	2.13E+05
54	Xenon	Stable	1.08E+07	9.16E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Xenon	129m	3.27E-03	3.27E-03	4.13E+02	4.13E+02	5.78E-01	5.78E-01
	Xenon	131m	2.04E+01	2.04E+01	1.71E+06	1.71E+06	1.64E+03	1.64E+03
	Xenon	133	5.01E+02	5.01E+02	9.39E+07	9.39E+07	1.01E+05	1.01E+05
55	Cesium	Stable	2.31E+06	1.99E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cesium	134	2.07E+05	5.49E+05	2.68E+08	7.10E+08	2.73E+06	7.23E+06
	Cesium	135	6.52E+05	5.48E+06	7.52E+02	6.32E+03	2.51E-01	2.11E+00
	Cesium	136	6.79E+01	6.79E+01	4.98E+06	4.98E+06	6.79E+04	6.79E+04
	Cesium	137	2.45E+06	1.83E+07	2.13E+08	1.60E+09	2.36E+05	1.77E+06
56	Barium	Stable	2.81E+06	2.38E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Barium	136m	3.05E-06	3.05E-06	8.21E+05	8.21E+05	9.92E+03	9.92E+03

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
	Barium	137m	3.75E-01	2.81E+00	2.02E+08	1.51E+09	7.92E+05	5.93E+06
	Barium	140	2.26E+03	2.26E+03	1.65E+08	1.65E+08	4.59E+05	4.59E+05
57	Lanthanum	Stable	2.51E+06	2.14E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Lanthanum	138	1.15E+01	1.01E+02	2.21E-07	1.94E-06	1.62E-09	1.42E-08
	Lanthanum	140	3.42E+02	3.42E+02	1.90E+08	1.90E+08	3.19E+06	3.19E+06
58	Cerium	Stable	2.50E+06	2.12E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cerium	141	1.40E+04	1.40E+04	3.99E+08	3.99E+08	5.84E+05	5.84E+05
	Cerium	142	2.33E+06	1.98E+07	5.58E-02	4.75E-01	0.00E+00	0.00E+00
	Cerium	144	5.16E+05	8.09E+05	1.65E+09	2.58E+09	1.09E+06	1.71E+06
59	Praseodymium	Stable	2.22E+06	1.88E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Praseodymium	143	2.45E+03	2.45E+03	1.65E+08	1.65E+08	3.08E+05	3.08E+05
	Praseodymium	144	2.18E+01	3.42E+01	1.65E+09	2.58E+09	1.21E+07	1.90E+07
	Praseodymium	144m	1.09E-01	1.71E-01	1.98E+07	3.10E+07	6.76E+03	1.06E+04
60	Neodymium	Stable	5.51E+06	4.73E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Neodymium	144	2.21E+06	2.20E+07	2.62E-06	2.60E-05	0.00E+00	0.00E+00
	Neodymium	147	6.75E+02	6.75E+02	5.42E+07	5.42E+07	1.31E+05	1.31E+05
61	Promethium	147	2.68E+05	8.82E+05	2.48E+08	8.18E+08	8.90E+04	2.93E+05
	Promethium	148	7.11E+01	7.11E+01	1.17E+07	1.17E+07	9.00E+04	9.00E+04
	Promethium	148m	4.44E+02	4.45E+02	9.50E+06	9.52E+06	1.20E+05	1.21E+05
62	Samarium	Stable	8.88E+05	7.72E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Samarium	147	1.55E+05	2.96E+06	3.53E-03	6.74E-02	4.83E-05	9.23E-04
	Samarium	148	3.47E+05	2.80E+06	1.05E-07	8.46E-07	1.25E-09	1.01E-08
	Samarium	149	6.03E+03	6.00E+04	1.45E-09	1.44E-08	0.00E+00	0.00E+00
	Samarium	151	2.72E+04	2.42E+05	7.17E+05	6.36E+06	8.40E+01	7.46E+02
63	Europium	Stable	2.24E+05	1.88E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Europium	152	6.59E+01	4.56E+02	1.14E+04	7.89E+04	8.62E+01	5.97E+02
	Europium	154	7.85E+04	4.25E+05	2.12E+07	1.15E+08	1.90E+05	1.03E+06
	Europium	155	2.75E+04	1.20E+05	1.28E+07	5.60E+07	9.29E+03	4.08E+04
	Europium	156	4.54E+02	4.54E+02	2.51E+07	2.51E+07	2.59E+05	2.59E+05
64	Gadolinium	Stable	1.16E+06	1.41E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Gadolinium	152	1.04E+02	2.23E+03	2.27E-09	4.86E-08	2.95E-11	6.34E-10
	Gadolinium	153	2.20E+02	3.70E+02	7.75E+05	1.31E+06	7.00E+02	1.18E+03
65	Terbium	Stable	1.93E+04	2.02E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Terbium	160	1.61E+02	1.66E+02	1.82E+06	1.88E+06	1.49E+04	1.53E+04
	Terbium	161	1.39E+00	1.39E+00	1.63E+05	1.63E+05	3.27E+02	3.27E+02
81	Thallium	Stable	1.97E-09	1.61E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Thallium	206	6.87E-22	6.87E-22	1.50E-13	1.50E-13	1.35E-15	1.35E-15
	Thallium	207	5.06E-12	2.52E-10	9.63E-04	4.80E-02	2.83E-06	1.41E-04
	Thallium	208	7.60E-09	3.07E-07	2.24E+00	9.05E+01	5.27E-02	2.13E+00
	Thallium	209	1.36E-14	8.75E-14	5.56E-06	3.58E-05	9.24E-08	5.94E-07
82	Lead	Stable	2.15E+03	2.16E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Lead	204	3.00E+01	3.01E+02	3.76E-13	3.77E-12	5.80E-15	5.80E-14
	Lead	205	6.98E-02	6.17E-01	4.06E-06	3.59E-05	1.18E-10	1.04E-09
	Lead	209	1.96E-10	5.04E-10	8.92E-04	2.29E-03	1.03E-06	2.63E-06

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
	Lead	210	7.31E-08	7.91E-06	5.58E-06	6.04E-04	1.29E-09	1.40E-07
	Lead	211	3.91E-11	1.95E-09	9.66E-04	4.82E-02	2.89E-06	1.44E-04
	Lead	212	4.48E-06	1.81E-04	6.23E+00	2.52E+02	1.19E-02	4.79E-01
	Lead	214	1.31E-12	1.41E-10	4.29E-05	4.62E-03	1.37E-07	1.47E-05
83	Bismuth	Stable	8.74E+02	8.74E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Bismuth	208	1.14E-02	9.89E-02	5.32E-05	4.62E-04	8.38E-07	7.27E-06
	Bismuth	210	1.53E-05	1.53E-05	1.89E+00	1.89E+00	4.36E-03	4.37E-03
	Bismuth	210m	6.63E-02	5.87E-01	3.76E-05	3.33E-04	1.18E-06	1.05E-05
	Bismuth	211	2.31E-12	1.15E-10	9.66E-04	4.82E-02	3.85E-05	1.92E-03
	Bismuth	212	4.25E-07	1.72E-05	6.23E+00	2.52E+02	1.06E-01	4.28E+00
	Bismuth	213	1.33E-11	8.56E-11	2.58E-04	1.66E-03	1.08E-06	6.96E-06
	Bismuth	214	9.71E-13	1.05E-10	4.29E-05	4.62E-03	5.50E-07	5.92E-05
84	Polonium	210	9.69E-03	1.13E-02	4.36E+01	5.08E+01	1.40E+00	1.63E+00
	Polonium	211	2.83E-17	1.41E-15	2.70E-06	1.35E-04	1.22E-07	6.07E-06
	Polonium	212	2.25E-17	9.09E-16	3.99E+00	1.61E+02	2.12E-01	8.55E+00
	Polonium	213	2.00E-20	1.28E-19	2.52E-04	1.62E-03	1.28E-05	8.20E-05
	Polonium	214	1.77E-19	1.44E-17	5.68E-05	4.64E-03	2.64E-06	2.15E-04
	Polonium	215	3.28E-17	1.63E-15	9.66E-04	4.82E-02	4.31E-05	2.15E-03
	Polonium	216	1.79E-11	7.23E-10	6.22E+00	2.52E+02	2.55E-01	1.03E+01
	Polonium	218	1.52E-13	1.63E-11	4.29E-05	4.62E-03	1.55E-06	1.68E-04
85	Astatine	217	1.60E-16	1.03E-15	2.57E-04	1.66E-03	1.10E-05	7.07E-05
86	Radon	218	9.40E-18	9.40E-18	1.39E-05	1.39E-05	5.98E-07	5.98E-07
	Radon	219	7.42E-14	3.70E-12	9.66E-04	4.82E-02	4.01E-05	2.00E-03
	Radon	220	6.75E-09	2.73E-07	6.22E+00	2.52E+02	2.36E-01	9.56E+00
	Radon	222	2.79E-10	3.00E-08	4.29E-05	4.62E-03	1.42E-06	1.53E-04
87	Francium	221	1.45E-12	9.34E-12	2.57E-04	1.66E-03	9.94E-06	6.39E-05
	Francium	223	3.76E-13	1.75E-11	1.45E-05	6.76E-04	3.77E-08	1.76E-06
88	Radium	222	1.04E-14	1.04E-14	1.39E-05	1.39E-05	5.50E-07	5.50E-07
	Radium	223	1.89E-08	9.40E-07	9.66E-04	4.82E-02	3.44E-05	1.72E-03
	Radium	224	3.91E-05	1.58E-03	6.22E+00	2.52E+02	2.14E-01	8.64E+00
	Radium	225	5.99E-09	4.17E-08	2.35E-04	1.63E-03	1.65E-07	1.15E-06
	Radium	226	4.38E-05	4.69E-03	4.33E-05	4.64E-03	1.25E-06	1.34E-04
	Radium	228	2.44E-11	2.76E-09	5.70E-09	6.47E-07	4.40E-13	4.99E-11
89	Actinium	225	4.43E-09	2.85E-08	2.57E-04	1.66E-03	8.99E-06	5.79E-05
	Actinium	227	1.46E-05	6.77E-04	1.05E-03	4.90E-02	5.10E-07	2.37E-05
	Actinium	228	4.21E-12	4.49E-12	9.44E-06	1.01E-05	8.16E-08	8.71E-08
90	Thorium	226	5.18E-13	5.18E-13	1.39E-05	1.39E-05	5.31E-07	5.31E-07
	Thorium	227	3.20E-08	1.56E-06	9.84E-04	4.78E-02	3.59E-05	1.75E-03
	Thorium	228	7.49E-03	3.05E-01	6.14E+00	2.50E+02	2.01E-01	8.18E+00
	Thorium	229	9.47E-04	7.53E-03	2.02E-04	1.60E-03	6.17E-06	4.91E-05
	Thorium	230	2.96E+00	9.14E+01	5.98E-02	1.85E+00	1.69E-03	5.22E-02
	Thorium	231	7.94E-05	7.68E-04	4.22E+01	4.08E+02	2.37E-02	2.29E-01
	Thorium	232	4.72E-01	1.57E+01	5.18E-08	1.72E-06	1.25E-09	4.17E-08
	Thorium	233	9.46E-12	9.46E-12	3.46E-04	3.46E-04	8.75E-07	8.75E-07
	Thorium	234	3.00E-02	3.02E-01	6.96E+02	7.00E+03	2.82E-01	2.84E+00

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
91	Protactinium	231	5.60E-01	5.75E+00	2.65E-02	2.72E-01	7.98E-04	8.19E-03
	Protactinium	232	1.04E-05	1.04E-05	4.45E+00	4.45E+00	2.91E-02	2.91E-02
	Protactinium	233	3.05E-02	2.49E-01	6.33E+02	5.16E+03	1.44E+00	1.17E+01
	Protactinium	234	4.57E-07	4.56E-06	9.15E-01	9.11E+00	1.31E-02	1.31E-01
	Protactinium	234m	1.01E-06	1.02E-05	6.96E+02	7.00E+03	3.44E+00	3.46E+01
	Protactinium	235	6.36E-17	6.36E-17	2.11E-09	2.11E-09	5.90E-12	5.90E-12
92	Uranium	230	5.08E-10	5.08E-10	1.39E-05	1.39E-05	4.93E-07	4.93E-07
	Uranium	231	4.65E-09	4.65E-09	6.26E-04	6.26E-04	5.17E-07	5.17E-07
	Uranium	232	1.05E+00	1.59E+01	2.25E+01	3.41E+02	7.22E-01	1.09E+01
	Uranium	233	2.77E+00	3.70E+01	2.68E-02	3.58E-01	7.80E-04	1.04E-02
	Uranium	234	3.71E+05	3.67E+06	2.32E+03	2.29E+04	6.68E+01	6.60E+02
	Uranium	235	1.69E+07	1.86E+08	3.65E+01	4.03E+02	9.55E-01	1.05E+01
	Uranium	236	8.03E+06	6.89E+07	5.20E+02	4.46E+03	1.41E+01	1.21E+02
	Uranium	237	5.39E+02	5.39E+02	4.40E+07	4.40E+07	8.33E+04	8.33E+04
	Uranium	238	2.07E+09	2.08E+10	6.96E+02	7.00E+03	1.76E+01	1.78E+02
	Uranium	239	1.98E-02	1.98E-02	6.61E+05	6.61E+05	1.78E+03	1.78E+03
	Uranium	240	2.62E-04	2.62E-04	2.43E+02	2.43E+02	1.99E-01	1.99E-01
93	Neptunium	235	6.30E-03	1.13E-02	8.84E+00	1.59E+01	5.14E-04	9.24E-04
	Neptunium	236	7.89E-01	6.11E+00	1.04E-02	8.05E-02	2.10E-05	1.62E-04
	Neptunium	236m	9.49E-05	9.49E-05	5.60E+01	5.60E+01	4.43E-02	4.43E-02
	Neptunium	237	8.97E+05	7.32E+06	6.33E+02	5.16E+03	1.93E+01	1.58E+02
	Neptunium	238	2.13E+01	2.13E+01	5.54E+06	5.54E+06	2.65E+04	2.65E+04
	Neptunium	239	1.69E+03	1.69E+03	3.92E+08	3.92E+08	9.48E+05	9.48E+05
	Neptunium	240	4.22E-04	4.22E-04	5.09E+03	5.09E+03	5.39E+01	5.39E+01
	Neptunium	240m	2.34E-06	2.34E-06	2.47E+02	2.47E+02	1.43E+00	1.43E+00
	Neptunium	241	1.67E-13	1.67E-13	8.13E-06	8.13E-06	2.27E-08	2.27E-08
94	Plutonium	236	2.03E+00	6.34E+00	1.08E+03	3.37E+03	3.75E+01	1.17E+02
	Plutonium	237	1.82E-02	1.83E-02	2.20E+02	2.21E+02	8.11E-02	8.14E-02
	Plutonium	238	2.79E+05	2.14E+06	4.78E+06	3.66E+07	1.58E+05	1.21E+06
	Plutonium	239	1.08E+07	1.05E+08	6.73E+05	6.52E+06	2.07E+04	2.01E+05
	Plutonium	240	4.80E+06	4.25E+07	1.09E+06	9.69E+06	3.40E+04	3.02E+05
	Plutonium	241	2.60E+06	1.78E+07	2.68E+08	1.83E+09	8.29E+03	5.69E+04
	Plutonium	242	9.80E+05	8.07E+06	3.74E+03	3.08E+04	1.10E+02	9.11E+02
	Plutonium	243	1.99E-01	1.99E-01	5.17E+05	5.17E+05	5.97E+02	5.97E+02
	Plutonium	244	5.21E+01	4.11E+02	9.24E-04	7.30E-03	2.68E-05	2.12E-04
	Plutonium	245	1.98E-06	1.98E-06	2.39E+00	2.39E+00	5.66E-03	5.66E-03
	Plutonium	246	4.27E-07	4.27E-07	2.09E-02	2.09E-02	1.76E-05	1.76E-05
95	Americium	239	3.69E-09	3.69E-09	4.07E-03	4.07E-03	9.84E-06	9.84E-06
	Americium	240	1.59E-05	1.59E-05	4.08E+00	4.08E+00	2.67E-02	2.67E-02
	Americium	241	1.30E+05	6.51E+06	4.47E+05	2.23E+07	1.48E+04	7.42E+05
	Americium	242	5.36E-01	6.57E-01	4.33E+05	5.31E+05	4.92E+02	6.03E+02
	Americium	242m	1.44E+03	1.16E+04	1.40E+04	1.13E+05	5.54E+00	4.46E+01
	Americium	243	1.89E+05	1.50E+06	3.77E+04	2.99E+05	1.21E+03	9.62E+03
	Americium	244	1.35E-02	1.35E-02	1.72E+04	1.72E+04	9.01E+01	9.01E+01
	Americium	244m	1.39E-04	1.39E-04	4.12E+03	4.12E+03	1.25E+01	1.25E+01

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
	Americium	245	4.65E-07	4.65E-07	2.88E+00	2.88E+00	5.34E-03	5.34E-03
	Americium	246	6.84E-10	6.84E-10	2.09E-02	2.09E-02	1.69E-04	1.69E-04
96	Curium	242	1.33E+04	1.61E+04	4.40E+07	5.33E+07	1.62E+06	1.96E+06
	Curium	243	7.19E+02	4.91E+03	3.71E+04	2.53E+05	1.36E+03	9.29E+03
	Curium	244	5.36E+04	3.43E+05	4.34E+06	2.77E+07	1.52E+05	9.70E+05
	Curium	245	2.00E+03	1.54E+04	3.44E+02	2.64E+03	1.14E+01	8.78E+01
	Curium	246	2.55E+02	1.93E+03	7.83E+01	5.94E+02	2.56E+00	1.95E+01
	Curium	247	2.45E+00	1.84E+01	2.27E-04	1.71E-03	7.26E-06	5.45E-05
	Curium	248	1.32E-01	9.72E-01	5.60E-04	4.13E-03	6.98E-05	5.15E-04
	Total		3.32E+09	3.39E+10	1.23E+10	2.34E+10	5.08E+07	8.86E+07

[a]Includes contributions from nuclides in the fuel, cladding, and fuel assembly structural material.
[b]The term "stable" represents a group of nonradioactive nuclides of a particular element.

Table A.5. Representative DOE LLW radionuclide composition by percent activity[a]

Uranium/thorium		Fission product		Induced activity		Alpha, <100 nCi/g		"Other"	
Nuclide	Composition	Nuclide	Composition	Nuclide	Composition	Nuclide	Composition	Nuclide	Composition
^{208}Tl	0.0017	^{60}Co	0.08	^{51}Cr	4.95	^{238}Pu	2.62	^{3}H	1.22
^{212}Pb	0.0045	^{90}Sr	7.77	^{54}Mn	38.10	^{239}Pu	0.20	^{14}C	0.06
^{212}Bi	0.0045	^{90}Y	7.77	^{58}Co	55.40	^{240}Pu	0.70	^{54}Mn	6.76
^{212}Po	0.0029	^{95}Zr	1.27	^{59}Fe	0.49	^{241}Pu	96.4	^{58}Co	6.24
^{216}Po	0.0045	^{95}Nb	2.83	^{60}Co	0.87	^{241}Am	0.004	^{60}Co	18.03
^{224}Ra	0.0045	^{99}Tc	0.02	^{65}Zn	0.19	^{242}Cm	0.056	^{90}Sr	8.48
^{228}Ra	0.0269	^{125}Sb	2.93			^{244}Cm	0.020	^{90}Y	8.48
^{228}Ac	0.0269	^{125m}Te	0.73		100.00			^{99}Tc	0.12
^{228}Th	0.0045	^{106}Ru	6.39				100.000	^{134}Cs	13.98
^{231}Th	0.0259	^{106}Rh	6.39					^{137}Cs	18.45
^{232}Th	0.273	^{134}Cs	0.38					^{137m}Ba	17.45
^{234}Th	33.197	^{137}Cs	17.31					^{238}U	0.73
^{234m}Pa	33.197	^{137m}Ba	16.38						
^{234}Pa	0.0034	^{144}Ce	14.67						100.00
^{235}U	0.0258	^{144}Pr	14.67						
^{238}U	33.197	^{147}Pm	0.06						
		^{151}Sm	0.11						
	100.0000	^{152}Eu	0.09						
		^{154}Eu	0.09						
		^{155}Eu	0.06						
			100.00						

[a]Based on ref. 1.

Table A.6. Average concentrations for representative radionuclides in LLW at commercial disposal sites[a]

Radionuclide	Half-life[b]	Concentration (Ci/m^3)
^{3}H	1.228E+01 y	5.897E-02
^{14}C	5.730E+03 y	2.900E-03
^{51}Cr	2.770E+01 d	8.659E-02
^{54}Mn	3.127E+02 d	9.932E-01
^{58}Co	7.080E+01 d	1.271E+00
^{59}Fe	4.463E+01 d	8.571E-03
^{60}Co	5.271E+00 y	8.872E-01
^{65}Zn	2.444E+02 d	3.323E-03
^{90}Sr	2.860E+01 y	4.432E-01
^{90}Y	6.110E+01 h	4.432E-01
^{95}Zr	6.402E+01 d	5.446E-03
^{95}Nb	3.506E+01 d	1.214E-02
^{99}Tc	2.130E+05 y	5.887E-03
^{125}Sb	2.770E+00 y	1.257E-02
^{125m}Te	5.800E+01 d	3.131E-03
^{106}Ru	3.682E+02 d	2.740E-02
^{106}Rh	2.992E+02 s	2.740E-02
^{134}Cs	2.062E+00 y	6.773E-01
^{137}Cs	3.017E+01 y	1.000E+00
^{137m}Ba	2.552E+00 min	9.460E-01
^{144}Ce	2.843E+02 d	6.291E-02
^{144}Pr	1.728E+01 min	6.291E-02
^{147}Pm	2.623E+00 y	2.573E-04
^{151}Sm	9.000E+01 y	4.717E-04
^{152}Eu	1.360E+01 y	3.860E-04
^{154}Eu	8.800E+00 y	3.860E-04
^{155}Eu	4.960E+00 y	2.573E-04
^{226}Ra	1.600E+03 y	1.156E-04
^{232}Th	1.405E+10 y	1.569E-05
^{235}U	7.038E+08 y	1.817E-06
^{238}U	4.468E+09 y	2.337E-03
^{238}Pu	8.775E+01 y	7.094E-01[c]
^{239}Pu	2.413E+04 y	1.915E-03[c]
^{241}Am	4.322E+02 y	3.603E-04
Total		7.757E+00

[a]Taken from ref. 1.

[b]y = years; d = days; h = hours; min = minutes; and s = seconds.

[c]The commercial disposal site at Barnwell, South Carolina, has not permitted disposal of plutonium; thus, its isotopes are omitted when this list is applied to waste disposed at Barnwell.

Table A.7. Projected chemical and radionuclide composition of saltstone at SRS[a,b]

End of calendar year	Fraction of radionuclide[c]										
	^{3}H	^{90}Sr	^{90}Y	^{99}Tc	^{106}Ru	^{106}Rh	^{125}Sb	^{137}Cs	^{137m}Ba	^{147}Pm	Total
1992	0.023	0.112	0.112	0.201	0.000	0.000	0.007	0.029	0.027	0.489	1.00
1993	0.020	0.087	0.087	0.259	0.001	0.001	0.016	0.023	0.021	0.487	1.00
1994	0.020	0.088	0.088	0.254	0.001	0.001	0.011	0.022	0.021	0.494	1.00
1995	0.022	0.095	0.095	0.262	0.000	0.000	0.009	0.024	0.022	0.468	1.00
1996	0.025	0.102	0.102	0.286	0.000	0.000	0.008	0.027	0.025	0.424	1.00
1997	0.030	0.109	0.109	0.303	0.000	0.000	0.007	0.028	0.026	0.386	1.00
1998	0.030	0.109	0.109	0.352	0.000	0.000	0.006	0.028	0.026	0.339	1.00
1999	0.033	0.115	0.115	0.365	0.000	0.000	0.006	0.028	0.025	0.313	1.00
2000	0.036	0.123	0.123	0.379	0.000	0.000	0.005	0.027	0.025	0.280	1.00
2001	0.039	0.132	0.132	0.394	0.000	0.000	0.005	0.027	0.025	0.245	1.00
2002	0.042	0.141	0.141	0.409	0.000	0.000	0.004	0.027	0.025	0.211	1.00
2003	0.044	0.150	0.150	0.422	0.000	0.000	0.004	0.027	0.025	0.178	1.00
2004	0.046	0.158	0.158	0.433	0.000	0.000	0.004	0.027	0.024	0.149	1.00
2005	0.048	0.165	0.165	0.442	0.000	0.000	0.004	0.026	0.024	0.124	1.00
2006	0.050	0.172	0.172	0.449	0.000	0.000	0.003	0.026	0.024	0.103	1.00
2007	0.050	0.178	0.178	0.456	0.000	0.000	0.003	0.026	0.024	0.085	1.00
2008	0.050	0.178	0.178	0.467	0.000	0.000	0.003	0.026	0.024	0.073	1.00
2009	0.051	0.178	0.178	0.477	0.000	0.000	0.003	0.026	0.024	0.063	1.00
2010	0.051	0.177	0.177	0.487	0.000	0.000	0.003	0.026	0.023	0.054	1.00
2011	0.052	0.176	0.176	0.496	0.000	0.000	0.003	0.025	0.023	0.047	1.00
2012	0.053	0.175	0.175	0.504	0.000	0.000	0.003	0.025	0.023	0.041	1.00
2013	0.054	0.176	0.176	0.508	0.000	0.000	0.003	0.025	0.023	0.035	1.00
2014	0.054	0.176	0.176	0.512	0.000	0.000	0.003	0.025	0.023	0.030	1.00
2015	0.055	0.176	0.176	0.516	0.000	0.000	0.003	0.024	0.022	0.026	1.00
2016	0.055	0.176	0.176	0.520	0.000	0.000	0.003	0.024	0.022	0.023	1.00
2017	0.056	0.176	0.176	0.523	0.000	0.000	0.003	0.024	0.022	0.020	1.00
2018	0.056	0.176	0.176	0.526	0.000	0.000	0.002	0.023	0.021	0.018	1.00
2019	0.057	0.176	0.176	0.529	0.000	0.000	0.002	0.023	0.021	0.016	1.00
2020	0.057	0.175	0.175	0.532	0.000	0.000	0.002	0.022	0.021	0.014	1.00

[a]Taken from ref. 3.

[b]Chemical composition (wt %): fly ash, 46.0; water, 30.2; cement, 11.5; $NaNO_3$, 6.0; NaOH, 1.9; $NaNO_2$, 1.5; $NaAl(OH)_4$, 1.3; Na_2SO_4, 0.7; and other, 0.9.

[c]The radionuclide composition at the end of a year is expressed in terms of the fraction of each significant nuclide making up an average unit of radioactivity in all the saltstone collected from the beginning of the operation of the saltstone plant to the end of the year indicated.

Table A.8. Historical and projected DOE/EIA No New Orders Case commercial LWR net annual electrical generation[a,b]

End of calendar year	Historical generation [MW(e)-years]			End of calendar year	No New Orders Case projected generation [MW(e)-years]		
	BWR	PWR	Total		BWR	PWR	Total
1960	29	4	33	1991	19,510	43,777	63,288
1961	60	97	157	1992	19,665	44,099	63,764
1962	137	96	233	1993	19,665	45,238	64,902
1963	136	208	344	1994	19,665	45,447	65,112
1964	164	198	362	1995	19,665	46,011	65,675
1965	164	212	376	1996	19,931	46,847	66,779
1966	221	334	556	1997	19,931	46,723	66,655
1967	184	419	603	1998	19,931	47,302	67,233
1968	205	781	986	1999	19,931	47,583	67,515
1969	238	1,049	1,287	2000	20,198	48,448	68,646
1970	1,011	1,192	2,203	2001	20,198	48,829	69,027
1971	1,969	2,103	4,075	2002	20,198	48,726	68,924
1972	3,188	2,450	5,641	2003	20,160	49,295	69,455
1973	4,446	4,620	9,073	2004	20,153	49,581	69,734
1974	5,298	6,650	11,955	2005	20,589	50,498	71,088
1975	6,309	12,089	17,395	2006	20,420	50,270	70,691
1976	8,044	13,113	21,343	2007	20,420	49,976	70,396
1977	9,636	17,737	27,388	2008	20,686	50,227	70,913
1978	11,353	19,596	31,142	2009	20,504	50,195	70,699
1979	11,390	17,332	28,662	2010	19,507	49,620	69,128
1980	10,416	17,848	28,343	2011	18,407	48,948	67,354
1981	10,187	20,310	30,517	2012	17,052	47,961	65,013
1982	10,201	20,716	30,938	2013	16,162	44,443	60,605
1983	9,363	22,494	31,883	2014	14,160	40,542	54,702
1984	9,766	26,427	35,072	2015	11,888	37,626	49,514
1985	12,151	30,413	41,382	2016	11,508	35,081	46,589
1986	12,737	33,726	46,495	2017	10,731	32,319	43,050
1987	14,810	36,465	51,275	2018	10,565	30,531	41,096
1988	16,722	41,639	58,361	2019	10,353	30,106	40,459
1989	16,845	43,489	60,334	2020	10,353	29,508	39,861
1990	20,861	44,947	65,808				

[a]Historical data for 1960-1989 are based on refs. 7 and 9 and for 1990 on ref. 10.
[b]Projected data for 1991-2020 are based on ref. 10.

Table A.9. Estimated sources and characteristics of commercial greater-than-Class-C LLW[a]

Waste source	Physical form	Primary isotopes of concern for disposal
Utilities		
Operations	Activated metals, instruments, filters, ion-exchange resins, sludges	^{59}Ni, ^{63}Ni, ^{94}Nb, and TRU isotopes
Decommissioning	Activated metals	^{59}Ni, ^{63}Ni, and ^{94}Nb
Fuel testing labs		
Burnup lab operation	Solidified liquids, metal cuttings, glassware, equipment, ion-exchange resins	^{90}Sr and TRU isotopes
Burnup lab decommissioning	Solidified liquids, metals, glassware, equipment	^{90}Sr and TRU isotopes
Sealed sources		
Manufacturer operations	Trash, metal, foils	^{14}C, ^{90}Sr, ^{137}Cs, ^{241}Am, and Pu isotopes
Manufacturer decommissioning	Trash, metal, foils	^{14}C, ^{90}Sr, ^{137}Cs, ^{241}Am, and Pu isotopes
Sources designated as waste	Sealed sources	^{137}Cs, ^{238}Pu, ^{239}Pu, and ^{241}Am
Other		
Carbon-14 users	Solidified process liquids	^{14}C
Test and research reactors	Activated metals	^{59}Ni, ^{94}Nb, and TRU isotopes
Other	Soil, trash	^{241}Am

[a]Gleaned from information given in U.S. Department of Energy, Recommendations for Management of Greater-than-Class-C Low-Level Radioactive Waste, report to Congress in response to Public Law 99-240, DOE/NE-0077 (February 1987) and O. I. Oztunali, W. D. Pon, R. Eng, and G. W. Roles, Update of Part 61 Impacts Analysis Methodology, Vol. 2, NUREG/CR-4370 (January 1986).

Table A.10. Projected number and volume of drums and classes of LLW incorporated in cement to be generated in the WVDP Low-Level Radwaste Treatment System[a,b,c,d]

End of calendar year	Number of drums			Total volume of drums (m^3)
	Class A[e]	Class B	Class C[f]	
1987	726	g	-	196
1988	-	g	2,024	546
1989	-	g	4,508	1,217
1990[h]	-	g	3,863	1,043
1991[i]	-	g	0	0
1992[j]	-	g	4,545	1,227
Total number	726	g	14,940	
Total volume, m^3	196	g	4,034	4,229

[a]The so-called square drums used are parallelopipeds of square cross section (~0.6 m × 0.6 m × 0.8 m) with a volume of 71 gal (0.27 m^3).

[b]The classes are in accordance with the Classes (A, B, or C) as set by requirements of the NRC in 10 CFR 61.55.

[c]Taken from ref. 11.

[d]Alkaline HLW liquid is processed (see Sect. 2) to yield a loaded ion-exchange material (zeolite), which is HLW, and an effluent, which is LLW. This effluent is solidified with cement.

[e]Generated in 1987 during equipment testing campaigns.

[f]Stored in a shielded drum cell.

[g]No Class B waste is expected to be generated with the effluent mentioned in footnote d.

[h]Processing of alkaline HLW liquid was completed in November 1990, leaving a 1,090-m^3 heel of liquid in the alkaline HLW waste (liquid plus sludge) storage tank.

[i]Processing of liquids from washing of HLW sludge is scheduled to begin in October 1991.

[j]The drums projected to be filled in 1992 will contain the liquids mentioned in footnotes h and i after treatment by ion exchange (see footnote d).

Table A.11. Composition of industrial and institutional waste by category[a]

	Composition,[b] %				
		Institutional			
Radionuclide	Industrial	Bioresearch	Medical	Nonbioresearch	Total
^{3}H	6.453E+01	5.286E+01	8.341E+00	8.824E+01	6.319E+01
^{14}C	3.815E-01	2.738E+01	6.107E+00	6.549E+00	4.454E+00
^{22}Na		1.652E-01			2.279E-02
^{32}P	6.340E+00	4.416E+00	7.367E+00		5.816E+00
^{36}Cl		3.239E-02			4.469E-03
^{35}S	5.519E+00	4.294E+00	8.735E-01		5.042E+00
^{45}Ca	8.671E-04	2.242E-02			3.791E-03
^{46}Sc			1.911E-02		2.571E-04
^{51}Cr	1.394E-01	2.775E-01	3.417E-01		1.550E-01
^{54}Mn	8.052E-02			3.987E-02	6.654E-02
^{55}Fe	2.336E-03	2.092E-03		6.577E-01	3.102E-02
^{57}Co	4.584E-03		6.575E-01		1.252E-02
^{58}Co	2.228E-03	2.318E-02			4.992E-03
^{59}Fe	9.859E-04			1.551E-02	1.473E-03
^{60}Co	3.366E+00			9.230E-01	2.748E+00
^{63}Ni	9.752E-03			5.037E-02	1.006E-02
^{65}Zn	1.196E-03	5.929E-02		1.398E-01	1.482E-02
^{67}Ga			7.758E-02		1.043E-03
^{75}Se	1.341E-02		2.419E-02		1.112E-02
^{85}Kr	4.061E-02				3.267E-02
^{90}Sr	3.310E-01				2.663E-01
^{90}Y	3.310E-01				2.663E-01
^{90}Mo			2.317E+00		3.114E-02
^{99m}Tc			7.023E-01		9.349E-03
^{109}Cd	8.790E-02				7.071E-02
^{111}In	6.475E-04		2.800E-02		8.969E-04
^{113}Sn			2.410E-02		3.240E-04
^{123}I	5.063E-04		2.190E-02		7.016E-04
^{125}I	1.703E+00	9.902E+00	7.064E+01		3.686E+00
^{131}I	1.465E-02	5.453E-01	5.652E-02		8.778E-02
^{133}Ba	2.674E-02				2.151E-02
^{133}Xe			3.828E-02		5.146E-04
^{134}Cs	2.605E-02				2.096E-02
^{137}Cs	6.008E+00	1.230E-02		1.250E+00	4.892E+00
^{137m}Ba	5.687E+00	1.164E-02		1.183E+00	4.625E+00
^{147}Pm	1.015E-01				8.167E-02
^{151}Sm	6.166E-03				4.960E-03
^{153}Gd			5.288E-03		7.107E-05
^{169}Yb	8.637E-02				6.948E-02
^{175}Hf	1.234E-02				9.924E-03
^{182}Ta	7.939E-01				6.387E-01
^{192}Ir	3.347E-01		1.995E+00		2.961E-01
^{201}Tl			2.585E-01		3.476E-03
^{210}Po	1.424E-01				1.146E-01
^{226}Ra			1.071E-01		1.439E-03
^{230}Th	7.489E-04				6.047E-03
^{232}Th	1.665E+00				1.341E+00
^{235}U	1.356E-02				1.091E-02
^{238}U	2.172E+00			9.484E-01	1.807E+00
^{241}Pu	1.806E-02				1.453E-02
Total	1.000E+02	1.000E+02	1.000E+02	1.000E+02	1.000E+02

[a]The volumetric composition of I/I is considered to be as follows: 70.3% industrial, 21.9% bioresearch, 2.3% medical, and 5.5% nonbioresearch. The radioactivity composition of I/I waste is considered to be: 80.5% industrial, 13.8% bioresearch, 1.3% medical, and 4.4% nonbioresearch.

[b]The composition is presented as percent of total curies in each individual category of I/I waste and as percent of the total in all I/I waste combined. This information is adapted from ref. 2.

APPENDIX B. CHARACTERISTICS OF IMPORTANT RADIONUCLIDES

APPENDIX B. CHARACTERISTICS OF IMPORTANT RADIONUCLIDES

B.1 DISCUSSION

The following Table B.1 lists radionuclides whose characteristics are most often referenced in the variety of studies and evaluations discussed in Chapters 1–7. It includes isotopes for HLW, TRU waste, LLW, and uranium mill tailings as defined by EPA,[1] NRC,[2,3] and DOE.[4,5] The data in Table B.1 were obtained from refs. 6–8.

B.2 REFERENCES

1. U.S. Environmental Protection Agency, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Code of Federal Regulations, 40 CFR Part 191 (1985).

2. U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste," Code of Federal Regulations, 10 CFR Part 61 (1982).

3. U.S. Nuclear Regulatory Commission, "Biomedical Waste Disposal," Fed. Regist. 46(47), 16230-16234 (Mar. 11, 1981).

4. U.S. Department of Energy, DOE Order 5820.2A, Radioactive Waste Management, Sept. 26, 1988.

5. U.S. Department of Energy, Energy Information Administration, Domestic Uranium Mining and Milling Industry 1989 – Viability Assessment, DOE/EIA-0477(89), Washington, D.C. (December 1990).

6. D. C. Kocher, Radioactive Decay Data Tables, DOE/TIC-11026, Washington, D.C. (1981).

7. D. C. Kocher, A Radionuclide Decay Data Base – Index and Summary Table, NUREG/CR-1413, ORNL/NUREG-70, Oak Ridge National Laboratory, Oak Ridge, Tennessee (May 1980).

8. E. Browne and R. B. Firestone, V. S. Shirley, ed., Table of Radioactive Isotopes, John Wiley and Sons, Inc., New York (1986).

Table B.1. Characteristics of important radionuclides[a]

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity	Daughter(s)
				α	e	γ(X)	(MeV/dis)	(W/Ci)	(Ci/g)	
^{3}H	1	1.233E+01 y	β		0.00568		5.68E-03	3.37E-05	9.650E+03	^{3}He
^{14}C	6	5.730E+03 y	β		0.0495		4.95E-02	2.93E-04	4.457	^{14}N
^{32}P	15	14.282 d	β		0.6947		6.95E-01	4.12E-03	2.853E+05	^{32}S
^{35}S	16	87.51 d	β		0.0486		4.86E-02	2.88E-04	4.263E+04	^{35}Cl
^{36}Cl	17	3.01E+05 y	β (98.1%); EC (1.9%)		0.2460		2.460E-01	1.458E-03	3.299E-02	^{36}Ar; ^{36}S
^{45}Ca	20	163.8 d	β		0.0770		7.70E-02	4.56E-04	1.780E+04	^{45}Sc
^{46}Sc	21	83.83 d	β	0.1120	2.0095		2.122E+00	1.257E-02	3.381E+04	^{46}Ti
^{51}Cr	24	27.704 d	EC		0.0031	0.0325	3.56E-02	2.11E-04	9.240E+04	^{51}V
^{54}Mn	25	312.20 d	EC		0.0034	0.8360	8.394E-01	4.975E-03	7.738E+03	^{54}Cr
^{55}Fe	26	2.73 y	EC		0.0038	0.0016	5.4E-03	3.2E-05	2.500E+03	^{55}Mn
^{59}Fe	26	44.496 d	β		0.1174	1.1882	1.3056	7.741E-03	4.918E+04	^{59}Co
^{57}Co	27	271.77 d	EC		0.0176	0.1252	1.428E-01	8.464E-01	8.456E+03	^{57}Fe
^{58}Co	27	70.92 d	EC		0.0336	0.9758	1.0094	5.99E-03	3.181E+04	^{58}Fe
^{60}Co	27	5.271 y	β		0.0958	2.5058	2.6016	1.541E-02	1.131E+03	^{60}Ni
^{60m}Co	27	10.47 min	IT (99.75%); β (0.25%)		0.0536	0.0066	6.02E-02	3.57E-04	2.993E+08	^{60}Co; ^{60}Ni
^{59}Ni	28	7.5E+04 y	EC		0.0043	0.0024	6.72E-03	3.98E-05	7.574E+04	^{59}Co
^{63}Ni	28	1.001E+02 y	β		0.0171		1.71E-02	1.01E-04	6.168E+01	^{63}Cu
^{65}Zn	30	244.1 d	EC		0.0066	0.5838	5.90E-01	3.51E-03	8.237E+03	^{65}Cu
^{67}Ga	31	3.261 d	EC		0.0333	0.1549	1.882E-01	1.115E-03	5.975E+05	^{67}Zn
^{75}Se	34	119.77 d	EC		0.0134	0.3924	4.06E-01	2.41E-03	1.453E+04	^{75}As
^{79}Se	34	<6.5E+04 y			0.0529		5.29E-02	3.13E-04	6.966E-02	^{79}Br
^{85}Kr	36	1.072E+01 y	β		0.2505	0.0022	2.53E-01	1.50E-03	3.923E+02	^{85}Rb
^{86}Rb	37	18.66 d	β		0.6670	0.0945	7.62E-01	4.52E-03	8.138E+04	^{86}Sr
^{89}Sr	38	50.55 d	β		0.5829	0.0001	5.83E-01	3.46E-03	2.905E+04	^{89}Y
^{90}Sr	38	2.85E+01 y	β		0.1958		1.96E-01	1.16E-03	1.364E+02	^{90}Y

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis) α	e	γ(X)	"Q" value[e] (MeV/dis)	(W/Ci)	Specific activity (Ci/g)	Daughter(s)
^{90}Y	39	2.671 d	β		0.9332		9.33E-01	5.54E-03	5.441E+05	^{90}Zr
^{91}Y	39	58.51 d	β		0.6039	0.0036	6.07E-01	3.60E-03	2.452E+04	^{91}Zr
^{93}Zr	40	1.53E+06 y	β		0.0471	0.0018	4.89E-02	2.90E-04	2.513E-03	^{93}Nb
^{95}Zr	40	64.02 d	β		0.1200	0.7337	8.54E-01	5.06E-03	2.148E+04	^{95}Nb
^{93m}Nb	41	1.36E+01 y	IT		0.0281	0.0018	2.99E-02	1.77E-04	2.826E+02	^{93}Nb
^{94}Nb	41	2.03E+04 y	β		0.1454	1.5715	1.7169	1.018E-02	1.873E-01	^{94}Mo
^{95}Nb	41	34.97 d	β		0.0435	0.7643	8.078E-01	4.788E-03	3.910E+04	^{95}Mo
^{99}Mo	42	2.748 d	β		0.4076	0.2723	6.799E-01	4.028E-03	4.796E+05	^{99}Tc
^{99}Tc	43	2.13E+05 y	β		0.0846		8.46E-02	5.01E-04	1.695E-02	^{99}Ru
^{99m}Tc	43	6.006 h	IT		0.0142	0.1240	1.382E-01	8.186E-04	5.271E+06	^{99}Tc
^{103}Ru	44	39.254 d	β		0.1105	0.4851	5.96E-01	3.53E-03	3.227E+04	^{103}Rh
^{106}Ru	44	1.020 y	β		0.1004		1.004E-01	5.951E-04	3.346E+03	^{106}Rh
^{103m}Rh	45	56.12 min	IT		0.0375	0.0017	3.92E-02	2.32E-04	3.253E+07	^{103}Rh
^{106}Rh	45	2.17 h	β		0.3144	2.8826	3.197	1.894E-02	3.560E+09	^{106}Pd
^{107}Pd	46	6.5E+06 y	β			0.0093	9.3E-03	5.5E-05	5.143E-04	^{107}Ag
^{110}Ag	47	24.6 s	β (99.70%); EC (0.30%)		1.1842	0.0316	1.216	7.208E-03	4.169E+09	^{110}Cd; ^{110}Pd
^{110m}Ag	47	249.76 d	β (98.64%); IT (1.36%)		0.0755	2.7392	2.815	1.669E-02	4.750E+03	^{110}Cd; ^{110}Ag
^{113m}Cd	48	1.37E+01 y	β (99.9%); IT (0.1%)			0.1834	1.83E-01	1.08E-03	2.168E+02	^{113}In; ^{113}Cd
^{115m}Cd	48	44.6 d	β		0.6029	0.0329	6.36E-01	3.76E-03	2.546E+04	^{115}In
^{111}In	49	2.807 d	EC		0.0340	0.4053	4.393E-01	2.604E-03	4.157E+05	^{111}Cd
^{113m}In	49	1.658 h	IT		0.1340	0.2555	3.89E-01	2.31E-03	1.673E+07	^{113}In
^{114m}In	49	49.51 d	IT (95.7%); EC (4.3%)		0.1431	0.0943	2.37E-01	1.40E-03	2.313E+04	^{114}In; ^{114}Cd
^{113}Sn	50	115.09 d	EC		0.1394	0.2808	4.20E-01	2.48E-03	1.004E+04	^{113}In
^{117m}Sn	50	13.61 d	IT		0.1613	0.1580	3.19E-01	1.89E-03	7.969E+04	^{117}Sn
^{119m}Sn	50	293.0 d	IT		0.0783	0.0114	8.97E-02	5.32E-04	4.478E+03	^{119}Sn
^{121m}Sn	50	5.5E+01 y	IT (77.6%); β (22.4%)		0.0352	0.0050	4.02E-02	2.43E-04	5.912E+01	^{121}Sn; ^{121}Sb
^{123}Sn	50	129.2 d	β		0.5222	0.0069	5.29E-01	3.14E-03	8.219E+03	^{123}Sb
^{125}Sn	50	9.64 d	β		0.8110	0.3124	1.123	6.656E-03	1.084E+05	^{125}Sb
^{126}Sn	50	~1E+05 y	β		0.1249	0.0573	1.82E-01	1.08E-03	2.837E-02	^{126}Sb

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis) α	e	γ(X)	"Q" value[e] (MeV/dis)	(W/Ci)	Specific activity (Ci/g)	Daughter(s)
^{124}Sb	51	60.20 d	β		0.3897	1.8523	2.242	1.329E-02	1.749E+04	^{124}Te
^{125}Sb	51	2.73 y	β		0.1257	0.4434	5.69E-01	3.37E-03	1.032E+03	^{125}Te
^{126}Sb	51	12.4 d	β		0.3527	2.7496	3.102	1.839E-02	8.360E+04	^{126}Te
^{126m}Sb	51	19.0 min	β (86%); IT (14%)		0.6323	1.5484	2.181	1.292E-02	7.854E+07	^{126}Te; ^{126}Sb
^{123m}Te	52	119.7 d	IT		0.1020	0.1482	2.502E-01	1.482E-03	8.870E+03	^{123}Te
^{125m}Te	52	58 d	IT		0.1106	0.0361	1.467E-01	8.690E-04	1.801E+04	^{125}Te
^{127}Te	52	9.35 h	β		0.2248	0.0048	2.30E-01	1.36E-03	2.639E+06	^{127}I
^{127m}Te	52	109 d	IT (97.6%); β (2.4%)		0.0821	0.0111	9.32E-02	5.52E-04	9.432E+03	^{127}Te; ^{127}I
^{129}Te	52	1.160 h	β		0.5422	0.0624	6.05E-01	3.58E-03	2.094E+07	^{129}I
^{129m}Te	52	33.6 d	IT (64%); β (36%)		0.2663	0.0370	3.03E-01	1.80E-03	3.013E+04	^{129}Te; ^{129}I
^{123}I	53	13.2 h	EC		0.0276	0.1729	2.005E-01	1.188E-03	1.940E+06	^{123}Te
^{125}I	53	60.14 d	EC		0.0179	0.0423	6.02E-02	3.57E-04	1.737E+04	^{125}Te
^{129}I	53	1.57E+07 y	β		0.0556	0.0248	8.04E-02	4.77E-04	1.765E-04	^{129}Xe
^{131}I	53	8.040 d	β		0.1913	0.3826	5.74E-01	3.40E-03	1.240E+05	^{130}Xe
^{133}Xe	54	5.245 d	β		0.1363	0.0459	1.82E-01	1.08E-03	1.872E+05	^{133}Cs
^{134}Cs	55	2.062 y	β		0.1639	1.5555	1.719	1.019E-02	1.294E+03	^{134}Ba
^{135}Cs	55	3.0E+06 y	β		0.0563		5.63E-02	3.32E-04	1.151E-03	^{135}Ba
^{137}Cs	55	3.00E+01 y	β (94.6%) β (5.4%)			0.1708	1.71E-01	1.01E-03	8.698E+01	^{137m}Ba; ^{137}Ba
^{133}Ba	56	1.054E+01 y	EC		0.0547	0.4045	4.592E-01	2.722E-03	2.500E+02	^{133}Cs
^{137m}Ba	56	2.552 min	IT		0.0652	0.5991	6.64E-02	3.94E-03	5.379E+08	^{137}Ba
^{141}Ce	58	32.50 d	β		0.1707	0.0770	2.48E-01	1.47E-03	2.848E+04	^{141}Pr
^{144}Ce	58	284.9 d	β		0.0918	0.0192	1.11E-01	6.58E-04	3.190E+03	^{144}Pr
^{143}Pr	59	13.58 d	β		0.3156		3.16E-01	1.87E-03	6.731E+04	^{143}Nd
^{144}Pr	59	17.28 min	β		1.2091	0.0289	1.238	7.338E-03	7.555E+07	^{144}Nd
^{144m}Pr	59	7.2 min	IT (99.96%); β (0.04%)		0.0464	0.0121	5.85E-02	3.43E-04	1.814E+08	^{144}Pr; ^{144}Nd
^{146}Pm	61	5.53 y	EC (66.1%); β (33.9%)		0.0928	0.7542	8.47E-01	5.02E-03	4.428E+02	^{146}Nd; ^{146}Sm
^{147}Pm	61	2.6234 y	β		0.6196		6.20E-02	3.67E-04	9.270E+02	^{147}Sm
^{148}Pm	61	5.370 d	β		0.7235	0.5747	1.298	7.691E-03	1.643E+05	^{148}Sm
^{148m}Pm	61	41.29 d	β (95.4%); IT (4.6%)		0.1695	1.9861	2.156	1.278E-02	2.136E+04	^{148}Sm; ^{148}Pm

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity	Daughter(s)
				α	e	γ(X)	(MeV/dis)	(W/Ci)	(Ci/g)	
^{151}Sm	62	9.0E+01 y	β		0.1251		1.25E-01	7.41E-04	2.631E+01	^{151}Eu
^{152}Eu	63	1.333E+01 y	EC (72.08%); β (27.92%)		0.1275	1.1628	1.290	7.646E-03	1.729E+02	^{152}Sm; ^{152}Gd
^{154}Eu	63	8.8 y	β		0.2794	1.2531	1.532	9.081E-03	2.699E+02	^{154}Gd
^{155}Eu	63	4.96 y	β		0.0650	0.0633	1.28E-01	7.59E-04	4.651E+02	^{155}Gd
^{153}Gd	64	241.6 d	EC		0.0399	0.1015	1.414E-01	8.381E-04	3.526E+03	^{153}Eu
^{160}Tb	65	72.3 d	β		0.2535	1.1271	1.381	8.186E-03	1.129E+04	^{160}Dy
^{169}Yb	70	32.02 d	EC		0.1117	0.3121	4.238E-01	2.512E-03	2.414E+04	^{169}Tm
^{175}Hf	72	70.0 d	EC		0.0439	0.3646	4.085E-01	2.422E-03	1.066E+04	^{175}Lu
^{182}Ta	73	115.0 d	β		0.2073	1.3011	1.508	8.940E-03	6.253E+03	^{182}W
^{192}Ir	77	73.831 d	β (95.4%); EC (4.6%)		0.2162	0.8137	1.030	6.105E-03	9.211E+03	^{192}Pt; ^{192}Os
^{201}Tl	81	3.046 d	EC		0.0481	0.0924	1.40E-01	8.30E-04	2.132E+05	^{201}Hg
^{207}Tl	81	4.77 min	β		0.4931	0.0022	4.95E-01	2.93E-03	1.904E+08	^{207}Pb
^{208}Tl	81	3.053 min	β		0.5979	3.3742	3.972	2.354E-02	2.945E+08	^{208}Pb
^{209}Pb	82	3.253 h	β		0.1980		1.98E-01	1.17E-03	4.544E+06	^{209}Bi
^{211}Pb	82	36.1 min	β		0.4523	0.0678	5.20E-01	3.083E-03	2.468E+07	^{211}Bi
^{212}Pb	82	10.64 h	β		0.1752	0.1453	3.20E-01	1.90E-03	1.389E+06	^{212}Bi
^{211}Bi	83	2.14 min	α (99.727%) β (0.273%)	6.5505	0.0099	0.0467	6.607	3.916E-02	4.184E+08	^{207}Tl; ^{211}Po
^{212}Bi	83	1.0092 h	α (35.94%); β (64.06%)	2.1740	0.5025	0.1061	2.783	1.649E-02	1.465E+07	^{208}Tl; ^{212}Po
^{213}Bi	83	45.59 min	α (2.16%); β (97.84%)	0.1268	0.4563	0.0825	6.66E-01	3.95E-03	1.934E+07	^{209}Tl; ^{213}Po
^{212}Po	84	2.98E-07 s	α	8.7844			8.784	5.207E-02	1.774E+17	^{208}Pb
^{213}Po	84	4.2E-06 s	α	8.3757			8.375	4.964E-02	1.261E+16	^{209}Pb
^{215}Po	84	1.780E-03 s	α	7.3864			7.386	4.378E-02	2.948E+13	^{211}Pb
^{216}Po	84	1.50E-02 s	α	6.7785			6.779	4.018E-02	3.482E+11	^{212}Pb
^{217}At	85	3.23E-02 s	α	7.0657		0.0002	7.066	4.189E-02	1.610E+12	^{213}Bi
^{219}Rn	86	3.96 s	α	6.8122	0.0064	0.0560	6.875	4.076E-02	1.301E+10	^{215}Po
^{220}Rn	86	55.6 s	α	6.2878		0.0005	6.288	3.727E-02	9.223E+08	^{216}Po
^{222}Rn	86	3.825 d	α	5.4892		0.0004	5.490	3.255E-02	1.538E+05	^{218}Po

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis) α	e	γ(X)	"Q" value[e] (MeV/dis)	(W/Ci)	Specific activity (Ci/g)	Daughter(s)
^{221}Fr	87	4.9 min	α	6.3571	0.0084	0.0277	6.393	3.789E-02	1.772E+08	^{217}At
^{223}Fr	87	21.8 min	β		0.3805	0.0542	4.35E-01	2.85E-03	3.868E+07	^{223}Ra
^{223}Ra	88	11.43 d	α	5.6972	0.0731	0.1348	5.905	3.500E-02	5.121E+04	^{219}Rn
^{224}Ra	88	3.66 d	α	5.6751	0.0022	0.0103	5.688	3.372E-02	1.593E+05	^{220}Rn
^{225}Ra	88	14.2 d	β		0.1057	0.0137	1.19E-01	7.08E-04	3.920E+04	^{225}Ac
^{226}Ra	88	1.600E+03 y	α	4.7741	0.0035	0.0067	4.784	2.836E-02	9.887E-01	^{222}Rn
^{228}Ra	88	5.75 y	β		0.0116		1.16E-02	6.88E-05	2.340E+02	^{228}Ac
^{225}Ac	89	10.0 d	α	5.7501	0.0257	0.0176	5.793	3.434E-02	5.803E+04	^{221}Fr
^{227}Ac	89	2.177E+01 y	β (98.62%); α (1.38%)	0.0673	0.0125	0.0002	8.00E-02	4.74E-04	7.233E+01	^{227}Th; ^{223}Fr
^{228}Ac	89	6.13 h	β		0.4292	0.9269	1.356	8.038E-03	2.242E+06	^{228}Th
^{227}Th	90	18.718 d	α	5.9022	0.0543	0.1113	6.068	3.597E-02	3.073E+04	^{223}Ra
^{228}Th	90	1.913 y	α	5.3992	0.0201	0.0034	5.423	3.214E-02	8.196E+02	^{224}Ra
^{229}Th	90	7.340E+03 y	α	4.8620		0.0343	4.896	2.902E-02	2.127E-01	^{225}Ra
^{230}Th	90	7.54E+04 y	α	4.6651		0.0004	4.665	2.765E-02	2.109E-02	^{226}Ra
^{231}Th	90	1.0633 d	β	0.1732		0.0295	2.03E-01	1.21E-03	5.316E+05	^{231}Pa
^{232}Th	90	1.405E+10 y	α	4.0056		0.0002	4.006	2.375E-02	1.097E-07	^{228}Ra
^{234}Th	90	24.10 d	β		0.0158	0.0094	2.52E-02	1.49E-04	2.316E+04	^{234}Pa
^{231}Pa	91	3.276E+04 y	α	4.9230	0.0483	0.0399	5.011	2.970E-02	4.723E-02	^{227}Ac
^{233}Pa	91	27.0 d	β		0.1941	0.2042	3.98E-01	2.36E-03	2.075E+04	^{233}U
^{234m}Pa	91	1.17 min	β (99.87%); IT (0.13%)		0.8227	0.0121	8.35E-01	4.95E-03	6.868E+08	^{234}U; ^{234}Pa
^{232}U	92	6.89E+01 y	α	5.3065		0.0002	5.307	3.146E-02	2.140E+01	^{228}Th
^{233}U	92	1.592E+05 y	α	4.8141	0.0055	0.0013	4.821	2.857E-02	9.680E-03	^{229}Th
^{234}U	92	2.454E+05 y	α	4.7732		0.0001	4.773	2.829E-02	6.248E-03	^{230}Th
^{235}U	92	7.037E+08 y	α	4.3785	0.0426	0.1561	4.577	2.713E-02	2.161E-06	^{231}Th
^{236}U	92	2.342E+07 y	α	4.4793	0.0108	0.0015	4.492	2.662E-02	6.469E-05	^{232}Th
^{238}U	92	4.468E+09 y	α	4.1945	0.0095	0.0013	4.205	2.492E-02	3.362E-07	^{234}Th
^{236}Np	93	1.550E+05 y	EC (91%); β (8.9%); α (0.20%)		0.1967	0.1411	3.38E-01	2.00E-03	1.317E-02	^{236}U; ^{236}Pu; ^{232}Pa
^{237}Np	93	2.140E+06 y	α	4.7604	0.0640	0.0327	4.857	2.879E-02	7.049E-04	^{233}Pa
^{239}Np	93	2.355 d	β		0.2521	0.1740	4.26E-01	2.53E-03	2.320E+05	^{239}Pu
^{236}Pu	94	2.851 y	α	5.7521	0.0126	0.0020	5.767	3.418E-02	5.313E+02	^{232}U
^{238}Pu	94	8.774E+01 y	α	5.4871	0.0099	0.0018	5.499	3.2593E-02	1.712E+01	^{234}U
^{239}Pu	94	2.411E+04 y	α	5.1011		0.0001	5.101	3.024E-02	6.216E-02	^{235}U
^{240}Pu	94	6.563E+03 y	α	5.1549			5.155	3.056E-02	2.279E-01	^{236}U
^{241}Pu	94	1.44E+01 y	β	0.0001		0.0052	5.3E-03	3.2E-05	1.030E+02	^{241}Am

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity	Daughter(s)
				α	e	γ(X)	(MeV/dis)	(W/Ci)	(Ci/g)	
^{242}Pu	94	3.763E+05 y	α	4.8901	0.0081	0.0014	4.900	2.904E-02	3.818E-03	^{238}U
^{244}Pu	94	8.26E+07 y	α (99.875%); SPF (0.125%)	4.5751	0.0007	0.0001	4.576	2.712E-02	1.774E-05	^{240}U; (fission products)
^{241}Am	95	4.327E+02 y	α	5.4801	0.0304	0.0287	5.539	3.283E-02	3.432	^{237}Np
^{242}Am	95	16.01 h	β (82.7%); EC (17.3%)		0.1781	0.0180	1.96E-01	1.16E-03	8.084E+05	^{242}Cm; ^{242}Pu
^{242m}Am	95	1.41E+02 y	IT (99.55%); α (0.45%)	0.0232	0.0403	0.0049	6.84E-02	4.05E-04	9.718	^{242}Am; ^{238}Np
^{243}Am	95	7.380E+03 y	α	5.2656		0.0481	5.3137	3.1496E-02	1.993E-01	^{239}Np
^{242}Cm	96	162.94 d	α	6.0434	0.0090	0.0018	6.0542	3.5886E-02	3.306E+03	^{238}Pu
^{243}Cm	96	2.85E+01 y	α (99.76%); EC (0.24%)	5.8380	0.1129	0.1316	6.083	3.605E-02	5.162E+01	^{239}Pu; ^{243}Am
^{244}Cm	96	1.811E+01 y	α	5.7965		0.0016	5.798	3.437E-02	8.090E+01	^{240}Pu
^{245}Cm	96	8.5E+03 y	α	5.3631	0.1342	0.1178	5.615	3.329E-02	1.717E-01	^{241}Pu
^{246}Cm	96	4.73E+03 y	α	5.3764	0.0072	0.0014	5.385	3.192E-02	3.072E-01	^{242}Pu
^{247}Cm	96	1.56E+07 y	α	4.9475		0.3152	5.263	3.119E-02	9.278E-05	^{243}Pu
^{248}Cm	96	3.40E+05 y	α (91.74%); SPF (8.26%)	4.6524			4.6524	2.7577E-02	4.251E-03	^{244}Pu; (fission products)
^{252}Cf	98	2.645 y	α (96.908%); SPF (3.092%)	5.9308	0.0051	0.0011	5.9370	3.5191E-02	5.378E+02	^{248}Cm; (fission products)

[a]Based on refs. 6-8.

[b]y – years; d – days; h – hours; min – minutes; and s – seconds.

[c]α – alpha decay; β – negative beta decay; EC – electron capture; IT – isomeric transition (radioactive transition from one nuclear isomer to another of lower energy); and SPF – spontaneous fission.

[d]α – alpha decay; e – total electron emissions; and γ(X) – gamma and X-ray photons.

[e]The sum of the average energies per different radiation types in MeV/disintegration or W/Ci (includes alpha and beta particles, discrete electrons, and photons). The "Q" value indicates the amount of energy (heat) that could be deposited in a radioactive material from each decay event if none of the radiation escaped from the material.

APPENDIX C. MISCELLANEOUS RADIOACTIVE MATERIALS

APPENDIX C. MISCELLANEOUS RADIOACTIVE MATERIALS

C.1 INTRODUCTION

This appendix lists most of the remaining spent fuel and TRU radioactive waste materials not reported in Chapters 1 or 3. They are now stored at DOE and commercial sites and will possibly require geologic disposal. The miscellaneous materials included are (1) intact spent fuel elements or solids remaining after experimental testing and for which no reprocessing is planned; (2) damaged, irradiated fuel elements; and (3) "TRU"-type commercial wastes. Data for the following materials are not included because they do not fit in the category: defense HLW in the tank farms, commercial spent fuel at power reactors, and both the DOE production fuel and U.S. Navy fuel that are scheduled for reprocessing.

Other kinds of miscellaneous radioactive materials (MRM) that might be considered for inclusion in this appendix are (1) special-case wastes, (2) spent fuel disassembly hardware and nonfuel-bearing components, and (3) high-activity sources. Special-case wastes are primarily those wastes that have limited or no planned disposal alternatives. Other than the fuel and fuel debris and the "TRU"-type commercial wastes mentioned above, the special-case wastes also consist of (1) WIPP noncertifiable defense TRU waste; (2) DOE-titled GTCC wastes (defined in DOE Order 5820.2A, ref. 1, as DOE wastes designated as GTCC, as defined in 10 CFR 61.55. These wastes must be handled as "special cases," and disposal systems for these wastes must be justified by a specific performance assessment.); and (3) low-level wastes that exceed site specific performance assessments limits. The Radioactive Waste Technical Support Program, managed by EG&G Idaho, Inc., was asked to identify and quantify these special-case wastes.[2,3] Spent fuel disassembly hardware is the structural component left after irradiated fuel pins are removed from a fuel assembly, as in consolidation. It consists of end fittings; grid spacers; water rods (BWR 8 × 8 only); control rod guide tubes (PWR assemblies only); and various nuts, washers, and springs. Other nonfuel-bearing components include fuel channels (BWR), control rods, fission chambers, neutron sources, and thimble plugs.[4] High-activity sources include sealed sources of ^{14}C, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu, and ^{241}Am.

The map of Fig. C.1 shows the current locations of MRM, and Fig. C.2 compares the masses of MRM now stored at the various sites. As seen in Fig. C.3, most of the material is in the form of either intact fuel elements or damaged fuel elements, such as those removed from the TMI-Unit 2 reactor.

C.2 INVENTORIES

Table C.1 summarizes the inventory of MRM that may require geologic disposal. These materials are presently stored at various sites throughout the United States. Tables C.2 through C.9 describe the separate materials at each site in more detail. The data presented in Tables C.1 through C.9 (derived from refs. 5–15) will be useful in planning for final disposal of these materials in a repository.

Inventories of special radioactive materials stored at INEL are given in Table C.6. These include materials stored at the Idaho Chemical Processing Plant (ICPP) and the Naval Reactors Facility (NRF). The spent fuels that comprise these inventories are scheduled to be stored indefinitely.[10-11] If required, future special campaigns could reprocess many of these nonstandard fuels.

Data for the unusual spent fuels now being stored at SRS are included in Table C.9. These materials are not presently regarded as reprocessible, due to the lack of defined reprocessing schemes or required facilities. Therefore, this fuel is considered to be in indefinite storage.[15]

Estimated current and projected inventories of TRU wastes from commercial sources are reported in Table C.10. This information is based on refs. 16–19.

C.3 REFERENCES

1. U.S. Department of Energy, Office of Defense Waste and Transportation Management, Radioactive Waste Management, DOE Order 5820.2A, Washington, D.C. (Sept. 26, 1988).

2. U.S. Department of Energy, Field Office, Idaho, Department of Energy Special Case Radioactive Waste Inventory and Characterization Data Report, DOE/LLW-96, Draft, Idaho Falls, Idaho (May 1990).

3. U.S. Department of Energy, Field Office, Idaho, Supplemental Data Report to the Department of Energy Special Case Radioactive Waste Inventory and Characterization Data Report, DOE/LLW-95, Draft, Idaho Falls, Idaho (June 1990).

4. A. T. Luksic et al., Spent Fuel Disassembly Hardware and Other Nonfuel Bearing Components: Characterization, Disposal Cost Estimates, and Proposed Repository Acceptance Requirements, PNL-6046, Pacific Northwest Laboratory, Richland, Washington (October 1986).

5. J. R. Worsham III, Methods and Procedures of Analysis for TMI-2 Criticality Calculations to Support Recovery Activities Through Head Removal, BAW-1738, Babcock & Wilcox, Lynchburg, Virginia (June 1982).

6. L. C. Witbeck, Argonne National Laboratory-West, Idaho Falls, Idaho, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update of Argonne National Laboratory-West Miscellaneous Waste Data in the Integrated Data Base Report," dated Apr. 12, 1991.

7. K. D. Long, Babcock & Wilcox, Lynchburg Technology Center, Lynchburg, Virginia, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update of Babcock & Wilcox, Lynchburg, LTC Miscellaneous Waste Data in the Integrated Data Base Report," dated Apr. 2, 1991.

8. D. A. Dickman, Battelle Pacific Northwest Laboratory, Richland, Washington, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update of PNL Miscellaneous Waste Inventory for the 1991 Integrated Data Base Report," dated Apr. 9, 1991.

9. R. J. Roberts, Westinghouse Hanford Company, Richland, Washington, letter to K. W. Bracken, DOE/RL, Richland, Washington, "Integrated Data Base, Miscellaneous Waste Data Submission," dated Mar. 22, 1991.

10. D. A. Knecht, Westinghouse Idaho Nuclear Company, Inc., Idaho Falls, Idaho, letter to M. J. Bonkoski, DOE/ID, Idaho Falls, Idaho, "CY-90 Integrated Data Base Information," dated Apr. 11, 1991.

11. D. R. Connors, Westinghouse Electric Corporation, Bettis Atomic Power Laboratory, West Mifflin, Pennsylvania, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Inventory of Expended Fuel at NRF-ECF for Civilian Nuclear Reactors on December 31, 1990," dated May. 28, 1991.

12. B. H. Erkkila, Los Alamos National Laboratory, Los Alamos, New Mexico, memo to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update of Los Alamos National Laboratory Miscellaneous Waste Inventory for the 1991 Integrated Data Base Report," (OS-2-216), dated Mar. 22, 1991.

13. A. M. Krichinsky, Oak Ridge National Laboratory, Oak Ridge, Tennessee, internal correspondence to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Miscellaneous Radioactive Materials Stored at ORNL," dated May 17, 1991.

14. Karl J. Notz, Decommissioning of the Molten Salt Reactor Experiment: A Technical Evaluation, ORNL/RAP-17, Oak Ridge National Laboratory, Oak Ridge, Tennessee (January 1988).

15. W. C. Dennis, Jr., DOE Field Office, Savannah River, Aiken, South Carolina, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update of Savannah River Site (SRS) Miscellaneous Spent Fuel in the Integrated Data Base Report," dated June 5, 1991.

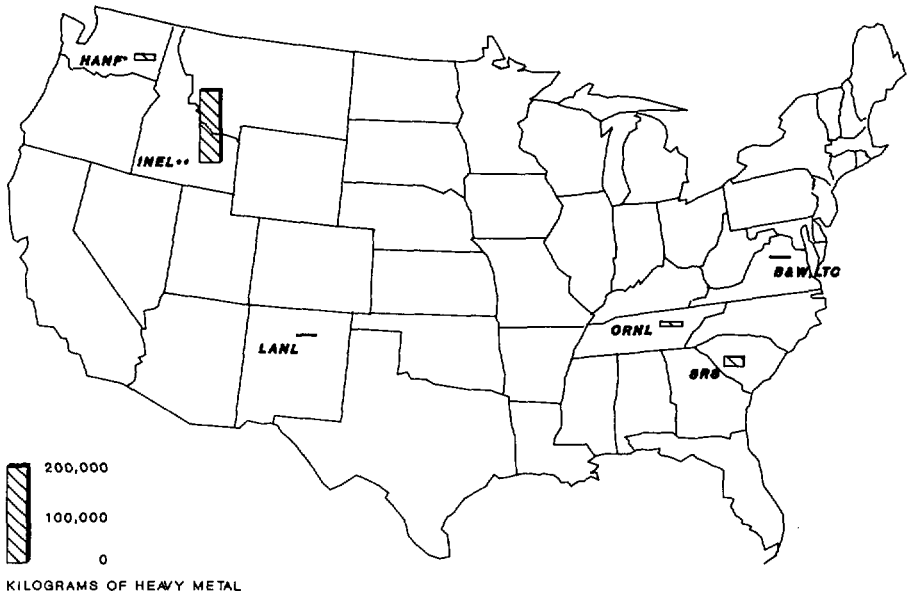
16. P. M. Daling et al., Repository Disposal Requirements for Commercial Transuranic Wastes (Generated Without Reprocessing), PNL-5597, Pacific Northwest Laboratory, Richland, Washington (June 1986).

17. T. J. Rowland, DOE-West Valley Project Office, West Valley, New York, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update to the DOE 1991 Integrated Data Base Report," dated Apr. 15, 1991.

18. W. T. Conaway, GPU Nuclear Corporation, Three Mile Island Site Office, Middletown, Pennsylvania, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 4230-91-031-WTC, transmitting updated summary of wastes from TMI-Unit 2 cleanup activities, dated Apr. 17, 1991.

19. A. W. Norwood, Standby Operations Manager, Cimarron Facility, Cimarron Corporation, Crescent, Oklahoma, letter to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, transmitting summary of wastes from decommissioning the Cimarron (fuel fabrication) Facility, dated Mar. 6, 1989; updated transmittal submitted by Cimarron Corporation on Apr. 5, 1991.

ORNL DWG 91-8686

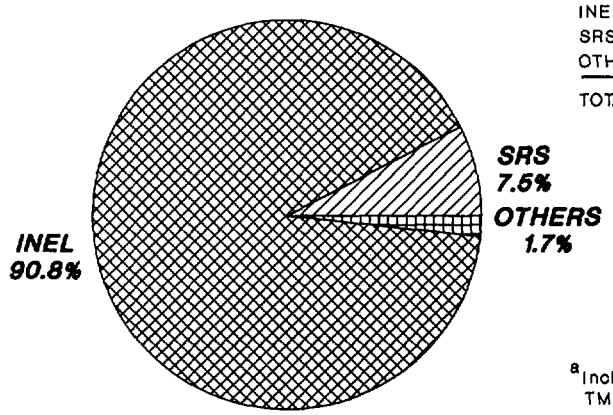


*Includes contribution from both PNL and 200 Area burial grounds.
**Includes contributions from ANL-W, ICPP, NRF, and other facilities. Also, excludes material from TMI-Unit 2.

Fig. C.1. Locations and total masses of miscellaneous radioactive materials through 1990.

ORNL DWG 91-8687

SITE	HEAVY METAL (METRIC TONS)
INEL	230.5[a]
SRS	19.1
OTHERS	4.3[b]
TOTAL	253.9



[a]Includes 82 t from TMI - Unit 2

[b]Inventory for four sites.

Fig. C.2. Mass and locations of miscellaneous radioactive materials as of December 31, 1990.

ORNL DWG 91-8688

FUEL TYPE	HEAVY METAL (METRIC TONS)
Intact	162.4
Damaged	80.1
Scrap	10.1
U-233	1.3
TOTAL	253.9

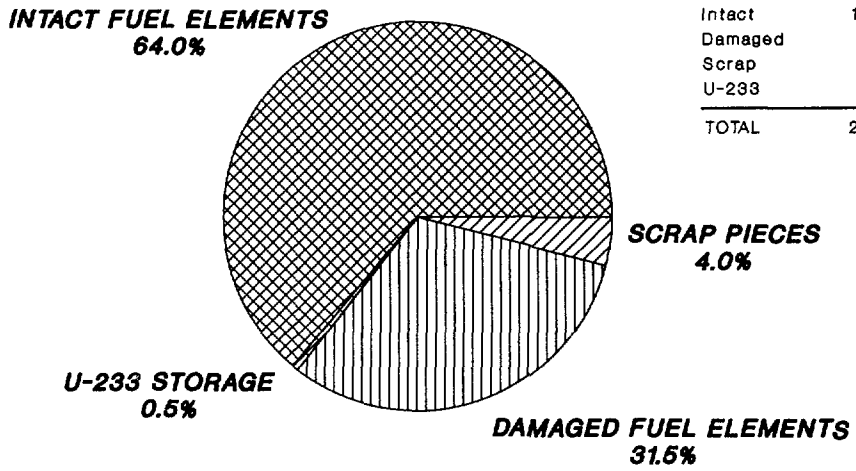


Fig. C.3. Types of miscellaneous radioactive materials in storage through 1990.

Table C.1. Inventory of miscellaneous radioactive materials that may require geologic disposal, as of December 31, 1990

Storage site and location	Total candidate materials (kg)	Uranium content, kg			Total plutonium content (kg)	Total thorium content (kg)
		Total	^{235}U	^{233}U[a]		
Reported potential miscellaneous materials inventory						
Argonne National Laboratory-West; Idaho Falls, ID	311.60	302.65	20.050		8.950	
Babcock & Wilcox, Lynchburg Technology Center; Lynchburg, VA	88.45	87.66	1.379		0.790	
Battelle Pacific Northwest Laboratory; Richland, WA	2,347.9	2,311.9	21.6		29.3	6.7
Hanford 200-Area burial grounds; Richland, WA	326.73	279.49	76.06		47.24	
Idaho National Engineering Laboratory; Idaho Falls, ID[b]	148,465.9	81,245.1	1,870.01	959.46	273.80	66,947.0
Los Alamos National Laboratory; Los Alamos, NM	10.84	9.53	7.21	0.058	1.31	
Oak Ridge National Laboratory; Oak Ridge, TN	1,253.72	1,252.92	798.7	280.29	0.801	
Savannah River Site; Aiken, SC	19,110.24	10,419.37	761.04	31.16	42.67	8,648.2
Total reported	171,915.38	95,908.62	3,556.05	1,270.97	404.86	75,601.9
Estimated potential miscellaneous materials inventory						
Three Mile Island-Unit 2[c,d]	82,023	82,023	2,064.4			

[a]Some of the ^{233}U waste may be certifiable as TRU waste and would therefore be reported in Chapter 3 in the future.

[b]Many of the fuels at ICPP have a lower uranium enrichment than that of fuels normally processed. These fuels could be reprocessed in a special campaign, if required.

[c]Initial fuel loadings have been provided in order to estimate the potential miscellaneous materials inventory. See ref. 5.

[d]It is estimated that about 156 t of spent fuel and core debris has been removed from the TMI-Unit 2 reactor and transferred to INEL. See Table 7.10 in Chapter 7.

Table C.2. Miscellaneous radioactive materials stored at Argonne National Laboratory-West, as of December 31, 1990[a]

Source of material	Composition	Description[b]	U content, kg		Total Pu content (kg)
			Total	^{235}U	
Radioactive Waste and Scrap Facility[c]					
Basic research – ANL	Scrap	Stored in canister[d]	182.00	12.980	5.052
EBR-2 blanket subassembly	Scrap	Stored in canister[d]	104.80	0.230	0.180
LMFBR test fuel	Scrap	Stored in canister[d]	13.33	5.253	3.026
Postirradiation test on NUMEC LMFBR	Scrap	Stored in canister[d]	0.72	0.345	0.123
Sodium Loop Safety Facility	Scrap	Stored in canister[d]	1.80	1.242	0.569
Total			302.65	20.050	8.950

[a]See ref. 6.

[b]No information regarding the burnup of this scrap is available.

[c]Radioactive Scrap and Waste Facility is located approximately 0.5 miles north of ANL-W site.

[d]Canisters are retrievable and constructed of stainless steel with minimum dimensions of 8-in. OD and 5-ft length. The canister lid is gasketed and tightly screwed on, welded closed, or screwed into a canister fitted with pipe threads.

Table C.3. Miscellaneous radioactive materials stored at Babcock & Wilcox, Lynchburg Technology Center, as of December 31, 1990[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg		Total Pu content (kg)
				Total	^{235}U	
Arkansas I	UO_2, Zr-clad	Stored in four 4.25-in.-diam x 33-in. Al canisters	47,000	11.761	0.046	0.133
B&W Test Reactor	UO_2, Zr-clad	Stored in fourteen 4.25-in.-diam x 33-in. Al canisters	Unknown[c]	0.015	0.005	<0.0005
Consolidated Edison	UO_2, Zr-clad	Stored in a 4.25-in.-diam x 33-in. Al canister	29,523	10.849	0.060	0.088
Oconee I	UO_2, Zr-clad	Stored in twenty-six 4.25-in.-diam x 33-in. Al canisters	18,686	0.531	0.004	0.003
			24,080	2.159	0.028	0.017
			26,480	6.482	0.033	0.056
			31,160	4.275	0.041	0.037
			39,180	11.000	0.057	0.101
			50,000	10.579	0.037	0.117
Oconee I	UO_2-Gd_2O_3, Zr-clad	Stored in four 4.25-in.-diam x 33-in. Al canisters	15,000	7.911	0.103	0.048
Oconee II	UO_2, Zr-clad	Stored in seven 4.25-in.-diam x 33-in. Al canisters	17,000	10.711	0.105	0.095
			31,000	6.329	0.057	0.056
			36,000	2.105	0.015	0.019
TMI-Unit 2	UO_2 debris	Stored in a 4.25-in.-diam x 33-in. Al canister	Unknown[c]	0.047	0.0307	<0.0005
Various fuel scrap samples	UO_2, Zr-clad	Stored in a 4.25-in.-diam x 33-in. Al canister	Unknown[c]	2.908	0.757	<0.0005
Hot cell solid waste	Miscellaneous[d]	Stored in forty-four 80-gal drums, thirty-three 55-gal drums, and fifty-two 30-gal drums	-	e	e	<0.082[f]
Total				87.662	1.379	0.790

[a]See ref. 7.
[b]Zr-clad = Zircaloy-clad.
[c]Currently in underground storage tubes.
[d]Miscellaneous materials from periodic hot cell cleanup.
[e]Negligible.
[f]Calculated assuming a contaminated level of <0.5 g of plutonium per drum.

Table C.4. Miscellaneous radioactive materials stored at Battelle Pacific Northwest Laboratory, as of December 31, 1990[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg		Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U		
Calvert Cliffs	UO_2, Zr-clad	0.440-in. diam x 147 in.					
		(stored as 175 intact rods, 1 cut rod[c])	30,000	370.5	2.6	5.3	
		(stored as 154 intact rods, 1 cut rod[c])	45,000	293.2	1.7	7.7	
Cooper	UO_2, Zr-clad	98 rods[c]	26,000	365.3	2.5	3.1	
Point Beach-1	UO_2, Zr-clad	Stored as three intact fuel assemblies, miscellaneous cut samples	32,000	1,163.6	10.3	10.6	6.7
H. B. Robinson	UO_2, Zr-clad	Stored as 19 cut fuel rod sections[c]	30,000	30.2	2.2	0.2	
Shippingport				3.9	0.1	0.1	
VBWR[d]	UO_2, Zr-clad	Twelve 3-ft fuel rod segments	20,000-30,000	11.1	0.1	0.7	
PNL Lot Numbers:							
ATM-5		Glass mix		0.1	e	<0.1	
ATM-6		Glass mix		0.1	e	<0.1	
Miscellaneous scrap and fuel	Cut pieces, scrap	Stored in hot cells		68.5	2.0	1.5	
Miscellaneous fuel	Cut pieces	Stored in hot cell	Unknown	5.4	0.1	0.1	
Total				2,311.9	21.6	29.3	6.7

[a]See ref. 8.
[b]Zr-clad = Zircaloy-clad.
[c]Stored in a hot cell.
[d]Vallecitos boiling-water reactor.
[e]Negligible.

Table C.5. Miscellaneous radioactive materials stored at the Hanford 200 Area burial grounds, as of December 31, 1990[a]

Source of material	Composition	Description[b]	U content, kg		Total Pu content (kg)
			Total	^{235}U	
EBR II (Experimental Breeder Reactor) From INEL	UO_2/PuO_2, SS-clad	Stored in four 30-in.-diam x 59.5-in. shielded carbon steel casks	45.53	7.64	3.60
From LANL	UO_2/PuO_2, SS-clad	Stored in twenty-four 30-in.-diam x 59.5-in. shielded carbon steel casks	78.34	51.42	28.45
From INEL and FFTF (Fast Flux Test Facility) at Hanford	UO_2/PuO_2, SS-clad	Stored in five 30-in.-diam x 59.5-in. shielded carbon steel casks	34.65	7.55	9.81
Fast Critical Facility and SEFOR (Southwest Experimental Fast Oxide Reactor) from GE, Vallecitos, CA	UO_2/PuO_2	Stored in twenty-two 75.5-in. x 65.5-in. x 65.5-in. concrete casks	40.49	4.88	4.70
K reactor	Unknown	12 americium target elements stored in one 30-in.-diam x 69-in. Zircaloy container	0.024[c]	0.024	.074
LWR from GETR,[d] Monticello Reactor, Quad Cities 1 Reactor, and Millstone Reactor	UO_2 pellets	Stored in six 30-in.-diam x 59.5-in. shielded carbon steel casks	63.26	1.29	0.59
TRIGA (Training Reactor, Isotopes, General Atomic) from Oregon State University	Zr-U hydride (8 wt % U), Al-clad	3.6-cm diam x 72 cm fuel assemblies stored/buried in thirteen 55-gal concrete-filled drums, six to seven assemblies per drum	17.2	3.26	0.013
Total			279.49	76.06	47.24

[a]See ref. 9.
[b]No information regarding the burnup of this fuel is available.
[c]Enrichment of uranium not provided.
[d]General Electric (GE) Testing Reactor.

Table C.6. Miscellaneous radioactive materials stored at the Idaho National Engineering Laboratory, as of December 31, 1990[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Defense plus other government agency material stored at ICPP								
GCRE (Gas-Cooled Reactor Experiment)	UO_2-BeO, Hastelloy X clad	One SS tube, 5 in. x 25.5 in.	NA	0.984	0.918			
LWBR (Shippingport Light-Water Breeder Reactor)	Ceramic pellets, Zr-clad, Th blanket	65 units	NA	982.173	10.349	826.016	0.177	56,167.0
Misc. fuels and scrap	Scrap	Stored in 92 SS and Al cans	NA	168.195	137.330	0.119	0.079	36.0
PWR Core 2 (Shippingport Pressurized-Water Reactor)	UO_2 pellets, Zr-clad	42 units	NA	521.613	395.969			
SM-1A (Stationary Media)	UO_2, SS-clad	Stored in 93 SS cans	Negligible	65.759	56.648			
TORY-11A	UO_2-BeO cermet crushed to 0.25 in. x 0.06 in.	Stored in 147 Al cans 3.25 in. x 1.5 in.	0.002[c]	48.645	45.325			
TORY-11C	UO_2-Y_2O_3-ZrO_2-BeO ceramic	Stored in three Al cans 2.68 in. x 52.5 in.	<1.5[c]	59.065	55.022			
Subtotal				1,846.434	701.561	826.135	0.256	56,203.0
DOE/Civilian Development Programs material stored at ICPP								
EBR Scrap (Experimental Breeder Reactor)	Scrap	Four cans	NA	1.618	0.839			
Fermi 1 Blanket	U-Mo (97% U), sodium-bonded, SS-clad	Stored in 510 SS cans, 0.4-in. diam x 41 in. or 61 in.	<1[c]	34,165.000	120.000		6.522	
FSVR (Fort St. Vrain Reactor)	U-Th carbide and Th carbide, pyrolytic carbon-coated particles in graphite matrix	732 hexagonal graphite blocks 14.2 in. across flats x 31.2 in.	6,000-26,000	299.758	164.431	87.013	0.752	8,124.0

Table C.6 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at ICPP (continued)								
Pathfinder	UO_2-B_4C cermet pellets, SS-clad	417 rods in 17 SS cans; each can is 9-in. diam x 80 in.	<<1[c]	53.406	49.242			
Peach Bottom	U-Th carbide, pyrolytic carbon-coated particles in graphite matrix	1,603 graphite blocks 3.5-in. diam x 12 ft	>1[c]	332.420	223.540	46.310	0.970	2,620.0
Pulstar, State University of New York at Buffalo	UO_2 pellets in Zr-clad pins	Stored in 24 SS cans, 3 in. x 3 in. x 35.5 in.	<0.01	251.431	12.083		0.793	
TRIGA (Training Reactor, Isotopes, General Atomic)	Al- or SS-clad elements	852 units stored in 121 cans	Varies	160.974	33.839			
VBWR (Geneva) (Vallecitos Boiling-Water Reactor)	UO_2 and UO_2-TiO_2, SS-clad	142 rods stored in four 6-in.-diam x 36-in. Al cans	8[c]	12.383	2.606			
Subtotal				35,276.990	606.580	133.323	9.037	10,744.0
DOE material stored at NRF[d]								
Shippingport PWR Core 1	UO_2 pellets, Zr-clad	Miscellaneous test specimens from blanket fuel assemblies	11,100	568	<0.5		3.4	
Shippingport PWR Core 2	UO_2 wafers, Zr-clad	Four modules from blanket fuel assemblies	14,273	1,028	2		8.9	
		One seed module		11.09	7.45			
Subtotal				1,607.09	9.45		12.3	

Table C.6 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at INEL (other than ICPP and NRF)								
CANDU (Canadian Deuterium Reactor)	UO_2 pellets, Zr-clad	8 pins	5,000	2.660	0.261			
Connecticut Yankee	UO_2, Zr-clad	1 assembly	NA	378.485	5.204		3.774	
Dresden	UO_2, Zr-clad	54 pins (depleted U)	NA	165.0	Unknown		1.064	
EMAD[e] (Engine Maintenance Assembly & Disassembly)	UO_2 pellets, Zr-clad	18 assemblies	25,000-30,000	7,831.273	58.103		65.255	
GAP CON (Gap Conductance)	UO_2 pellets, Zr-clad	20 pins	42-115	12.838	1.285			
GE (General Electric)	UO_2 pellets, Zr-clad	Pins	NA	18.644	0.394		0.071	
Halden Assy	UO_2 pellets, Zr-clad	5 pins	4,000	2.313	0.233		0.005	
Halden 226 and 239 Assy	UO_2-PuO_2 pellets, Zr-clad	12 pins	NA				0.324	
IE (Irradiation Effects)	UO_2 pellets, Zr-clad	Pins	27-17,600	7.833	0.867		0.012	
LLR (LOFT Lead Rod)	UO_2 pellets, Zr-clad	7 pins	36-150	3.510	0.327			
LOC (Loss of Coolant)	UO_2 pellets, Zr-clad	60 pins	16-150	7.777	0.816		0.010	
LOFT (Loss of Fluid Test)	UO_2 pellets, Zr-clad	15^+ assemblies	0-1,050	2,201.696	89.371		2.029	
MAPI (Mitsubishi Atomic Power Industries)	UO_2 pellets, Zr-clad	43 pins	2,990-8,770	22.499	1.267		0.032	
Miscellaneous fuel pins	UO_2 pellets, Zr-clad	Pins	Varies	173.354	1.758		2.626	
Miscellaneous rods and scrap	Scrap	Stored in 8 cans	Varies	13.553	1.197			

Table C.6 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at INEL (other than ICPP and NRF) (continued)								
OPTRAN (Operational Transient)	UO_2 pellets, Zr-clad	Pins	0-15,000	19.669	0.472		0.087	
PBF (Power-Burst Facility)	UO_2-ZrO_2-CaO; Zr sleeves, SS-clad	Pins	NA	725.690	132.890			
PCM (Power Coolant Mismatch)	UO_2 pellets, Zr-clad	30 pins	<70	18.828	6.557			
Peach Bottom	UO_2 pellets, Zr-clad	1 assembly and pieces	NA	364.1	2.512		1.878	
RIA (Reactivity Initiated Accident)	UO_2 pellets, Zr-clad	23 pins	0-6,090	8.989	0.504		0.013	
H. B. Robinson	UO_2 pellets, Zr-clad	Pins	28,000	263.916	1.890		2.153	
Saxton	UO_2 pellets, Zr-clad	21 pins	10,400-18,253	7.607	0.660		0.025	
SFD (Severe Fuel Damage)	UO_2 pellets, Zr-clad	143 pins	NA	50.867	2.711		0.150	
TC (Thermocouple)	UO_2 pellets, Zr-clad	Pins	0-<20	6.186	0.683			
TMI-Unit 2	Rubble	360 cans	NA	(Quantities unknown until entire core received)				
VEPCO (Virginia Electric Power Company)		69 assemblies	NA	30,207.295	242.457		172.695	
Subtotal				42,514.582	552.419		252.203	
Total at INEL				81,245.096	1,870.01	959.458	273.796	66,947.0

[a]See refs. 10-11. Many of the fuels at INEL have lower uranium enrichment than is found in those fuels that are normally processed. These fuels could be reprocessed in a special campaign, if required.
[b]Zr-clad = Zircaloy-clad.
[c]Data expressed in percentage.
[d]Based on ref. 11.
[e]Turkey Point Fuel.
NA = not available.

Table C.7. Miscellaneous radioactive materials stored at the Los Alamos National Laboratory, as of December 31, 1990[a]

Source of material	Composition	Description	U content, kg			Total Pu content (kg)
			Total	^{235}U	^{233}U	
EBR-2	U-Pu oxide, carbide or nitride SS-clad fuel rod segments	0.3-in. diam x 13.5 in.	3.09	1.84	0.058	1.31
B&W (Lynchburg, VA)	UO_2 spent fuel elements	Stored in racks	6.44[c]	5.37		
Total			9.53[c]	7.21	0.058	1.31

[a]See ref. 12.
[b]No information regarding the burnup of this fuel is available.
[c]Includes 0.428 kg of ^{236}U.

Table C.8. Miscellaneous radioactive materials stored at the Oak Ridge National Laboratory, as of December 31, 1990[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)
				Total	^{235}U	^{233}U	
CEU (Consolidated Edison Uranium)	U_3O_8-CdO solid cake	Stored in 401 3.5-in.-OD x 24-in. SS cans	c	1,044.38	797.70	101.32	
Dresden-1	UO_2, Zr-clad	Sheared fuel pins stored in two 1-qt paint cans	~24,000	5.00	0.024		0.020
		9/16-in.-diam x 8-in. fuel rod sections plus short lengths	20,000	0.930	0.005		0.006
GETR (General Electric Test Reactor)	UO_2, Zr-clad	9/16-in.-diam x 8-in. fuel test capsules	1,000-2,000	0.399	0.022		
Monticello	UO_2, Zr-clad	1/2-in.-diam x 6-in. fuel rod sections plus short lengths	40,000	1.00	0.004		0.008
MSRE[d] (Molten Salt Reactor Experiment)	LiF_2-BeF_2-ZrF_2-UF_4	See ref. 13	~5 x 10^4 Ci total (see ref. 13)	36.95	0.940	31.01	0.743
Oconee-1	UO_2, Zr-clad	1/2-in.-diam x 6-in. fuel rod sections plus short lengths	38,000	1.00	0.005		0.005
Peach Bottom-2	UO_2, Zr-clad	9/16-in.-diam x 8-in. fuel rod sections plus short lengths	10,000	0.324	0.001		0.001
Quad City-1	UO_2, Zr-clad	1/2-in.-diam x 6-in. fuel rod sections plus short lengths	40,000	1.00	0.004		0.008
H. B. Robinson	UO_2, Zr-clad	1/2-in.-diam x 12-in. fuel rod sections plus short lengths	30,000	1.00	0.005		0.004
BR-3 (Belgium)	UO_2, Zr-clad	3/8-in.-diam x 6-in. fuel rod lengths	42,000	0.837	0.020		0.006
ORNL Inventory Item Nos. AUA-67/AUA-70 from LANL	U metal chunks	Stored in two 3.75-in.-OD x 18-in. SS cans	c	6.02		5.89	
CZA-91 from ANL	UO_x powder	Stored in one 3.5-in.-OD x 13-in. SS can	c	0.881		0.856	

Table C.8 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)
				Total	^{235}U	^{233}U	
HUA-2A from HEDL	UO_x powder	Stored in five 3.75-in.-OD x 7-in. SS cans	c	0.317		0.307	
LAE-03 from Atomics International (AI)	Metal	Stored in one 3-in.-OD x 10-in. SS can	c	0.01		0.01	
RCP-02 from SRO	UO_2 powder	Stored in thirty-two 3.5-in.-OD x 24-in. SS cans	c	11.14		10.72	
RCP-03 from SRO	UO_2 powder	Stored in 140 3.88-in.-OD x 10-in. SS cans	c	67.41		61.61	
RCP-04 from SRO	UF_4-LiF_2 powder converted from UO_2	Stored in four 3.5-in.-OD x 24-in. SS cans	c	3.19		2.92	
RCP-06	U_3O_8-CdO solid cake	Stored in twenty-seven 3.5-in.-OD x 24-in. SS cans	c	65.55		60.60	
RCP-20/JZBL from LANL	U metal chunks	Stored in six 3.5-in.-OD x 24-in. SS cans	c	5.15		5.05	
Total				1,252.92	798.7	280.29	0.801

[a]See ref. 13.
[b]Zr-clad = Zircaloy-clad.
[c]No information regarding the burnup of this fuel is available.
[d]The Molten Salt Reactor Experiment was concluded in 1969, and the fuel has never been removed from the facility. A surveillance and monitoring program has been in force since shutdown. See ref. 14. Decommissioning of the MSRE facility is an environmental restoration activity discussed earlier in Chapter 6.

Table C.9. Miscellaneous radioactive materials stored at the Savannah River Site, as of December 31, 1990[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at SRS								
CANDU (Canadian Deuterium Reactor)	UO_2, Zr-clad	Rods stored in three 5.0-in.-diam x 14-ft cans; pieces stored in three 3.5-in.-diam x 1-ft cans	6,500	50.07	0.231			
Carolinas-Virginia Tube Reactor	UO_2-Zr or SS-clad	One bundle of 34 rods in a 5.0-in.-diam x 14-ft can	Unknown	67.37	0.640		0.200	
Dresden	UO_2-ThO_2, SS-clad	Intact assemblies stored in 4.4-in. x 4.4-in. x 135-in. cans	4,000-10,000	683.88	37.545	15.391	1.879	1,857.2
ERR (Elk River Reactor)	UO_2-ThO_2, SS-clad	Assemblies 3.5 in. x 3.5 in. x 81.62 in.	Max. 50,000	224.34	186.159	14.722		4,818.6
LWR samples (Light-Water Reactors)	UO_2-PuO_2; SS- and Zr-clad	Fuel rod pieces stored in five 3.75-in.-diam x 32.5-in.-long cans	Unknown	12.631	0.192		0.109	
Nereide (a French Experiment using DOE fuel)	UAl-Si_x, Al-clad	Materials Test Reactor plate-type fuel assembly 34.37 in. x 2.98 in. x 3.14 in.	600	35.45	7.015			
H. B. Robinson	UO_2-PuO_2, Zr-clad, SS casing	Four 6- to 8-in.-long fragments in 4.5-in.-diam x 32-in.-long can	6,800-30,000	0.52	0.004		0.003	
Saxton	UO_2-PuO_2, Zr- or SS-clad	567 rods stored in eight 5.0-in.-diam x 14-ft cans and 64 rods stored in one 3.75-in.-diam x 50-in. can	1,000	276.67	1.411		15.408	
	UO_2, Zr-clad	Multiple pins stored in four 5.0-in.-diam x 14-ft cans and one bundle stored in one 12-in.-diam x 14-ft can	1,600	66.79	6.866		0.233	

Table C.9 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at SRS (continued)								
VBWR (Vallecitos Boiling-Water Reactor)	UO_2, Zr-clad	Stored in four 3.5-in.-diam x 12-in. cans	1,500	4.04	0.998		0.003	
Subtotal				1,421.761	241.061	30.113	17.835	6,675.8
DOE plus other government agencies material stored at SRS								
B&W scrap	UO_2-PuO_2, SS-clad	Stored in 3.5-in.-diam x 32-in. cans	6-54	0.025	0.013		0.048	
EBR-2 (Experimental Breeder Reactor)	UO_2-PuO_2, SS-clad (from ANL)	Eight rods stored in a 3.5-in.-diam x 30-in. can	120 kW total in 1975	0.44	0.376		0.114	
	UO_2-PuO_2, SS-clad (from HEDL)	Rod segments stored in 0.5-in.-diam x 42-in. cans	10,000-34,000	2.04	1.624		0.680	
EBWR (Experimental Boiling-Water Reactor)	UO_2, SS-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	1.73	1.612			
	UO_2, Zr-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	1,604.30	95.456			
	UO_2-Zr, Zr-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	5,031.77	73.967		9.092	
	UO_2-ZrO_2-CaO, Zr-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	28.93	26.651			
	UO_2-PuO_2, Zr-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	907.39	2.087		13.952	
EPR-1	PuO_2, SS-clad	Pieces stored in 4.5-in.-diam x 32-in. cans	Unknown				0.022	

Table C.9 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE plus other government agencies material stored at SRS (continued)								
GCRE (Gas-Cooled Reactor Experiment)	UO_2 or UO_2-BeO, Hastelloy-clad	Four 2-in.-diam x 32-in. Al cans of scrap pieces; two 1.5-in.-diam Al cans of plates; 66 pin-type assemblies		61.290	56.559			
HWCTR (Heavy-Water Components Test Reactor)	U and UO_2, Zr-clad	Intact assemblies 3 in. diam x 132 in. Pieces of assemblies stored in 3.5-in.-diam x 12-in. cans	6,200	863.958	8.294		0.007	
	U-Zr, Zr-clad			37.165	31.590			
HTRE (High-Temperature Reactor Experiment)	UO_2-BeO, Nichrome-clad	Segments and pieces of fuel assemblies and test pieces in thirteen 4-in.-diam x 36-in. Al cans		3.698	3.423			
ML-1 (Mobile Low Power Plant No. 1)	UO_2 and PuO_2-BeO, SS-clad	Sixty-eight 19-pin assemblies		58.575	54.478			
ORNL (Oak Ridge National Laboratory) SIW-1 rods	U, Zr-clad	Rods stored in three 4.5-in.-diam x 9.25-in. Al cans	Unknown but low	0.184	0.171			
ORNL mixed oxide	UO_2-PuO_2, Zr- or SS-clad	Stored in one 3.5-in.-diam x 15.12-in. can	Unknown but low	0.376	0.030		0.094	
Shippingport	UO_2, Zr-clad	Stored in a 10.5-in.-diam x 15-in. container	18,000	16.429	0.023		0.108	
SPERT-3 (Special Power Excursion Reactor Test)	UO_2, Zr-clad	Stored in three 4.0-in.-diam x 12-ft cans	Unknown	12.64	0.603			
SRE (Sodium Reactor Experiment)	U, Th rods, SS-clad	Stored in 3.5-in.-diam x 110.25-in. cans	10,000	155.24	143.410	1.045		1,972.4
	UC, SS-clad			47.42	4.344		0.016	

Table C.9 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE plus other government agencies material stored at SRS (continued)								
SRS (Savannah River Site)	UO_2-PuO_2, Zr-clad	Stored in a 12.0-in.-diam x 14-ft can	Unknown	69.00	0.304		0.161	
ORR-LEU (Oak Ridge Reactor Low Enriched Uranium)	U_3Si_2, Al-clad	Stored in fourteen 3.5-in. x 3.5-in. x 168-in. Al cans	15,600	95.006	14.960	-	0.537	-
Subtotal				8,997.606	519.975	1.045	24.831	1,972.4
Total				10,419.367	761.036	31.158	42.666	8,648.2

[a]See refs. 14 and 15. The spent fuels listed in this table are not reprocessible in existing facilities.
[b]Zr-clad = Zircaloy-clad.

Table C.10. Estimated current and projected volumes of TRU-type wastes from commercial sources[a]

Facility/source	Waste description	Accumulated packaged waste volume as of December 31, 1990 (m^3)	Estimated annual volume addition (m^3/year)	Projected total packaged waste volume (m^3)
1. West Valley Demonstration Project[b]	Rubbish, trash, spent resins and filters, contaminated equipment, contaminated rubble	42[c]	INA[d]	300
2. Nuclear power plants	Resins and filters, sludges, metals			
• TMI-Unit 2 cleanup[e]		0	INA[d]	0
• Operating reactors		201	14-25	INA[d]
3. Industrial/institutional	NA[f]			
• Commercial research laboratories		13	0-0.4	NA[f]
• Other industrial users of TRU isotopes		28	11-40	NA[f]
4 Decommissioning programs for commercial fuel fabrication plants	Contaminated glove boxes, tanks, process equipment and piping, laboratory equipment[g]	~256[g]	INA[d]	0
5. Dry rod consolidation at a federal facility	NA[f]	INA[d]	315[h]	NA[f]
Total		~540	340-380.4	300[i]

[a]Data from ref. 16 except where noted.
[b]Data from ref. 17.
[c]Includes 14 m^3 (and 13.2 Ci) of TRU-type waste generated during 1989.
[d]INA = information not applicable.
[e]Data from ref. 18.
[f]NA = not available.
[g]Waste inventory at the Cimarron Fuel Fabrication Facility (ref. 19).
[h]Waste generation rate, assuming that spent fuel is consolidated at the rate of 3000 MTU/year. These wastes could be generated at a potential MRS facility or at a geologic repository.
[i]Total volume reported is probably low due to lack of data.

APPENDIX D. REFERENCE SITES AND FACILITIES

APPENDIX D. REFERENCE SITES AND FACILITIES

D.1 DISCUSSION

This appendix provides a listing of major DOE and commercial sites and facilities discussed in this report. Table D.1 lists major DOE sites and facilities. Major commercial radioactive waste disposal sites are given in Table D.2. For each site or facility listed in these tables, additional information is provided, including reference symbol or label, location, operations contractor, and, for DOE sites, the supervisory DOE field office.

Table D.1. Major DOE sites and facilities referred to in this report

Site/facility	Symbol/label	Location	Principal contractor(s) for site operations (Phone number)[a]	DOE field office (Phone number)[a]
Ames Laboratory	Ames	Ames, IA	Iowa State University (515/294-1856)	Chicago (708/972-2000)
Argonne National Laboratory-East	ANL-E	Argonne, IL	University of Chicago (708/972-2000)	Chicago (708/972-2000)
Argonne National Laboratory-West[b]	ANL-W	Idaho Falls, ID	University of Chicago (208/533-7537)	Idaho (208/526-0111)
Battelle Columbus Laboratories Decommissioning Project	BCLDP	Columbus, OH	Battelle Memorial Institute (614/424-3990)	Chicago (708/972-2000)
Brookhaven National Laboratory	BNL	Upton, NY	Associated Universities, Inc. (516/282-2123)	Chicago (708/972-2000)
Colonie Interim Storage Site	CISS	Colonie, NY	Bechtel National, Inc. (615/482-1552)	Oak Ridge (615/576-5454)
Feed Materials Production Center (Fernald Environmental Management Project)	FMPC (FEMP)	Fernald, OH	Westinghouse Materials Company of Ohio, Inc. (513/738-6200)	Oak Ridge Fernald Area Office (513/738-6200)
Fermi National Accelerator Laboratory	FNAL	Batavia, IL	University Research Association (708/840-3401)	Chicago (708/972-2000)
Grand Junction Project Office	GJPO	Grand Junction, CO	DOE Grand Junction Projects Office (303/248-6000)	Idaho (208/256-0111)
Hanford Site	HANF	Hanford, WA	Westinghouse Hanford Company, Inc. (509/376-7511)	Richland (509/376-7411)
Idaho National Engineering Laboratory	INEL	Idaho Falls, ID	EG&G Idaho, Inc. (208/526-9822)	Idaho (208/526-0111)
Inhalation Toxicology Research Institute	ITRI	Albuquerque, NM	Lovelace Foundation (505/844-2203)	Albuquerque (505/845-4154)
Kansas City Plant	KCP	Kansas City, MO	Allied Signal, Inc. Kansas City Division (816/997-2000)	Albuquerque Kansas City Area Office (816/997-3348)
Lawrence Berkeley Laboratory	LBL	Berkeley, CA	University of California (415/422-1100)	San Francisco (415/273-4428)

Table D.1 (continued)

Site/facility	Symbol/label	Location	Principal contractor(s) for site operations (Phone number)[a]	DOE field office (Phone number)[a]
Lawrence Livermore National Laboratory	LLNL	Livermore, CA	University of California (415/422-1100)	San Francisco (415/273-4428)
Los Alamos National Laboratory	LANL	Los Alamos, NM	University of California (505/667-5061)	Albuquerque Los Alamos Area Office (505/667-5061)
Mound Plant	MOUND	Miamisburg, OH	EG&G Mound Applied Technologies (513/865-4020)	Albuquerque Dayton Area Office (513/865-4020)
Naval Reactors Program Facilities Bettis Atomic Power Laboratory	BAPL	West Mifflin, PA	Westinghouse Electric Corporation (412/476-5000)	DOE/HQ Office of Naval Reactors (NE-60) Pittsburgh Naval Reactors Area Office (412/476-5000)
Knolls Atomic Power Laboratory	KAPL	Schenectady, NY	General Electric Company (518/393-4000)	DOE/HQ Office of Naval Reactors (NE-60) Schenectady Naval Reactors Area Office (518/393-4000)
Naval Reactors Facility (INEL)	NRF	Idaho Falls, ID	Westinghouse Electric Corporation (208/526-5526)	DOE/HQ Office of Naval Reactors (NE-60) Pittsburgh Naval Reactors Area Office (412/476-5000)
Nevada Test Site	NTS	Mercury, NV	Reynolds Electrical & Engineering Company, Inc. (702/295-1000)	Nevada (702/295-1000)
Oak Ridge Associated Universities	ORAU	Oak Ridge, TN	Oak Ridge Associated Universities (615/576-3000)	Oak Ridge (615/576-5454)
Oak Ridge K-25 Site	K-25	Oak Ridge, TN	Martin Marietta Energy Systems, Inc. (615/574-1000)	Oak Ridge (615/576-5454)
Oak Ridge National Laboratory	ORNL	Oak Ridge, TN	Martin Marietta Energy Systems, Inc. (615/574-1000)	Oak Ridge (615/576-5454)

Table D.1 (continued)

Site/facility	Symbol/label	Location	Principal contractor(s) for site operations (Phone number)[a]	DOE field office (Phone number)[a]
Oak Ridge Y-12 Plant	Y-12	Oak Ridge, TN	Martin Marietta Energy Systems, Inc. (615/574-1000)	Oak Ridge (615/576-5454)
Pacific Northwest Laboratory[c]	PNL	Richland, WA	Battelle Memorial Institute (509/376-7411)	Richland (509/376-7411)
Paducah Gaseous Diffusion Plant	PAD	Paducah, KY	Martin Marietta Energy Systems, Inc. (502/444-6311)	Oak Ridge (615/576-5454)
Pantex Plant	PANT	Amarillo, TX	Mason & Hanger – Silas Mason Company, Inc. (806/477-3000)	Albuquerque Amarillo Area Office (806/381-3000)
Pinellas Plant	Pinellas	Largo, FL	General Electric Company (813/541-8001)	Albuquerque St. Petersburg Area Office (813/541-8691)
Portsmouth Gaseous Diffusion Plant	PORTS	Portsmouth, OH	Martin Marietta Energy Systems, Inc. (614/289-2111)	Oak Ridge Portsmouth Area Office (614/289-0111)
Princeton Plasma Physics Laboratory	PPPL	Princeton, NJ	Princeton University (609/243-2000)	Chicago (708/972-2000)
Reactive Metals, Incorporated Extrusion Plant	RMI	Astabula, OH	RMI Titanium Company (216/992-7442)	Albuquerque Astabula Area Office (216/992-2000)
Rocky Flats Plant	RFP	Golden, CO	EG&G Inc. (303/966-7000)	Albuquerque Rocky Flats (303/966-7000)
Sandia National Laboratories Albuquerque	SNLA	Albuquerque, NM	AT&T Technologies, Inc. (505/844-5678)	Albuquerque (505/845-4154)
Livermore	SNLL	Livermore, CA	AT&T Technologies, Inc. (415/422-7011)	Albuquerque (505/845-4154)
Santa Susana Field Laboratory (Energy Technology Engineering Center)	SSFL	Canoga Park, CA	Rockwell International Rocketdyne Division (818/710-6300)	San Francisco (415/273-4428)

Table D.1 (continued)

Site/facility	Symbol/label	Location	Principal contractor(s) for site operations (Phone number)[a]	DOE field office (Phone number)[a]
Savannah River Site	SRS	Aiken, SC	Westinghouse Savannah River Company (803/725-6211)	Savannah River (803/725-6211)
Stanford Linear Accelerator Center	SLAC	Palo Alto, CA	Stanford University (415/926-2601)	San Francisco (415/273-4428)
Three Mile Island-Unit 2 Reactor	TMI-Unit 2	Middletown, PA	General Public Utilities (717/948-1037)	Idaho Three Mile Island Site Office (717/948-1037)
Waste Isolation Pilot Plant	WIPP	Carlsbad, NM	Westinghouse Electric Corporation WIPP Project Office (505/885-7443)	Albuquerque WIPP Project Office (505/885-7327)
Weldon Spring Site Remedial Action Project	WSSRAP	Weldon Spring, MO	Jacobs Engineering Group, Inc. MK-Fergusion Company (314/441-8978)	Oak Ridge (615/576-5454)
West Valley Demonstration Project	WVDP	West Valley, NY	Westinghouse Electric Corporation West Valley Nuclear Services (716/942-3235)	Idaho West Valley Project Office (716/942-4314)

[a]Phone number for access to main organizations.
[b]Part of the Idaho National Engineering Laboratory.
[c]Part of the Hanford Site.

Table D.2. Major commercial radioactive waste disposal sites included in this report[a]

Site	Symbol/label	Location	Principal contractor for site operations (Phone number)[b]
Barnwell	BARN	Barnwell, SC	Chem-Nuclear Systems, Inc. (803/256-0450)
Beatty	BETY	Beatty, NV	US Ecology, Nuclear (702/553-2203)
Maxey Flats	MFKY	Hillsboro, KY	Westinghouse Electric Corporation Environmental Technology Division (606/784-6612)
Richland	RICH	Richland, WA	US Ecology, Nuclear (509/377-2411)
Sheffield	SHEF	Sheffield, IL	US Ecology, Nuclear (815/454-2077)
West Valley	WVNY	West Valley, NY	Westinghouse Electric Corporation West Valley Nuclear Fuel Services Company, Inc. (716/942-3235) New York State Energy Research and Development Authority (518/465-6251)

[a]Does not include uranium mill tailings sites. See Table 5.2.
[b]Phone number for access to main organizations.

GLOSSARY OF TERMS

Actinides: Elements with atomic numbers from 90 to 103 inclusive. (Note that actinium is not part of this group.)

Activation product: A radioactive material produced by bombardment with neutrons, protons, or other nuclear particles.

Agreement State: A state that has entered into an agreement with the Nuclear Regulatory Commission (as specified by the 1954 Atomic Energy Act) and has authority to regulate the disposal of low-level radioactive waste under such an agreement. This term is used in the Low-Level Radioactive Waste Policy Act (Public Law 99-240).

Alpha decay: Radioactive decay in which an alpha particle (^{4}He nucleus) is emitted.

Beta decay: Radioactive decay in which a negative electron (beta particle) is emitted.

Borosilicate glass: A type of glass containing at least 5% boric oxide. It is used in glassware that resists heat and is a leading candidate for use in high-level waste immobilization and disposal.

Branching ratio: The fraction of nuclei that disintegrates in a specific way. (It is usually expressed as a percentage.)

Burnup, specific: The total energy released per initial unit mass of reactor fuel as a result of fission. The unit commonly used for specific burnup is megawatt-days per metric ton of initial heavy metal, Mwd/MTIHM.

By-product material: (1) Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material; (2) the tailings or waste products produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.

Calcine: A form of high-level waste produced from defense reactor fuel reprocessing waste (at the Idaho Chemical Processing Plant) by heating to a temperature below the melting point to bring about loss of moisture and oxidation to a chemically stable form.

Canister: A metal container used for the storage or disposal of heat-producing solid radioactive waste.

Capacity factor, plant: The ratio of the electrical energy actually supplied by a power plant in a given time interval to the electrical energy that could have been produced at continuous full-power operation during the same time period.

Capsules: Encapsulated strontium and cesium high-level wastes produced from defense reactor fuel reprocessing at the Hanford site.

Cladding: A corrosion-resistant tube, commonly made of zirconium alloy or stainless steel, surrounding the reactor fuel pellets which provides protection from a chemically reactive environment and containment of fission products.

Code of Federal Regulations: A documentation of the general rules by the executive departments of the federal government. The code is divided into 50 titles that represent broad areas subject to federal regulation. Each title is divided into chapters that usually bear the name of the issuing agency. Each chapter is further subdivided into parts covering specific regulatory areas.

Control rod: A movable part of a reactor used to regulate the degree of fuel fissioning in the core.

Conversion, fuel: Chemical treatment of yellowcake (U_3O_8) to uranium hexafluoride (UF_6) in preparation for enrichment.

Core, nuclear reactor: That part of the reactor which contains the nuclear fuel and in which most or all of the nuclear fissions occur.

Daughter product(s): The nuclide(s) formed by the radioactive disintegration of a first radionuclide (parent).

Decay, radioactive: The transition of a nucleus from one energy state to a lower one, usually involving the emission of a photon, electron, or neutron.

Decay chain, radioactive: A series of nuclides in which each member transforms into the next through radioactive decay until a stable nuclide has been formed.

Decommissioning: Preparations taken for retirement of a nuclear facility from active service, accompanied by the execution of a program to reduce or stabilize radioactive contamination.

Decommissioning wastes: Wastes (generally low-level) collected or resulting from facility decommissioning activities.

Decontamination: Those activities employed to reduce radiation levels or to remove radioactive contamination in or on structures, equipment, and materials.

Deep bed plant: A BWR facility using a demineralizer vessel for water purification which contains an ion-exchange resin that is 3 or more feet deep.

Disintegration energy (Q): The amount of energy released in a particular nuclear disintegration. This is usually expressed in MeV per disintegration.

DOE waste: Radioactive waste produced from activities supported by the Department of Energy and/or U.S. government defense programs.

Double-shell tank wastes: High-level wastes, generated from defense reactor fuel reprocessing at Hanford, which are stored in double-shelled tanks. These wastes consist of a mixture of liquid and suspended solids referred to as slurry. See also "single-shell tank wastes."

Electron capture: Radioactive decay in which an orbital electron is captured by the nucleus.

Equilibrium cycle: An assumed nuclear fuel cycle condition in which the feed and waste materials of a facility have constant compositions. In a reactor this condition typically results after the third or fourth fuel loading schedule.

Enrichment, fuel: A nuclear fuel cycle process in which the concentration of fissionable uranium (i.e., ^{235}U) is increased above its natural level of 0.71%. (The method currently utilized in the United States is gaseous diffusion.)

Environmental Impact Statement: A report that documents the information required to evaluate the environmental impact of a project. Such a report informs decision-makers and the public of the reasonable alternatives which would avoid or minimize adverse impacts or enhance the quality of the environment.

Environmental restoration project: A group of activities initiated to access a DOE facility or radioactive waste site that may require restoration to acceptable radiation levels.

Fabrication, fuel: Conversion of enriched UF_6 into pellets of ceramic uranium dioxide (UO_2). These pellets are then sealed into corrosion-resistant tubes of zirconium alloy or stainless steel. The loaded tubes, called fuel elements or rods, are then mounted into special assemblies for loading into the reactor core.

Fertile nuclide: A nuclide capable of being transformed into a fissile nuclide by neutron capture at specific neutron energies.

Filter/demineralizer plant: A facility that combines filtration and ion-exchange processing using nonregenerable powered resins.

Fissile nuclide: A nuclide capable of undergoing nuclear fission with neutrons.

Fission, nuclear: The division of a heavy atomic nucleus into two (or, rarely, more) parts with similar masses, usually accompanied by the emission of neutrons and gamma radiation.

Fission products: Nuclides produced either by fission or by the subsequent decay of the nuclides thus formed.

Fission, spontaneous: Nuclear fission that occurs without the addition of particles or energy to the nucleus.

Formerly utilized site: A site contaminated with radioactive wastes which was previously used for supporting nuclear activities of the DOE's predecessor agencies, the Manhattan Engineer District (Manhattan Project) and the Atomic Energy Commission.

Fuel assembly: A grouping of nuclear fuel rods that remains integral during the charging and discharging of a reactor core.

Fuel cycle, nuclear: The complete series of steps involved in supplying fuel for nuclear reactors. It includes mining, refining, enrichment, fabrication of fuel elements, use in a reactor, chemical processing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, refabrication of new fuel elements, and management of radioactive waste.

Generation (electricity): The process of producing electric energy from other forms of energy; also, the amount of electric energy produced, commonly expressed in kilowatt-hours (kWh) or megawatt-years [MW(e)-years].

Generation (gross): The total amount of electric energy produced by the generating units in a generating station or stations, measured at the generator terminals.

Generation (net): Gross generation less the electric energy consumed at the generating station for station use.

Glass frit: A fusible ceramic mixture used to make glass for use in the immobilization and disposal of high-level wastes.

Greater-than-Class-C low-level waste: Waste from commercial sources containing radionuclide concentrations that exceed Nuclear Regulatory Commission limits for Class C low-level radioactive waste as defined in 10 CFR Part 61.55.

Grout: A mortar or cement mixture used to immobilize radioactive wastes.

Half-life, radioactive: For a single radioactive decay process, the time required for the activity to decrease to half its initial value by that process.

Hazardous waste: Nonradioactive waste containing concentrations of either toxic, corrosive, flammable, or reactive chemicals above maximum permissible levels as defined by the Environmental Protection Agency in 40 CFR Part 261 or polychlorinated biphenyls (PCBs) above maximum permissible levels as defined by the EPA in 40 CFR Parts 702–799.

High-level waste: As defined by the Nuclear Waste Policy Act, high-level waste is (1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including the liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (2) other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule to require permanent isolation.

Hydrofracture: A process formerly used for permanent disposal of low-level (approximately 0.25 Ci/L) liquid waste at the Oak Ridge National Laboratory. The process involved mixing the waste with a blend of cement and other additives with the resulting grout being injected into shale at a depth of 200 to 300 m. The injected grout hardened into thin, horizontal sheets several hundred meters wide.

Industrial waste: Commercial low-level waste resulting from non-nuclear fuel cycle sources. These include the commercial producers of radiochemicals and radiopharmaceuticals, luminous dial manufacturers, and instruments that incorporate sealed source components (e.g., smoke detectors).

Institutional waste: Commercial low-level waste resulting from bioresearch, medical, and certain nonbioresearch sources. Bioresearch wastes include wastes from animal studies at universities. Medical wastes include those generated from diagnostic and therapeutic procedures on humans at hospitals. Nonbioresearch wastes include research reactor wastes, small-volume, sealed radiation sources, and accelerator targets.

Leaching: The process of removal or separation of soluble components from a solid by percolating water or other liquids through the solid.

Low-level waste: As specified in the Low-Level Radioactive Waste Policy Amendments Act of 1985 (Public Law 99-240), radioactive waste not classified as high-level waste, spent nuclear fuel, or by-product material specified as uranium or thorium tailings and waste.

Mill tailings, uranium: Earthen residues that remain after the extraction of uranium from ores. Tailings may also contain other minerals or metals not extracted in the process.

Mixed waste: Waste that includes concentrations of both radionuclides and hazardous chemicals.

Mixed low-level waste: Waste that satisfies the definition of low-level radioactive waste (LLW) in the Low-Level Radioactive Waste Policy Amendments Act of 1985 and contains hazardous waste that has at least one of the following characteristics: (1) is listed as a hazardous waste in Subpart D of 40 CFR Part 261, (2) exhibits any of the hazardous waste characteristics identified in Subpart C of 40 CFR Part 261, or (3) contains polychlorinated biphenyl (PCB)-containing wastes subject to regulation under the Toxic Substances Control Act and 40 CFR Parts 702–799.

Moderator: A material used to reduce neutron energy (for fissioning if in a reactor) by elastic scattering.

MRS facility: A proposed facility for the monitored retrievable storage of spent fuel from commercial power plants. Such a facility would permit continuous monitoring, management, and maintenance of these wastes and provide for their ready retrieval for further processing or disposal.

Neutron activation: The process of irradiating a material with neutrons so that the material itself is transformed into a radioactive nuclide.

Nonfuel components: Nuclear reactor core parts and hardware, excluding the nuclear fuel itself. Such components include shrouds, control rods, fuel channels, in-core chambers, support tubes, and dummy fuel rods.

Parent: A radionuclide that upon decay yields a specified nuclide (the daughter) either directly or as a later member of a radioactive decay series.

Pressure vessel, reactor: A strong-walled container housing the core of most types of power reactors. It usually also contains other core components such as the moderator and control rods.

PUREX process: A solvent extraction process that may be employed in the reprocessing of uranium/plutonium-based nuclear fuels.

Radioactivity: The number of spontaneous nuclear disintegrations occurring in a given quantity of material during a suitably small period of time. A unit of activity commonly used is the curie (Ci), which is 3.7×10^{10} disintegrations per second.

Reactor, boiling-water: A light-water reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam is used directly to drive a turbine.

Reactor, breeder: A reactor that produces more fissionable fuel than it consumes. The new fissionable material is created by a process (breeding) in which fission neutrons are captured in fertile materials.

Reactor, fast flux: A reactor in which fission is induced predominantly by fast neutrons.

Reactor, high-temperature, gas-cooled: A nuclear reactor that uses an inert gas (helium) as the primary coolant and a graphite moderator.

Reactor, light-water: A nuclear reactor that uses light water (H_2O) as the primary coolant and moderator, with slightly enriched uranium as the fuel. There are two types of commercial light-water reactors: boiling-water and pressurized-water.

Reactor, naval propulsion: A reactor used to power a vessel or submarine of the U.S. Navy.

Reactor, pressurized-water: A light-water reactor in which heat is transferred from the core to a heat exchanger via water kept under high pressure, so that high temperatures can be maintained in the primary system without boiling the water. Steam is generated in a secondary circuit.

Reactor, production: A reactor whose primary purpose is to produce fissile or other materials or to perform irradiations on an industrial scale. Unless otherwise specified, the term usually refers to either a tritium- or plutonium-production facility used to produce materials for nuclear weapons.

Reactor, research: A reactor whose nuclear radiations are used primarily as a tool for basic or applied research. Typically, it has a thermal power of 10 MW(t) or less and may include facilities for testing reactor materials.

Reactor, test: A reactor associated with an engineering-scale test program conducted for the purpose of developing basic design information or demonstrating safety characteristics of nuclear reactor systems.

Reinserted fuel: Irradiated reactor fuel that is discharged in one cycle and inserted in the same reactor during a subsequent refueling. In a few cases, fuel discharged from one reactor has been used to fuel a different reactor.

Repository, geologic: A facility that has an excavated subsurface system for the permanent disposal of spent fuel and high-level waste.

Reprocessing, fuel: The chemical/mechanical processing of irradiated nuclear reactor fuel to remove fission products and recover fissile and fertile material.

Salt cake: A salt form of high-level waste stored in tanks which is produced from neutralizing acidic liquid waste from defense reactor fuel reprocessing with an alkaline agent (caustic soda).

Saltstone: A low-level waste by-product from the solidification of high-level waste at the Savannah River Site. Saltstone is retained in trenches at Savannah River.

Sea-bed disposal: Placement of waste packages in deep ocean sediments.

Sea dumping (disposal): The practice of periodically dumping shiploads of drummed, solidified waste at specified locations in the ocean.

Separative work unit: The standard measure of enrichment services. The separative work unit (SWU) is expressed as a unit of mass. For example, one kilogram of separative work is expressed as 1 kg SWU.

Single-shell tank wastes: High-level wastes, generated from defense reactor fuel reprocessing at Hanford, which are stored in single-shelled tanks. These tanks contain inventories of liquid, sludge, and salt cake. See also "double-shell tank wastes."

Slurry, high-level waste: A watery mixture of highly radioactive, insoluble matter.

Solvent extraction: The separation of materials of different chemical types and solubilities by selective solvent action; used to recover and separate uranium and plutonium in reprocessing spent nuclear fuel.

Source term (IDB Program usage): A set of qualitative and quantitative features used to describe the origin and concentration of radioactive waste. The qualitative features include a flowchart of waste streams generated by a facility or an activity. Quantitative features include (1) the number of curies of radioactivity expressed either per unit of facility production or per unit of waste volume or mass; and (2) a listing of the relative concentrations of component radioisotopes per curie of waste activity.

Special nuclear material: Plutonium or uranium enriched to a higher than natural assay.

Spent fuel: Nuclear fuel that has been permanently discharged from a reactor after it has been irradiated. Typically, spent fuel is measured in terms of either the number of discharged fuel assemblies or the quantity of discharged fuel mass. The latter is measured either in metric tons of heavy metal (i.e., only the heavy metal content of the spent fuel is considered) or in metric tons of initial heavy metal (essentially, the initial mass of the fuel before irradiation). The difference between these two quantities is the weight of the fission products.

Thermal power: A measure of the rate of heat energy emission that results from the radioactive decay of a material. A unit of thermal power commonly used is the watt (W).

THOREX process: A solvent extraction process developed for the reprocessing of thorium-based nuclear fuels.

Transuranic waste: As defined and used by the Department of Energy (DOE Order 5820.2A), radioactive waste that, at the time of assay, contains more than 100 Nci/g of alpha-emitting isotopes with atomic numbers greater than 92 and half-lives greater than 20 years.

Transuranic waste acceptance criteria: A set of conditions established for permitting transuranic wastes to be disposed at the Waste Isolation Pilot Plant.

Transuranic waste certification: The process for verifying that a suspect radioactive waste is transuranic.

Transuranic waste, contact-handled: Transuranic waste with a surface dose rate of less than 200 mrem/h and minimal heat generation to permit handling by contact methods.

Transuranic waste nondestructive assay/nondestructive examination: Nondestructive test procedures performed on suspect transuranic wastes to determine their transuranic isotope concentration. From these tests such wastes can be properly classified (certified) as transuranic or low-level.

Transuranic waste, remote-handled: Transuranic waste with a surface dose rate of greater than 200 mrem/h and/or heat generation to require remote handling and/or shielding.

Vitrification: The conversion of high-level waste materials into a glassy or noncrystalline solid for subsequent disposal.

Waste Isolation Pilot Plant: A research and development facility, located near Carlsbad, New Mexico, to be used for demonstrating the safe disposal of wastes from DOE activities.

Yellowcake: A uranium oxide concentrate that results from milling (concentrating) uranium ore. It typically contains 80 to 90% U_3O_8.

INDEX

Academic/medical/industrial (AMI) waste
[see **Industrial and institutional (I/I) wastes**]
Agreement State, 99, 199
Argonne National Laboratory
Argonne, Illinois (ANL-E), 290
LLW at, 115-116
mixed LLW at, 205-208, 210-215
TRU waste at, 89, 91, 95-96
Idaho Falls, Idaho (ANL-W), 290
LLW at, 115-116
miscellaneous radioactive materials at, 268, 270-271
mixed LLW at, 205-208, 210-215
Ames Laboratory, 290
LLW at, 115-116
mixed LLW at, 205-208, 210-215
Atomic Energy Act (AEA), 7, 144, 199

Barnwell (South Carolina) commercial waste site, 294
LLW at, 102, 105, 108, 118, 122-123, 246
Beatty (Nevada) commercial waste site, 294
LLW at, 102, 105, 108, 118, 122-123
Boiling-water reactor (BWR), 17-18, 23-24, 26, 29, 32-35, 100-101, 230, 232, 235-237, 248
Borosilicate glass (see **High-level waste**)
Brookhaven National Laboratory (BNL), 290
LLW at, 115-116
mixed LLW at, 205-208, 210-215
Burnup, spent fuel, 13, 17
distribution in BWRs, 35
distribution in PWRS, 36
of miscellaneous materials, 272-273, 275-278, 280-285
By-product material, 3, 99, 133

Calcine (see **High-level waste**)
Cape Henry (HEN) LLW, 107, 117
Ceramic (see **High-level waste**)
Code of Federal Regulations (CFR)
10 CFR Part 61, 3, 99, 101, 265
40 CFR Part 191, 3
40 CFR Parts 260-271, 199
40 CFR Parts 702-799, 200
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 144

Decommissioning of reactors, 6-7, 169-172, 176-184, 186-195
NRC alternatives, 170
reactor shutdown dates, 176, 179-180
Decommissioning wastes, commercial, 4, 6-7, 169-196
characteristics of, 177, 183, 232-233, 237
from specific facilities and sites
Cimarron Fuel Fabrication Facility, 172, 196
Diablo Canyon Units 1 & 2 Reactors, 171, 191
Dresden Unit 1 Reactor, 171, 187
Elk River Reactor, 170, 181
Fort St. Vrain Reactor, 171, 193
Humboldt Bay-Unit 3 Reactor, 171, 190
La Crosse Reactor, 171, 188
Pathfinder Reactor, 171-172, 194
Peach Bottom Reactors
Unit 1 (HTGR), 171
Units 2 and 3 (BWRs), 171, 194
Rancho Seco Reactor, 171, 192
Santa Susana Sodium Reactor Experiment, 170, 182
Saxton Reactor, 171, 189
Shippingport Station Decommissioning Project, 171, 184
Shoreham Reactor, 172, 195
Three Mile Island-Unit 2 Reactor, 171, 186
West Valley Demonstration Project, 171, 185
Defense Waste Processing Facility (DWPF), 5, 13, 41, 234
Department of Energy (DOE), 1-2, 255
Energy Information Administration (EIA), 4-5, 133-134
Environmental Restoration and Waste Management Five-Year Plan, 6, 144
Order 5820.2A, 265
Transuranic Waste Program, 78
waste program offices, 2
Disintegration energy (see **Q-value**)
Double-shell tank waste (see **High-level waste**)

locations of,
site priority,

Fabrication (nuclear fuel),
Farallon Islands (FIS) LLW,
Fast Flux Test Facility (FFTF),
Feed Materials Production Center (FMPC) [recently renamed Fernald Environmental Management Project (FEMP)],
LLW at,
mixed LLW at,
Fermi National Accelerator Laboratory (FNAL),
LLW at,
mixed LLW at,
Fort St. Vrain Reactor (FSVR),
decommissioning of,
spent fuel from,
Formerly Utilized Site Remedial Action Program (FUSRAP),
Fuel assemblies,
projected for LWRs,
reference characteristics of,

Generation, commercial nuclear electrical,
Glass frit,
Grand Junction Remedial Action Project (GJRAP),
Greater-than-Class-C (GTCC) low-level waste,
from LWR decommissioning,
sources and characteristics,

Hanford Site,
HLW at,
canisters,
chemical composition of,
radionuclide composition of,
treatment methods for,
LLW at,
environmental restoration wastes at,
miscellaneous radioactive materials at,
mixed LLW at,
TRU wastes at,
Hanford Waste Vitrification Plant (HWVP),
Hazardous waste,
Hazardous Waste Remedial Actions Program (HAZWRAP),
High-level waste (HLW),
acid liquid,
alkaline liquid,
calcine,
canisters,
capsules,
double-shell tank,
glass,
locations of,
precipitate,
salt cake,
significant inventory, revisions of,
single-shell tank,
sludge,
slurry,
zeolite,
Hydrofracture,

Idaho Chemical Processing Plant (ICPP),
HLW at,
calcine chemical composition of,
canisters,
liquid chemical composition of,
treatment methods for,
miscellaneous radioactive materials at,
Idaho National Engineering Laboratory (INEL) [includes **Idaho Chemical Processing Plant (ICPP)**],
HLW at,
radionuclide composition of,
treatment methods for,
LLW at,
environmental restoration wastes at,
miscellaneous radioactive materials at,
mixed LLW at,
TRU wastes at,
Industrial and institutional (I/I) wastes,
source term for,
Inhalation Toxicology Research Institute (ITRI),
LLW at,
mixed LLW at,
Integrated Data Base (IDB) Program,

Kansas City Plant,
LLW at,
mixed LLW at,
Knolls Atomic Power Laboratory (KAPL)
environmental restoration wastes at,

Lawrence Berkeley Laboratory (LBL),
LLW at,
mixed LLW at,
Lawrence Livermore National Laboratory (LLNL),
LLW at,
mixed LLW at,
TRU wastes at,
Light-water reactor (LWR)
disposed waste core components and structurals,
lifetime waste generation,
radionuclide characteristics of spent fuel,
Los Alamos National Laboratory (LANL),
LLW at,
miscellaneous radioactive materials at,
mixed LLW at,

Industrial and institutional (I/I) wastes, 5, 13, 99, 101–103, 105, 109, 126, 223, 236, 251
source term for, 251
Inhalation Toxicology Research Institute (ITRI), 290
LLW at, 115–116
mixed LLW at, 205–208, 210–215
Integrated Data Base (IDB) Program, 1–2, 12

Kansas City Plant (KCP), 290
LLW at, 115–116
mixed LLW at, 205–208, 210–215
Knolls Atomic Power Laboratory (KAPL), 291

Lawrence Berkeley Laboratory (LBL), 290
LLW at, 115–116
mixed LLW at, 205–208, 210–215
Lawrence Livermore National Laboratory (LLNL), 291
LLW at, 115–116
mixed LLW at, 205–208, 210–215
TRU wastes at, 80, 89, 92, 95–96
Light-water reactor (LWR)
lifetime waste generation, 237
LLW (see **Low-level waste**)
radionuclide characteristics of spent fuel, 238–244
Los Alamos National Laboratory (LANL), 291
LLW at, 107, 112, 115–116, 118
miscellaneous radioactive materials at, 268, 270, 279
mixed LLW at, 205–208, 210–215
TRU wastes at, 78, 80–82, 85–89, 91, 94–96
Low-Level Radioactive Waste Policy Act (LLRWPA), 102
Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA), 101–103
Low-level waste (LLW)
commercial, 100–103, 105–106, 109, 111, 122–131, 246
fuel fabrication for LWRs, 102, 109, 131, 229
greater-than-Class-C (GTCC) wastes, 3, 101–102, 125, 265
I/I waste, 5, 13, 99, 101–103, 105, 109, 126, 223, 236, 251
locations of disposal sites, 108, 118
nonroutine LWR operations, 129, 230–231
routine BWR operations, 127, 230
routine PWR operations, 128, 231
state shipments to disposal sites, 124
UF_6 conversion for LWRs, 102, 109, 130, 229
DOE, 99–100, 105–107, 109–110, 112–121
locations of disposal sites, 107
physical characteristics of, 114
radionuclide characteristics of, 113, 115–116, 245
saltstone (at SRS), 121, 247
sea disposal of, 99, 117
inventory, significant revisions of, 119
land usage status, 118

Low-Level Waste Management Program (LLWMP), 124, 235

Manifest Information Management System (MIMS), 100
Massachusetts Bay wastes, 107, 117
Maxey Flats (Kentucky) commercial waste site, 294
LLW at, 108, 118, 122–123
Midwest Fuel Recovery Plant (MFRP) spent fuel, 2, 17
Miscellaneous radioactive materials (MRM), 7, 265–286
characteristics of, 7, 265
inventories of, 270–286
locations of, 268
Mixed LLW, 3, 7, 199–219
commercial, 200–201, 216–219
characteristics of, 200–201, 217–219
generation, 217–219
LWR-generated, 219
DOE, 199–200
characteristics of, 205–215
generation, 207–208, 212–215
inventories, 205–206, 210–211
Monitored retrievable storage (MRS) facility, 2
Mound Plant, 291
LLW at, 115–116
mixed LLW at, 203, 205–208, 210–215
TRU wastes at, 78, 80, 82, 86–89, 92, 94–96

Naturally occurring radioactive materials (NORM), 99
Naval Nuclear Fuel Division (Babcock & Wilcox) — Research Laboratory (NNFD-RL), 268, 270, 272
Naval Reactors Program Facilities (DOE/HQ, NE-60), 291
LLW at, 115–116
mixed LLW at, 205–208, 210–215
Neutron activation products, 169–170, 249
Nevada Test Site, 291
LLW at, 105, 107, 112, 115–116, 118
mixed LLW at, 205–208, 210–215
TRU wastes at, 78, 80, 82, 87–88, 90, 92, 94, 96
Nonfuel LWR core components, 101, 129
Nuclear accelerator-generated radioactive materials (NARM), 99
Nuclear Management and Resources Council (NUMARC), 201, 219
Nuclear power reactors in U.S., 2, 4–5, 13–15, 17–18, 100–102, 169–172, 223, 230–233, 237
locations of, 20
Nuclear Regulatory Commission (NRC), 3, 99–101, 169–170, 199, 255
Nuclear Waste Policy Act (NWPA) of 1982, 41
Nuclear Waste Policy Amendments Act (NWPAA) of 1987, 41

Oak Ridge Associated Universities (ORAU), 291
mixed LLW at, 205-208, 210-213
Oak Ridge K-25 Site (K-25), 291
LLW at, 105, 107, 112, 115-116
mixed LLW at, 203, 205-208, 210-215
Oak Ridge National Laboratory (ORNL), 291
environmental restoration wastes at, 148, 150, 156, 158
LLW at, 105, 107, 112, 115-116
miscellaneous radioactive materials at, 268, 270, 280-281
mixed LLW at, 205-208, 210-215
TRU wastes at, 80-82, 85-88, 90, 92, 94-96
Office of Technology Assessment (OTA)
U.S. Congress, 200-201, 217-219
ORIGEN2 computer code, 4, 78, 237

Pacific Northwest Laboratory (PNL), 292
miscellaneous radioactive materials at, 268, 270, 273
Paducah (PAD) Gaseous Diffusion Plant, 292
LLW at, 107, 115-116
mixed LLW at, 205-208, 210-215
Pantex (PANT) Plant, 292
LLW at, 115-116
mixed LLW at, 205-208, 210-215
Pinellas Plant, 292
LLW at, 115-116
mixed LLW at, 205-208, 210-215
Portsmouth (PORTS) Gaseous Diffusion Plant, 292
LLW at, 107, 115-116
mixed LLW at, 203, 205-208, 210-215
Pressurized-water reactor (PWR), 17-18, 23-24, 27, 30, 32-34, 36, 101, 231, 233, 235-237, 248
Princeton Plasma Physics Laboratory (PPPL), 292
LLW at, 115-116
mixed LLW at, 205-208, 210-215
Projections scenarios (DOE/EIA), commercial LWR, 4-5, 17-18, 21-22, 24-33, 102, 134, 248
Lower Reference Case
for electric power generating capacity, 24
for discharged spent fuel, 21-22, 25, 29-31, 33
No New Orders Case
for electric power generating capacity, 13, 24
for electrical generation, 248
for discharged spent fuel, 21-22, 25-28, 32
PUREX process waste, 40, 70-71, 73-74

Q-value, 256-261

Radionuclide characteristics, 255-261
Reactive Metals, Incorporated (RMI), Extrusion Plant, 292
LLW at, 115-116
mixed LLW at, 205-208, 210-215
Remedial action projects, 6, 143-145, 148, 150, 152, 154-166
mixed LLW from, 205-208, 210-215
Repository, geologic, 2, 3, 18, 39, 52, 265
Reprocessing, fuel, 2, 4, 5, 13, 17-18, 39-41, 52, 70-72, 77, 265
Resource Conservation and Recovery Act (RCRA)
wastes regulated by, 3, 144, 199
Richland (Washington) commercial waste site, 294
LLW at, 102, 108, 118, 122-123
Rocky Flats Plant (RFP), 292
mixed LLW at, 203, 205-208, 210-215
TRU wastes at, 80, 82, 87-88, 90, 92, 94-96

Salt cake (see **High-level waste**)
Saltstone (see **Low-level waste**)
Sandia National Laboratory, Albuquerque (SNLA), 292
LLW at, 107, 115-116
mixed LLW at, 205-208, 210-215
TRU wastes at, 80-81, 85
Sandia National Laboratory, Livermore (SNLL), 292
LLW at, 115-116
mixed LLW at, 205-208, 210-215
San Diego (SDG) LLW, 107, 117
Santa Cruz Basin (SCB) LLW, 107, 117
Santa Susana Field Laboratory (SSFL), 292
Savannah River Site (SRS), 293
Defense Waste Processing Facility (DWPF), 5, 13, 41, 234
HLW at, 13-15, 39-41, 43-45, 49, 51-55, 57, 59, 62-63
canisters, 51-52
chemical composition of, 62
radionuclide composition of, 63
treatment methods for, 45
LLW at, 100, 105, 107, 112, 115-116, 118, 121
saltstone, 100, 121
environmental restoration wastes at, 148, 150, 156, 158
miscellaneous, radioactive materials at, 268, 270, 282-285
mixed LLW at, 203, 205-208, 210-215
TRU wastes at, 78, 80-82, 85, 87-88, 90, 93-96
Sea-bed disposal, 99-100, 117
Sheffield (Illinois) commercial waste site, 294
LLW at, 102, 105, 108, 118, 122-123
Single-shell tank waste (see **High-level waste**)
Slurry (see **High-level waste**)
Source terms, waste, 7, 223, 225-233, 245-247, 251
for commercial LLW disposal sites, 246
for DOE LLW disposal sites, 245
for fuel fabrication wastes, 229
for I/I wastes, 251
for LLW from LWR operations, 230-231
for saltstone at SRS, 247
for UF_6 conversion wastes, 226-227

for uranium enrichment wastes, 228
for uranium mill tailings, 225
for wastes from D&D of LWRs, 232-233
Special nuclear material, 99, 265
Specific activity, 217-219, 232-233, 256-261
Spent fuel, 2, 5, 17-36, 265
disposal of, 2, 18, 265
radioactivity and thermal power as a function of burnup, 23
radionuclide inventory, 238-244
reference LWR characteristics, 34
Stanford Linear Accelerator Center (SLAC), 293
LLW at, 115-116
mixed LLW at, 205-208, 210-215
Surplus Facilities Management Program (SFMP), 6, 144, 171

Tailings (see **Uranium or Thorium mill tailings**)
THOREX process waste, 72-74
Thorium mill tailings, 99
Three Mile Island-Unit 2 Reactor, 293
wastes from, 186, 265, 268, 278, 286
Toxic Substances Control Act (TSCA)
wastes regulated by, 3, 7, 199
Transuranic (TRU) waste, 2-3
buried, 5, 77, 80-81, 85, 89-94
contact-handled (CH), 3, 77-78, 84, 87-96
from commercial sources, 286
generated, 89-93, 95
inventory, significant revisions of, 88
isotopic composition of, 91-93
locations of, 80
packaged for shipment to WIPP, 96
physical composition of, 89-90
points of origin, 80
remote-handled (RH), 3, 77-78, 84, 87-96
soil contaminated by, 85-86
storage in WIPP, 77-80, 83, 96
volume data relationships, 83

Uranium hexafluoride, 226-229
Uranium mill tailings, 3, 6, 99, 133-141
characteristics of, 134, 141, 225
generated, 140
historical and projected volume of, 137
locations of active sites, 136
site status, 138-139
Uranium Mill Tailings Remedial Action Program (UMTRAP), 6, 143-144, 152
wastes from, 6, 14-15, 143-144, 151-152, 155, 160-162

Vitrification, 5, 13, 39-41, 45-46, 49, 51, 55-60, 62-63

Waste Isolation Pilot Plant (WIPP), 293
TRU wastes to be placed in, 77-80, 83, 96
Waste Management Information System (WMIS), 3, 99, 199
Waste sites, 289-294
Weldon Spring Site Remedial Action Project (WSSRAP), 293
wastes at, 150, 158
West Valley Demonstration Project (WVDP), 293
HLW at, 13-15, 39-41, 43-44, 46-49, 51, 53-54, 56, 58, 60, 70-74, 185
acid liquid, chemical composition of, 72
alkaline liquid, chemical composition of, 70-71
alkaline sludge, chemical composition of, 73-74
canisters, 51
inventory, significant revisions of, 61
radionuclide composition of, 73-74
treatment methods for, 46
zeolite resin, 39-40, 53-54, 56, 58, 60, 73-74
LLW at, 122-123, 185, 250
mixed LLW at, 205-208, 210-215
Radwaste Treatment System, 46, 223, 250
spent fuel at, 2, 17-18, 185
TRU wastes at, 185, 286
West Valley (New York) commercial waste site, 294
LLW at, 102, 108, 118, 122-123

Yellowcake, 5, 225-227
Yucca Mountain, Nevada
potential repository site characterization, 18
Y-12 Plant (Oak Ridge), 292
LLW at, 105, 107, 112, 115-116
mixed LLW at, 203, 205-208, 210-215

Zeolite (see **High-level waste**)

DISTRIBUTION

DOE Headquarters

Energy Information Administration, EI-53, Washington, DC 20585

Office of Civilian Radioactive Waste Management, RW-432, Washington, DC 20585

Office of Environmental Restoration and Waste Management, EM-35, Germantown, MD 20874

Office of Environmental Restoration and Waste Management, EM-451, Germantown, MD 20874

Office of Naval Reactors, NE-60, Washington, DC 20585

DOE Field Offices

DOE Field Office, Albuquerque, P.O. Box 5400, Albuquerque, NM 87115

DOE Field Office, Chicago, Building 201, 9800 S. Cass Ave., Argonne, IL 60439

DOE Field Office, Idaho, 785 DOE Place, Idaho Falls, ID 83402

DOE Field Office, Nevada, P.O. Box 98518, Las Vegas, NV 89193-8518

DOE Field Office, Oak Ridge, P.O. Box 2001, Oak Ridge, TN 37831

DOE Field Office, Richland, P.O. Box 550, Richland, WA 99352

DOE Field Office, San Francisco, 1333 Broadway, Oakland, CA 94612

DOE Field Office, Savannah River, P.O. Box A, Aiken, SC 29801

DOE Sites, Contractors, and Area Offices

Ames Laboratory, Iowa State University, Ames, IA 50011-3020

Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439

Brookhaven National Laboratory:
Associated Universities, Inc., Upton, NY 11973

DOE Brookhaven Area Office, Upton, NY 11973

DOE Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831

Feed Materials Production Center (FMPC):
DOE FMPC (Fernald) Site Office, P.O. Box 398705, 7400 Wiley Road, Cincinnati, OH 45239-8705

Westinghouse Materials Company of Ohio, P.O. Box 398704, 7400 Wiley Road, Cincinnati, OH 45239

Fermi National Accelerator Laboratory:
DOE Batavia Area Office, P.O. Box 2000, Batavia, IL 60510

University Research Association, P.O. Box 500, Batavia, IL 60510

Hanford Site:
Pacific Northwest Laboratory, Battelle Memorial Institute, P.O. Box 999, Richland, WA 99352

Westinghouse Hanford Company, P.O. Box 1970, MS H4-52, Richland, WA 99352

Idaho National Engineering Laboratory:
Argonne National Laboratory-West, P.O. Box 2528, Idaho Falls, ID 83401

EG&G Idaho, Inc., P.O. Box 1625, Idaho Falls, ID 83415-4201

Idaho Chemical Processing Plant, Westinghouse Idaho Nuclear Company, Inc., P.O. Box 4000, Idaho Falls, ID 83404

Naval Reactors Facility, Westinghouse Electric Corporation, P.O. Box 2068, Idaho Falls, ID 83403-2068

Inhalation Toxicology Research Institute:
DOE Kirtland Area Office, P.O. Box 5890, Kirtland Air Force Base, Albuquerque, NM 87185

Lovelace Foundation, P.O. Box 5890, P.O. Box 5890, Kirtland Air Force Base, Albuquerque, NM 87185

Kansas City Plant:
Allied-Signal Inc., Kansas City Division, Bannister Federal Complex, Kansas City, MO 64141

DOE Kansas City Area Office, P.O. Box 410202, Kansas City, MO 64141-0202

Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720

Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94550

Los Alamos National Laboratory:
DOE Los Alamos Area Office, P.O. Box 1663, Los Alamos, NM 87545

University of California, P.O. Box 1663, Los Alamos, NM 87545

Mound Plant:
DOE Dayton Area Office, P.O. Box 3000, Miamisburg, OH 45343-3000

EG&G Mound Applied Technologies, Inc., P.O. Box 3000, Miamisburg, OH 45343-0987

Naval Reactors Program (DOE/HQ, NE-60) Facilities:
Bettis Atomic Power Laboratory, Westinghouse Electric Corporation, P.O. Box 79, West Mifflin, PA 15122-0079

DOE Pittsburgh Naval Reactors Area Office, P.O. Box 109, West Mifflin, PA 15122-0109

DOE Schenectady Naval Reactors Area Office, P.O. Box 1069, Schenectady, NY 12301-1069

Knolls Atomic Power Laboratory, General Electric Company, P.O. Box 1072, Schenectady, NY 12301-1072

Naval Reactors Facility (see Idaho National Engineering Laboratory)

Nevada Test Site:
Reynolds Electric and Engineering Company, P.O. Box 98521, Mail Stop 738, Las Vegas, NV 89193-8521

Oak Ridge Reservation:
Oak Ridge Associated Universities, 246 Laboratory Road, Oak Ridge, TN 37831-0117

Oak Ridge K-25 Site, P.O. Box 2003, Oak Ridge, TN 37831-7358

Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6235

Oak Ridge Y-12 Plant, P.O. Box 2009, Oak Ridge, TN 37831-8010

Paducah Gaseous Diffusion Plant, P.O. Box 1410, Paducah, KY 42001

Pantex Plant:
DOE Amarillo Area Office, P.O. Box 30020, Amarillo, TX 79177

Mason and Hanger – Silas Mason Co., P.O. Box 30020, Amarillo, TX 79177

Pinellas Plant:
DOE Pinellas Area Office, P.O. Box 2900, Largo, FL 34649

General Electric Company, Largo, FL 33700

Portsmouth Gaseous Diffusion Plant, P.O. Box 628, Piketon, OH 45661

Princeton Plasma Physics Laboratory, Princeton University, P.O. Box 451, Princeton, NJ 08544

Reactive Materials Incorporated (RMI) Extrusion Plant, P.O. Box 579, Astabula, OH 44004

Rocky Flats Plant:
DOE Rocky Flats Office, P.O. Box 928, Golden, CO 80401-0928

EG&G Rocky Flats Inc., P.O. Box 464, Golden, CO 80401-0464

Sandia National Laboratories – Albuquerque, P.O. Box 5800, Albuquerque, NM 87185

Sandia National Laboratories – Livermore, P.O. Box 969, Livermore, CA 94550

Santa Susana Field Laboratory, Canoga Park, CA 91303

Savannah River Site, Westinghouse Savannah River Company, P.O. Box 616, Aiken, SC 29802

Stanford Linear Accelerator Center, P.O. Box 4349, Palo Alto, CA 94309

Waste Isolation Pilot Plant (WIPP):
Department of Energy, WIPP Project Office, P.O. Box 3090, Carlsbad, NM 88221

Westinghouse Electric Corporation, WIPP Project Office, P.O. Box 2078, Carlsbad, NM 88221

<u>DOE Environmental Restoration Program/Project Offices and Contractors</u>

DOE Environmental Restoration Projects:
Department of Energy, Office of Environmental Restoration, EM-40, Germantown, MD 20874

Office of Technical Services, 12800 Middlebrook Road, Suite 207, Germantown, MD 20874

DOE Three Mile Island Site Office, P.O. Box 88, Middletown, PA 17057

Formerly Utilized Sites Remedial Action Program (FUSRAP):
Bechtel National, Inc., 151 Lafayette Drive, P.O. Box 350, Oak Ridge, TN 37831-0350

DOE Field Office, Oak Ridge, P.O. Box 2001, Oak Ridge, TN 37831-8723

Grand Junction Remedial Action Project (GJRAP):
Department of Energy, Grand Junction Projects Office, P.O. Box 2567, Grand Junction, CO 81502

Hazardous Waste Remedial Actions Program, Tri-County Mall, P.O. Box 2003, Oak Ridge, TN 37831-7606

Uranium Mill Tailings Remedial Action Program (UMTRAP):
DOE Field Office, Albuquerque, UMTRA Project Office, P.O. Box 5400, Albuquerque, NM 87115

Jacobs Engineering Group, Inc., Suite 1700, 5301 Central Ave., N.E., Albuquerque, NM 87108

West Valley Demonstration Project Office, DOE Field Office, Idaho, P.O. Box 191, West Valley, NY 14171

Federal (non-DOE) Agencies

Congressional General Accounting Office, P.O. Box 321, Richland, WA 99352

Congressional Office of Technology Assessment, 600 Pennsylvania Ave., S.E., Washington, DC 20510-8025

Environmental Protection Agency, 401 M St., S.W., Washington, DC 20460

Nuclear Regulatory Commission, 1717 H St., N.W., Washington, DC 20555

Extra copies for DOE/OSTI to fill orders (100).

For additional information regarding the distribution of this report, contact:

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management
RW-432
Washington, DC 20585
Phone: (202) 586-9867

U.S. Department of Energy
Office of Environmental
Restoration and Waste
Management
EM-35 or EM-451
Germantown, MD 20874
Phone: (301) 353-7178;
(301) 353-7221

Oak Ridge National Laboratory
Integrated Data Base Program
P.O. Box 2008, Mail Stop 6495
105 Mitchell Road
Oak Ridge, TN 37831-6495
Phone: (615) 574-6823

★U.S. GOVERNMENT PRINTING OFFICE: 1991-648-191/40042