RAS 9245

January 28, 2005

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

DOCKETED
USNRC

January 31, 2005 (8:05am)

OFFICE OF SECRETARY
RULEMAKINGS AND
ADJUDICATIONS STAFF

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of

Louisiana Energy Services, L.P.
National Enrichment Facility

Docket No. 70-3103

ASLBP No. 04-826-01-ML

HEARING EXHIBITS OFFERED
ON BEHALF OF NUCLEAR INFORMATION AND RESOURCE SERVICE
AND
PUBLIC CITIZEN
REVISED JAN. 28, 2005

The following exhibits will be offered on behalf of Nuclear Information and Resource Service and Public Citizen ("NIRS/PC") at the hearing scheduled for February 7 through 16, 2005. In listing exhibits NIRS/PC have not included as exhibits those portions of the Application itself (i.e., Environmental Report and Safety Analysis Report) that are planned to be referred to by witnesses, since such documents are contained in the record of this proceeding. When an item is readily available from a public Internet location, the location is cited. This list is subject to further revisions based upon conferences with other parties to eliminate duplicate exhibits.

NIRS/PC Exhibits:

1. Areva, 2004a, *Calculation Summary Sheet, Water Balance Tables for National Enrichment Facility Basins,* September 2004, Bates numbers LES-05129 – LES-05188.

2. Barrett, M.E., R.D. Zuber, E.R. Collins, J.F. Malina, Jr., R.J. Charbeneau, and G.H. Ward, 1993, *A Review and Evaluation of Literature Pertaining to the Quality and Control of Pollution from Highway Runoff and Construction,* Technical Report CRWR

Template = SECY-028

SECY-02

239, April 1993 URL (2nd ed., 1995), URL: http://www.crwr.utexas.edu/reports/pdf/1995/rpt95-5.pdf.

3. Bouwer, H., 1978, *Groundwater Hydrology,* pp. 128-31 (witness: G. Rice).

4. Cook-Joyce Inc., 2003a, *Hydrogeologic Investigation, Section 32; Township 21 range 38, Eunice New Mexico*, 19 November, 2003, attached to the *Ground Water Discharge Permit Application* (LES, 2004b).

5. Cook-Joyce Inc., 2004a, *Section VI, Geology Report*, August 2004, prepared for Waste Control Specialists LLC, Andrews Texas.

6. Davis, S.N., and R.J.M. DeWiest, 1966, *Hydrogeology,* pp. 164-65 (witness: G. Rice).

7. DOE, 2000a, *Yucca Mountain Project, Unsaturated PMR and Associated AMRs, Conceptual and Numerical Models of UZ Flow and Transport*, March 2000, MDL-NBS-HS-000005 Rev00, U0030,URL: http://www.ocrwm.doe.gov/documents/amr/23353/23353.pdf#search='NBSHS000005%20Rev00,%20U0030'.

8. Dutton, A.R., 1995. *Groundwater Isotopic Evidence for Paleorecharge in US High Plains Aquifers*. Quatern. Res, 43, 221±231.

9. Dutton, A. R., and W. W. Simpkins, 1986, Hydrogeochemistry and Water Resources of the Triassic Lower Dockum Group in the Texas panhandle and eastern New Mexico, Texas Bureau of Economic Geology, Report of Investigations No. 161.

10. EPA, 1994a, *The Hydrologic Evaluation of Landfill Performance (HELP) Model, User's Guide for Version 3*, EPA/600/R-94/168a, September 1994, URL: http://www.wes.army.mil/el/elmodels/ (Note: User's Guide contained in compressed file to be downloaded with model (zhelp3p.exe)).

11. EPA, 1994b, *Slug Tests,* SOP# 2046, October 3, 1994, URL: http://www.westonrst2.com/sop/2046.pdf#search='epa%20slug%20test'.

12. EPA, 2003a, *EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP), Parameters/Data Background Document*, April 2003, URL: http://www.epa.gov/epaoswer/non-hw/industd/tools/cmtp/epacmtp.htm

13. EPA, 2004a, *Survey of Technologies for Monitoring Containment Liners and Covers,* EPA 542-R-04-013, June 2004, URL: http://www.epa.gov/tio/download/char/epa542r04013.pdf.

14. Freeze, R.A., and Cherry, J.A., 1979, *Groundwater,* pp. 29, 37 (witness: G. Rice).

15. G.L. Environmental Inc., 2004, *Comments on New Mexico Ground Water Discharge Permit*, attached to an email sent to George Harper, April 6, 2004.

16. Hach Company, 2004, *Chemical Oxygen Demand*, Technical Information Series, Booklet No. 9, URL: http://www.hach.com/hc/static.template/templateName=HcLearningLibrary.

17. Harper, G., and R. Peery, 2004a, transcript of deposition taken on September 17, 2004.

18. Hillel, D., 1971, *Soil and Water*, pp. 131-33 (witness: G. Rice).

19. Holt, J.H., 1993, *Geotechnical Investigation and Engineering Analysis for Waste Control Specialists Inc. Landfill Project, Andrews County, Texas*, 12 March, 1993.

20. IUPAC, 1997, *Compendium of Chemical Terminology*, 2nd Edition, URL: http://www.iupac.org/goldbook/B00653.pdf

21. Krich, R.M., G.R. Campbell, R.L. Peery, LR. Stokes, and T. Woomer, 2004a, transcript of deposition taken on September 17, 2004.

22. Laine, D.L., and M.P. Miklas, Jr., 1989, *Detection and Location of Leaks in Geomembrane Liners Using an Electrical Method: Case Histories*, Southwest Research Institute, San Antonio, Texas, Proceedings of the 10th National Conference, Superfund '89, Washington, D.C., U.S.A., Nov. 27-29, 1989, URL: http://www.leaklocationservices.com/pubs/detection_location.pdf.

23. Langman, J. B., F. E. Gebhardt, and S. E. Faulk, 2004, *Ground-Water Hydrology and Water Quality of the Southern High Plains Aquifer, Melrose Air Force Range, Cannon Air Force Base, Curry and Roosevelt Counties, New Mexico, 2002-2003*, USGS Scientific Investigations Report 2004-5158, URL: http://water.usgs.gov/pubs/sir/2004/5158/.

24. Leedshill-Herkenhoff, Inc., John Shoemaker & Associates, Inc., Montgomery & Andrews, P.A., 2000, *Lea County Regional Water Plan*, prepared for Lea County Water Users Association, December 7, 2000.

25. Linsley, R.K., Kohler, M.A., and Paulhus, J.L.H., 1958; *Hydrology for Engineers*, pp. 128-33 (witness: G. Rice).

26. Louisiana Energy Services, 2003c, National Enrichment Facility Wall Map; December 2003, downloaded from: http://www.nrc.gov/materials/fuel-cycle-fac/licapp-envir-rpts.html.

27. Louisiana Energy Services, 2004b, *Ground Water Discharge Permit Application*, April 26, 2004.

28. Louisiana Energy Services, 2004c, *Response to NRC Request for Additional Information Regarding the National Enrichment Facility Environmental Report*, letter NEF#04-019, May 20, 2004.

29. Louisiana Energy Services, 2004d, *Answer of Louisiana Energy Services, L.P. to the Requests for Hearing and Petitions for Leave to Intervene of the New Mexico Attorney General and Nuclear Information and Resource Service and Public Citizen*, Docket No. 70-3103-ML, May 3, 2004.

30. Louisiana Energy Services, 2004e, *Applicant's Objections and Responses to Interrogatories From Nuclear Information and Resource Service and Public Citizen*, September 23, 2004.

31. Louisiana Energy Services, 2004g, Comments Regarding Draft Report NUREG-1790, Environmental Impact for the Proposed National Enrichment Facility in Lea County, New Mexico, November 5, 2004.

32. Lockwood Greene, 2004a, *Data/Information for Environmental Permit,* document number L4-50-01-RES, March 29, 2004, Bates stamp: LES-00768 – LES-00781.

33. Mehta, S., A. E. Fryar, and J. L., Banner, 2000, *Controls on the Regional-Scale Salinization of the Ogallala Aquifer, Southern High Plains, Texas, USA*, in Applied Geochemistry, 15 (2000) 849-864,URL: http://www.geo.utexas.edu/faculty/banner/Publications/Mehta%20et%20al%202000.pdf.

34. Murphy, R.J., and E. Garwell, 1998, *Infiltration Rates through Landfill Liners*, Florida Center for Solid and Hazardous Waste Management, Report #97-11, February 1998 URL: http://www.floridacenter.org/publications/infiltration_rates_landfill_liners_97-11.pdf.

35. New Mexico Environment Department, (NMED), 2004a, *NMED Comments on Draft EIS for LES - Docket Number 70-3103*, November 8, 2004.

36. New Mexico Water Quality Control Commission, 2002, *Regulations*, 20.6.2 NMAC, Effective September15, 2002, URL: http://www.nmenv.state.nm.us/NMED_Regs/gwb/20_6_2_NMAC.pdf.

37. Nicholson, A., and A. Clebsch Jr., 1961, *Geology and Ground-Water Conditions in Southern Lea County, New Mexico*; Ground-Water Report 6, New Mexico Bureau of Mines and Mineral Resources, 1961.

38. G. Rice Figure 1, Schematic—Geologic Cross Section in Vicinity of Proposed Site (showing playa and perched water body).

39. G. Rice Figure 2, Laboratory Hydraulic Conductivity

40. G. Rice Figure 3, Schematic—Geologic Cross Section in Vicinity of Proposed Site (showing fracture flow).

41. Nuclear Regulatory Commission (NRC), 2004a, *Environmental Impact Statement for the Proposed National Enrichment Facility in Lea County, New Mexico, Draft Report for Comment*, NUREG-1790, September 2004.

42. Nuclear Regulatory Commission (NRC), 2004b, *NRC Staff's Response to Interrogatories and Document Request by Petitioners Nuclear Information and Resource Service and Public Citizen to Commission Staff*, November 10, 2004.

43. Olson, R.E., D.E. Daniel, 1981, *Measurement of the Hydraulic Conductivity of Fine-Grained Soils*, in "Permeability and Groundwater Contaminant Transport", Zimmie and Riggs, editors, ASTM Special Technical Publication 746.

44. Rainwater, K., 1996, *Evaluation of Potential Groundwater Impacts by the WCS Facility in Andrews County, Texas*, December 1996.

45. Reddy, D.V., Butul, B., 1999, *A Comprehensive Literature Review of Liner Failures and Longevity*, Florida Center for Solid and Hazardous Waste Management, July 12, 1999 URL: http://www.floridacenter.org/publications/liner_failure_99.pdf.

46. United States Department of the Interior (USDOI), 2004a, C*omments on the Draft Environmental Impact Statement (DEIS) for the Proposed National Enrichment Facility (NEF) to Produce Enriched Uranium, Lea County, New Mexico (Document No. NUREG-1790)*, November 5, 2004.

47. United States Geological Survey (USGS), 2004a, *Concentrations of Polycyclic Aromatic Hydrocarbons (PAHs) and Major and Trace Elements in Simulated Rainfall Runoff from Parking Lots, Austin, Texas, 2003*, Open File report 2004-1208 URL: http://water.usgs.gov/pubs/of/2004/1208/.

48. Walvoord, M.A., M.A. Plummer, F.M. Phillips, and A.V. Wolfsberg, 2002, *Deep arid system hydrodynamics, 1. Equilibrium states and response times in thick desert vadose zones*, in Water Resources Research, December 2002.

49. Yazdani, G., 1997, *Leakage through Liner Systems*, URL: http://www.poly-flex.com/news07.html.

50. U.S. Department of Energy, Record of Decision for Construction and Operation of a Depleted Uranium Hexafluoride Conversion Facility at the Paducah, KY, Site, July 27, 2004.

51. U.S. Department of Energy, Record of Decision for Construction and Operation of a Depleted Uranium Hexafluoride Conversion Facility at the Portsmouth, OH, Site, July 27, 2004.

52. Final EIS for the Construction and Operation of a Depleted Uranium hexafluoride Conversion Facility at the Paducah, Kentucky, Site, DOE/EIS-0359 (June 2004); http://www.eh.doe.gov/nepa/eis/eis0359/

53. Final EIS for the Construction and Operation of a Depleted Uranium hexafluoride Conversion Facility at the Portsmouth, Ohio, Site, DOE/EIS-0360 (June 2004); http://www.eh.doe.gov/nepa/eis/eis0360/

54. Final Programmatic EIS for Alternative Strategies for the Long-Term Management and Use of Depleted Uranium Hexafluoride (April 1999), DOE/EIS-0269; http://web.ead.anl.gov/uranium/documents/nepacomp/peis/parts/maintext.cfm

55. LLNL Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride, UCRL-AR-124080 (May 1997); http://web.ead.anl.gov/uranium/pdf/EARVol1.pdf

56. LLNL Cost Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride, UCRL-AR-127650 (May 1997); http://web.ead.anl.gov/uranium/pdf/CAR_Part1.pdf

57. Voilleque et al. *Fernald Dosimetry Reconstruction Project, Tasks 2 and 3: Radionuclide Source Terms and Uncertainties.* Neeses, SC: Radiological Assessments Corporation, 1995. (hard copy)

58. Final EIS for the Construction and Operation of the Claiborne Enrichment Center, Homer, Louisiana, NUREG-1484 (August 1994) (hard copy)

59. NEF statement, Uranium Hexafluoride Deconversion and Disposal in the United States, Jan. 19, 2004. (PDF file)

60. Ranek, N.L., and F.A. Monette, Evaluation of UF_6-to-UO_2 Conversion Capability at Commercial Nuclear Fuel Fabrication Facilities, Argonne National Laboratory, ANL/EAD/TM-110 (May 2001).

61. Hartmann, D., B. LeMotais, and B. DuPerret, The French Approach for Management of Depleted Uranium, A Constantly Improved Technology, Waste Management 2001

62. U.S. National Transportation Safety Board, Railroad Accident Brief, NTSB/RAB-0408 (Dec. 16, 2004).

63. Fears, D., and S.K. Goo, "Thousands Can't Return Home After Toxic Train," Washington Post, Jan. 10, 2005.

64. NEF Environmental Report, Dec. 2003, Table 1.1-3

65. EIA, *U.S. Nuclear Fuel Cycle Projections 2000-2025*, January 2003. www.eai.doe.gov/cneaf/nuclear/page/forecast/projection.html.

66. World Enrichment Requirements Projections by Region and Country Reference Case, 2000-2020

67. NEF Environmental Report, Dec. 2003, Table 1.1-8

68. PACE, USEC—Heading into the Perfect Storm? (Sept. 2003).

69. Urenco Limited Annual Report and Accounts, Year to 31 December 2003.

70. Urenco Limited Annual Report and Accounts: Year to 31 December 2002.

71. www.exeloncorp.com/generation/nuclear/gn_nuclear.shtml. (16015).

72. USEC 10-Q for September 30, 2004, p.25 (1440).

73. "US DOC dumping case against Eurodif and Urenco" at www.antenna.nl/wise/uranium/epusa.html (January 4, 2005).

74. Public Citizen, *Urenco Limited: A Corporate Profile* (April 2004).

75. Applicant's Objections and Responses to Interrogatories from Nuclear Information and Resource Service and Pubic Citizen, September 23, 2004, responses to interrogatories 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17.

76. Louisiana Energy Services, L.P. Response to Nuclear Information and Resource Service and Public Citizen Interrogatories, December 20, 2004, responses to interrogatories 1, 2, 3.

77. NRC Staff's Response to Interrogatories and Document Request by Petitioners Nuclear Information and Resource Service and Public Citizen to Commission Staff, November 10, 2004, responses to interrogatories 3, 10, 11, 12.

78. Deposition of George A. Harper and Roger L. Peery, September 17, 2004, at:

    a. Page 16 line 4 through page 18 line 17.
    b. Page 20 line 22 through page 21 line 17
    c. Page 48 line 3 through line 14.
    d. Page 54 line 1 through line 23.
    e. Page 55 line 7 through page 56 line 22.
    f. Page 57 line 16 through page 58 line 14.
    g. Page 61 line 2 through page 62 line 2.
    h. Page 72 line 4 through page 73 line 7.
    i. Page 100 line 18 through page 101 line 23.
    j. Page 117 line 6 through page 118 line 1.

79. Deposition of George R. Campbell, et al., September 17, 2004, at:

a. Page 20 line 23 through page 22 line 8.
b. Page 22 line 23 through page 24 line 1.
c. Page 47 line 7 through page 48 line 18.

80. Deposition of Kirk Schnoebelen, et al., September 29, 2004, at:

a. Page 54 line 5 through page 55 line 14.
b. Page 60 line 16 through page 61 line 13.
c. Page 83 line 17 through page 87 line 20.
d. Page 107 line 2 through page 108 line 3.

81. Exhibit 8 to Schnoebelen deposition, e-mail from C. Chater to C. Andrews, January 10, 2003, Subject: Comments on the ERI No Need Analysis.

Respectfully submitted,

Lindsay A. Lovejoy, Jr.
618 Paseo de Peralta, Unit B
Santa Fe, NM 87501
(505) 983-1800
(505) 983-0036 (facsimile)
E-mail: lindsay@lindsaylovejoy.com

Counsel for Petitioners
Nuclear Information and Resource Service
1424 16th St., N.W. Suite 404
Washington, D.C. 20036
(202) 328-0002

and

Public Citizen
1600 20th St., N.W.
Washington, D.C. 20009
(202) 588-1000

January 28, 2005

CERTIFICATE OF SERVICE

Pursuant to 10 CFR § 2.305 the undersigned attorney of record certifies that on January 28, 2005, the foregoing Hearing Exhibits Offered on Behalf of Nuclear Information and Resource Service and Public Citizen, Revised Jan. 28, 2005, was served by electronic mail and by expedited delivery upon the following:

G. Paul Bollwerk, III
Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
Third Floor, Two White Flint North
11545 Rockville Pike
Rockville, MD 20852-2738
e-mail: gpb@nrc.gov

Dr. Paul B. Abramson
Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
Third Floor, Two White Flint North
11545 Rockville Pike
Rockville, MD 20852-2738
e-mail: pba@nrc.gov

Dr. Charles N. Kelber
Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
Third Floor, Two White Flint North
11545 Rockville Pike
Rockville, MD 20852-2738
e-mail: cnk@nrc.gov

James Curtiss, Esq.
David A. Repka, Esq.
Winston & Strawn
1400 L St., N.W.
Washington, D.C. 20005-3502
e-mail: jcurtiss@winston.com
drepka@winston.com
moneill@winston.com

John W. Lawrence, Esq.
National Enrichment Facility
100 Sun Avenue, N.E.
Suite 204
Albuquerque, NM 87109
e-mail: jlawrence@nefnm.com

Office of the General Counsel
U.S. Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738
Attention: Lisa B. Clark, Esq.
e-mail: OGCMailCenter@nrc.gov
lbc@nrc.gov
abc1@nrc.gov
jth@nrc.gov
dmr1@nrc.gov
dac3@nrc.gov

Office of Commission Appellate Adjudication
Mail Stop O-16C1
U.S. Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738

Tannis L. Fox, Esq.
Deputy General Counsel
New Mexico Environment Department
1190 St. Francis Drive
Santa Fe, NM 87502-1031
e-mail: tannis_fox@nmenv.state.nm.us

Glenn R. Smith, Esq.
Christopher D. Coppin, Esq.
Stephen R. Farris, Esq.
David M. Pato, Esq.
Office of the Attorney General
Bataan Memorial Building
407 Galisteo Street
Second Floor
Santa Fe, NM 87501
e-mail: ccoppin@ago.state.nm.us
dpato@ago.state.nm.us
gsmith@ago.state.nm.us
sfarris@ago.state.nm.us

Secretary
U.S. Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738
Attention: Rulemakings and Adjudications Staff
e-mail: hearingdocket@nrc.gov

Lindsay A. Lovejoy, Jr.
618 Paseo de Peralta, Unit B
Santa Fe, NM 87501
(505) 983-1800
(505) 983-0036 (facsimile)
e-mail: lindsay@lindsaylovejoy.com

EPA
United States
Environmental Protection
Agency

EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP)

Parameters/Data Background Document

April 2003

Office of Solid Waste (5305W)
Washington, DC 20460
EPA530-R-03-003
April 2003
www.epa.gov/osw

EPA's COMPOSITE MODEL FOR LEACHATE MIGRATION WITH TRANSFORMATION PRODUCTS (EPACMTP)

PARAMETERS/DATA BACKGROUND DOCUMENT

U.S. Environmental Protection Agency
Office of Solid Waste
Washington, DC 20460

April 2003

This page intentionally left blank.

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS viii
LIST OF SYMBOLS AND ABBREVIATIONS ix

1.0 INTRODUCTION 1-1

2.0 WASTE MANAGEMENT UNIT (SOURCE) PARAMETERS 2-1
2.1 SOURCE PARAMETERS 2-4
2.2 DATA SOURCES FOR WMU PARAMETERS 2-4
2.3 LANDFILLS 2-10
2.3.1 Landfill Area (A_w) 2-10
2.3.2 Landfill Depth (D_{LF}) 2-11
2.3.3 Landfill Base Depth below Grade (d_{BG}) 2-12
2.3.4 Waste Fraction (F_h) 2-14
2.3.5 Waste Volume (PWS) 2-14
2.3.6 Leaching Duration (t_p) 2-15
2.4 SURFACE IMPOUNDMENTS 2-16
2.4.1 Surface Impoundment Area (A_w) 2-17
2.4.2 Surface Impoundment Ponding Depth (H_p) 2-18
2.4.3 Surface Impoundment Total Thickness of Sediment (D_s) 2-19
2.4.4 Surface Impoundment Liner Thickness (D_{lin}) 2-20
2.4.5 Surface Impoundment Liner Conductivity (K_{lin}) 2-21
2.4.6 Surface Impoundment Base Depth Below Grade (d_{BG}) .. 2-22
2.4.7 Surface Impoundment Leak Density (ρ_{leak}) 2-23
2.4.8 Distance to Nearest Surface Water Body (R_w) 2-24
2.4.9 Surface Impoundment Leaching Duration (t_p) 2-25
2.5 WASTE PILES 2-26
2.5.1 Waste Pile Area (A_w) 2-27
2.5.2 Waste Pile Leaching Duration (t_p) 2-28
2.5.3 Waste Pile Base Depth below Grade (d_{BG}) 2-28
2.6 LAND APPLICATION UNITS 2-29
2.6.1 Land Application Unit Area (A_w) 2-29
2.6.2 Land Application Unit Leaching Duration (t_p) 2-30

3.0 WASTE AND CONSTITUENT PARAMETERS 3-1
3.1 WASTE AND CONSTITUENT PARAMETERS 3-2
3.2 WASTE CHARACTERISTICS 3-3
3.2.1 Waste Density (ρ_{hw}) 3-3
3.2.2 Concentration of Constituent in the Waste (C_w) 3-5
3.2.3 Concentration of Constituent in the Leachate (C_L) 3-5
3.3 CONSTITUENT PHYSICAL AND CHEMICAL CHARACTERISTICS 3-7
3.3.1 All Constituents 3-7
3.3.1.1 Molecular Diffusion Coefficient (D_i) 3-8
3.3.1.2 Drinking Water Standard (DWS) 3-8
3.3.1.3 Molecular Weight (MW) 3-9

TABLE OF CONTENTS (continued)

Page

3.3.2 Organic Constituents 3-10
3.3.2.1 Organic Carbon Partition Coefficient (k_{oc}) ... 3-10
3.3.2.2 Parameters Related to Chemical Hydrolysis . 3-12
3.3.2.2.1 Dissolved Phase Hydrolysis Decay Rate (λ_1) 3-13
3.3.2.2.2 Sorbed Phase Hydrolysis Decay Rate (λ_2) 3-14
3.3.2.2.3 Acid-Catalyzed Hydrolysis Rate Constant (K_a^{Tr}) 3-14
3.3.2.2.4 Neutral Hydrolysis Rate Constant (K_n^{Tr}) 3-16
3.3.2.2.5 Base-Catalyzed Hydrolysis Rate Constant (K_b^{Tr}) 3-17
3.3.2.2.6 Reference Temperature (T_r) 3-17
3.3.2.3 Parameters Related to Hydrolysis Transformation Products 3-18
3.3.2.3.1 Daughter Species Number (ℓ) 3-18
3.3.2.3.2 Number of Immediate Parents (M_ℓ) .. 3-19
3.3.2.3.3 Species Number(s) of Immediate Parent(s) ($m_\ell(i)$, i = 1, M_ℓ) 3-20
3.3.2.3.4 Fraction of the Parent Species (ξ_{km}) .. 3-21
3.3.3 Metals 3-22
3.3.3.1 Empirical K_d Data 3-23
3.3.3.1.1 K_d Data Compiled from a Literature Survey 3-23
3.3.3.1.2 pH-based Isotherms 3-24
3.3.3.2 MINTEQA2-Derived Sorption Isotherm Data . 3-25
3.3.3.2.1 Metal Identification Number (ID) 3-27
3.3.3.2.2 Soil and Aquifer pH (pH) 3-29
3.3.3.2.3 Iron-Hydroxide Content (FeOx) 3-30
3.3.3.2.4 Leachate Organic Matter (LOM) 3-31
3.3.3.2.5 Percent Organic Matter (%OM) 3-32
3.3.3.2.6 Fraction Organic Carbon (f_{oc}) 3-34
3.3.3.2.7 Ground-water Type (IGWT) 3-35

4.0 INFILTRATION AND RECHARGE PARAMETERS 4-1
4.1 INFILTRATION AND RECHARGE PARAMETERS 4-1
4.2 CLIMATE CENTER INDEX (ICLR) 4-2
4.3 INFILTRATION RATES 4-6
4.3.1 Landfill Infiltration Rate (I) 4-7
4.3.2 Waste Pile Infiltration Rate (I) 4-9
4.3.3 Land Application Unit Infiltration Rate (I) 4-11
4.3.4 Surface Impoundment Infiltration Rate (I) 4-13
4.4 RECHARGE RATE (I_R) 4-15

TABLE OF CONTENTS (continued)

Page

5.0 HYDROGEOLOGICAL PARAMETERS 5-1
5.1 HYDROGEOLOGICAL PARAMETERS 5-2
5.2 UNSATURATED ZONE PARAMETERS 5-2
5.2.1 Unsaturated Zone Thickness (D_u) 5-2
5.2.2 Soil Type (ISTYPE) 5-6
5.2.3 Soil Hydraulic Characteristics 5-7
5.2.3.1 Soil Hydraulic Conductivity (K_s) 5-7
5.2.3.2 Alpha (α) 5-11
5.2.3.3 Beta (β) 5-12
5.2.3.4 Residual Water Content (θ_r) 5-13
5.2.3.5 Saturated Water Content (θ_s) 5-15
5.2.3.6 Soil Bulk Density (ρ_b) 5-16
5.2.3.7 Percent Organic Matter (%OM) 5-17
5.2.4 Unsaturated Zone Dispersivity (α_{Lu}) 5-19
5.2.5 Freundlich Adsorption Isotherm Parameters 5-21
5.2.5.1 Leading Coefficient of Freundlich Isotherm for Unsaturated Zone (K_d) 5-23
5.2.5.2 Exponent of Freundlich Isotherm for Unsaturated Zone (η) 5-24
5.2.6 Chemical Degradation Rate Coefficient for Unsaturated Zone (λ_{cu}) 5-25
5.2.7 Biodegradation Rate Coefficient for Unsaturated Zone (λ_{bu}) 5-26
5.2.8 Soil Temperature (T) 5-26
5.2.9 Soil pH (pH) 5-28
5.3 SATURATED ZONE PARAMETERS 5-29
5.3.1 Particle Diameter (d) 5-29
5.3.2 Porosity (ϕ) 5-31
5.3.3 Bulk Density (ρ_b) 5-33
5.3.4 Aquifer Characteristics 5-35
5.3.4.1 Methodology 5-38
5.3.4.2 Hydrogeologic Environment (IGWR) 5-39
5.3.4.3 Saturated Zone Thickness (B) 5-43
5.3.4.4 Hydraulic Conductivity (K) 5-45
5.3.4.5 Regional Hydraulic Gradient (r) 5-47
5.3.5 Seepage Velocity (V_x) 5-49
5.3.6 Anisotropy Ratio (A_r) 5-51
5.3.7 Retardation Coefficient for the Saturated Zone (R^s) 5-52
5.3.8 Dispersivity 5-53
5.3.8.1 Longitudinal Dispersivity (α_L) 5-54
5.3.8.2 Horizontal Transverse Dispersivity (α_T) 5-56
5.3.8.3 Vertical Dispersivity (α_v) 5-58
5.3.9 Aquifer Temperature (T) 5-59
5.3.10 Ground-water pH (pH) 5-61
5.3.11 Fractional Organic Carbon Content (f_{oc}^s) 5-63

TABLE OF CONTENTS (continued)

Page

5.3.12 Leading Coefficient of Freundlich Isotherm for Saturated Zone (K_d^s) 5-64
5.3.13 Exponent of Freundlich Isotherm for Saturated Zone (η^s) 5-66
5.3.14 Chemical Degradation Rate Coefficient for Saturated Zone (λ_c^s) 5-67
5.3.15 Biodegradation Rate Coefficient for Saturated Zone (λ_b^s) 5-68

6.0 RECEPTOR WELL PARAMETERS 6-1
6.1 RECEPTOR WELL PARAMETERS 6-1
6.2 RADIAL DISTANCE TO RECEPTOR WELL (R_{rw}) 6-4
6.3 ANGLE OF WELL OFF OF PLUME CENTERLINE (θ_{rw}) 6-5
6.4 DOWN-GRADIENT DISTANCE TO RECEPTOR WELL (x_{rw}) ... 6-6
6.5 WELL DISTANCE FROM PLUME CENTERLINE (y_{rw}) 6-8
6.6 DEPTH OF INTAKE POINT BELOW WATERTABLE (z^*_{rw}) 6-10
6.7 AVERAGING PERIOD FOR Ground-water CONCENTRATION AT RECEPTOR WELL (t_d) 6-11

7.0 REFERENCES 7-1

APPENDIX A: Determination of Infiltration and Recharge Rates

APPENDIX B: Nonlinear Sorption Isotherms Calculated Using the MINTEQA2 Model

APPENDIX C: Physical and Chemical Properties for Organic Constituents

APPENDIX D: WMU and Hydrogeologic Environment Databases

LIST OF FIGURES

		Page
Figure 2.1	WMU Types Modeled in EPACMTP	2-3
Figure 2.2	Geographic Locations of Landfill WMUs	2-6
Figure 2.3	Geographic Locations of Surface Impoundment WMUs	2-7
Figure 2.4	Geographic Locations of Waste Pile WMUs	2-8
Figure 2.5	Geographic Locations of Land Application Unit WMUs	2-9
Figure 2.6	WMU with Base Elevation below Ground Surface	2-13
Figure 2.7	Schematic Cross-Section View of SI Unit	2-17
Figure 4.1	Locations of EPACMTP Climate Stations	4-5
Figure 5.1	Ground-water Temperature Distribution for Shallow Aquifers in the United States (from Todd, 1980)	5-27
Figure 5.2	Geographical distribution of sites in the API-HGDB data base (Reproduced from API, 1989)	5-37
Figure 5.3	Ground-water Temperature Distribution for Shallow Aquifers in the United States (from Todd, 1980)	5-60
Figure 6.1	Schematic plan view showing procedure for determining the downstream location of the receptor well: (a) well location determined using radial distance, R_{rw}, and angle off center θ_{rw}; and (b) well location generated uniformly within plume limit	6-3

This page intentionally left blank.

LIST OF TABLES

		Page
Table 2.1	Waste Management Unit (Source) Parameters	2-4
Table 2.2	Cumulative Frequency Distribution of Landfill Area	2-11
Table 2.3	Cumulative Frequency Distribution of Landfill Depth	2-12
Table 2.4	Cumulative Frequency Distribution of Surface Impoundment Area	2-18
Table 2.5	Cumulative Frequency Distribution of Surface Impoundment Ponding Depth	2-19
Table 2.6	Cumulative Frequency Distribution of Surface Impoundment Depth Below Grade	2-22
Table 2.7	Cumulative Frequency Distribution of Leak Density for Composite-Lined SIs	2-23
Table 2.8	Cumulative Frequency Distribution of Distance to Nearest Surface Water Body	2-24
Table 2.9	Cumulative Frequency Distribution of Surface Impoundment Operating Life	2-26
Table 2.10	Cumulative Frequency Distribution of Waste Pile Area	2-27
Table 2.11	Cumulative Frequency Distribution of Land Application Unit Area	2-30
Table 3.1	Waste and Constituent Parameters	3-2
Table 3.2	Default Cumulative probability distribution of waste density	3-4
Table 3.3	Empirical pH-dependent Adsorption Relations (Loux et al., 1990)	3-25
Table 3.4	Metals that have MINTEQA2-derived Non-linear Isotherms	3-28
Table 3.5	Probability distribution of soil and aquifer pH	3-29
Table 3.6	Probability distribution of fraction iron hydroxide	3-31
Table 3.7	Probability distribution of leachate organic matter	3-32
Table 3.8	Probability distribution of percent organic matter in the unsaturated zone	3-33
Table 3.9	Probability distribution of fraction organic carbon in the saturated zone	3-35
Table 4.1	Climate Parameters	4-2
Table 4.2	Climate Centers Used in the HELP Modeling to Develop Infiltration and Recharge Rates	4-3
Table 4.3	Cumulative Frequency Distribution of Landfill Infiltration	4-8
Table 4.4	Cumulative Frequency Distribution of Waste Pile Infiltration	4-10
Table 4.5	Cumulative Frequency Distribution of Land Application Unit Infiltration	4-12
Table 4.6	Cumulative Frequency Distribution of Surface Impoundment Infiltration	4-14
Table 4.7	Cumulative Frequency Distribution of Regional Recharge Rate	4-16
Table 5.1	Hydrogeological Parameters	5-3
Table 5.2	Cumulative Frequency Distribution of Unsaturated Zone Thickness	5-5
Table 5.3	Default EPACMTP Soil Types	5-6

LIST OF TABLES (continued)

		Page
Table 5.4	Statistical parameters for soil properties for three soil types used in the EPACMTP model (Carsel and Parrish, 1988 and Carsel et al., 1988). All values are in arithmetic space	5-8
Table 5.5	Cumulative Frequency Distribution of Soil Hydraulic Conductivity	5-9
Table 5.6	Descriptive statistics for van Genuchten water retention model parameters, α, β, and γ (Carsel and Parrish, 1988)	5-10
Table 5.7	Cumulative Frequency Distribution of Alpha	5-11
Table 5.8	Cumulative Frequency Distribution of Beta	5-13
Table 5.9	Cumulative Frequency Distribution of Residual Water Content	5-14
Table 5.10	Cumulative Frequency Distribution of Saturated Water Content	5-15
Table 5.11	Cumulative Frequency Distribution of Soil Bulk Density	5-17
Table 5.12	Cumulative Frequency Distribution of Percent Organic Matter	5-18
Table 5.13	Cumulative Frequency Distribution of Dispersivity	5-20
Table 5.14	Compilation of field dispersivity values (EPRI, 1985)	5-21
Table 5.15	Empirical distribution of mean particle diameter (based on Shea, 1974)	5-30
Table 5.16	Cumulative Frequency Distribution of Particle Diameter	5-30
Table 5.17	Ratio between effective and total porosity as a function of particle diameter (after McWorter and Sunada, 1977)	5-33
Table 5.18	Cumulative Frequency Distribution of Bulk Density	5-34
Table 5.19	HGDB Hydrogeologic Environments (from Newell et al., 1990)	5-35
Table 5.20	Cumulative Frequency Distribution of Saturated Zone Thickness	5-44
Table 5.21	Cumulative Frequency Distribution of Hydraulic Conductivity	5-45
Table 5.22	Cumulative Frequency Distribution of Regional hydraulic gradient	5-48
Table 5.23	Cumulative Frequency Distribution of Ground-water Seepage Velocity	5-50
Table 5.24	Probabilistic representation of longitudinal dispersivity	5-55
Table 5.25	Cumulative Frequency Distribution of Longitudinal Dispersivity	5-55
Table 5.26	Cumulative Frequency Distribution of Horizontal Transverse Dispersivity	5-57
Table 5.27	Cumulative Frequency Distribution of Vertical Dispersivity	5-59
Table 5.28	Probability distribution of aquifer pH	5-62
Table 5.29	Probability distribution of fraction organic carbon in the saturated zone	5-64
Table 6.1	Receptor Well Parameters	6-1
Table 6.2	Cumulative Probability of Distance to Nearest Receptor Well for Landfills (from EPA, 1993)	6-4

ACKNOWLEDGMENTS

A large number of individuals have been involved with the development of EPACMTP since its inception in the early 1990's. Dr. Zubair A. Saleem of the U.S. EPA, Office of Solid Waste (EPA/OSW) has coordinated and guided the development of EPACMTP throughout much of this period. Ms. Ann Johnson, Mr. David Cozzie, and Mr. Timothy Taylor provided review for the development of this background document. This report was prepared by the staffs of HydroGeoLogic, Inc. (HGL), and Resource Management Concepts, Inc. (RMC), under EPA Contract Number 68-W-01-004.

This page intentionally left blank.

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Definition	Section
A_r	anisotropy ratio = K_x/K_z	5.3.6
A_w	area of a WMU (m^2)	2.3.1, 2.4.1, 2.5.1, 2.6.1
B	thickness of the saturated zone (m)	5.3.4.3, 6.6
C_d	metal concentration in the dissolved phase at equilibrium (mg/L)	3.3.3.2
C_s	metal concentration in the sorbed phase at equilibrium (mg/L)	3.3.3.2
C_L	leachate concentration (mg/L)	3.2.3
CV	coefficient of variation (%)	5.2.4
C_w	constituent concentration in the waste (mg/kg)	3.2.2
d_{BG}	depth below grade of WMU (m)	2.3.3, 2.4.6, 2.5.3
D_i	molecular diffusion coefficient in free water for species i (m^2/yr)	3.3.1.1
D_{LF}	landfill depth (m)	2.3.2
D_{lin}	liner thickness (m)	2.4.4
D_s	total sediment thickness (m)	2.4.3
D_u	total depth of the unsaturated zone (m)	5.2.1
D^{s*}	effective molecular diffusion coefficient for species of interest (m^2/y)	6.6
DWS	drinking water standard (mg/L)	3.3.1.2
E_a	Arrhenius activation energy (Kcal/mol)	3.3.2.2.3
F_h	volume fraction of the waste in the landfill at time of closure (m^3/m^3)	2.3.4
FeOx	iron hydroxide content (wt % Fe)	3.3.3.2.3
f_{oc}	fractional organic carbon content (dimensionless)	3.3.3.2.6
f_{oc}^s	fractional organic carbon content of the aquifer material (dimensionless)	5.3.11
g	gravitational acceleration (m/s^2)	5.3.4.4
$[H^+]$	hydrogen ion concentration (mol/L)	3.3.2.2.1
H_P	SI ponding depth (m)	2.4.2
I	annual infiltration rate through the source (m/y)	4.3.1, 4.3.2, 4.3.3, 4.3.4
ICLR	climate center index	4.2
ID	metal identification number (unitless)	3.3.3.2.1
IGWR	hydrogeologic environment index (unitless)	3.3.3.2.7,5.3.4.2
IGWT	ground-water type - carbonate/non-carbonate (unitless)	3.3.3.2.7
ISTYPE	soil type	5.2.2

Symbol	Definition	Section
IWLOC	R_{rw} (Receptor well) origination method	6.5
I_R	effective recharge rate outside the strip source area (m/y) or recharge rate outside the source area (m/y)	4.4
J	symbol used to denote a for the acid-catalyzed reaction, b for the base-catalyzed reaction and n for the neutral reaction	3.3.2.2.3
K	hydraulic conductivity (m/yr)	5.3.4.4
k_1	nonlinear Freundlich parameter for the unsaturated zone (mg constituent/kg dry soil))	5.2.9
K_a^T	acid-catalyzed hydrolysis rate constant (1/(mol.yr))	3.3.2.2.1
K_a^{Tr}	acid-catalyzed hydrolysis rate constant at reference temperature (1/(mol.yr))	3.3.2.2.3
K_b^T	base-catalyzed hydrolysis rate constant (1/(mol.yr))	3.3.2.2.2
K_b^{Tr}	base-catalyzed hydrolysis rate constant at reference temperature (1/(mol.yr))	3.3.2.2.5
K_d	distribution (solid-aqueous phase) partition coefficient in the unsaturated zone (cm^3/g) (Freundlich Coefficient)	3.3.3, 5.2.8
K_d^s	solid-liquid distribution coefficient of the aquifer (cm^3/g)	5.3.12
K_J^T	hydrolysis rate constant for reaction process J, corrected for the subsurface temperature T (1/(mol.yr) for the acid- and base-catalyzed reactions; 1/yr for the neutral reaction)	3.3.2.2.3
K_J^{Tr}	hydrolysis rate constant for reaction process J, measured at the reference temperature T_r (1/(mol.yr) for the acid- and base-catalyzed reactions; 1/yr for the neutral reaction)	3.3.2.2.3
K_{lin}	saturated hydraulic conductivity of liner (m/y)	2.4.5
K_n^T	neutral hydrolysis rate constant at (1/yr)	3.3.2.2.1
K_n^{Tr}	neutral hydrolysis rate constant at reference temperature (1/yr)	3.3.2.2.3
k_d	soil-water partition coefficient (L/kg)	3.3.2.1
k_{oc}	constituent-specific organic carbon partition coefficient (cm^3/g)	3.3.2.1
k_{ow}	octanol-water partition coefficient (cm^3/g)	3.3.2.1
K_s	saturated hydraulic conductivity (cm/hr)	5.2.3
K_x	hydraulic conductivity in the *x* direction (m/y)	5.3.5
K_y	hydraulic conductivity in the horizontal transverse (y) direction (m/y)	5.3.6
ℓ	daughter species number	3.3.2.3.1
LOM	leachate organic acid concentration (mol/L)	3.3.3.2.4
LYCHK	constraint on well distance from plume centerline	6.5
LZCHK	constraint on depth of intake point below water table	6.6

LIST OF SYMBOLS AND ABBREVIATIONS (continued)

Symbol	Definition	Section
ℓ	daughter species number	3.3.2.3.1
LN	log normal distribution	5.2.2
M	number of immediate parent species	3.3.2.3.2
m	species number of immediate parent	3.3.2.3.3
MW_ℓ	molecular weight of species ℓ (g/mol.)	3.3.1.3
N	sample size	5.2.4
NO	Normal distribution	5.2.2
$[OH^-]$	hydroxyl ion concentration (mol/L)	3.3.2.2.2
%OM	percent organic matter (dimensionless)	3.3.3.2.5, 5.2.7
PWS	waste volume (m^3)	2.3.5
pH	ground-water pH (standard units)	3.3.3.2.2, 5.2.10, 5.2.13
Q_1^F	background ground-water flux (m^2/y)	6.6
Q_4^F	recharge flux downgradient of the source (m^2/y)	6.6
r	regional hydraulic gradient (m/m)	5.3.4.5
R_g	Universal Gas Constant (1.987E-3 Kcal/deg-mol)	3.3.2.2.3
R_i	retardation factor for species i (dimensionless)	3.3.2.1
R_{rw}	radial distance between waste management unit and well (m)	6.2
R_∞	distance between the center of the source and the nearest downgradient boundary where the boundary location has no perceptible effects on the heads near the source (m)	2.4.8
R^s	retardation coefficient (dimensionless)	5.3.7
SB	log ratio distribution	5.2.2
SD	standard deviation	5.2.4
T_r	hydrolysis reference temperature (°C)	3.3.2.2.6
T	ground-water/subsurface temperature (°C)	3.3.2.2.3, 5.2.12, 5.3.9
t_d	exposure time interval of interest (yr)	6.8
t_p	leaching duration (yr)	2.3.6, 2.4.9, 2.5.2, 2.6.2
V_x	longitudinal ground-water (seepage) velocity (in the x-direction) (m/y)	5.3.5
$\bar{X}$	sample mean	5.2.4
x	principal Cartesian coordinate along the regional flow direction (m)	6.4
x_{rw}	distance from the downgradient boundary of the WMU to the receptor well (m)	6.4

Symbol	Definition	Section
x_t	average travel distance in the x direction (m)	5.3.8.1
x_w	length of the WMU in the x-direction (parallel to ground-water flow) (m)	6.6
y	principal Cartesian coordinate normal to the flow direction, or distance from the plume centerline (m)	6.5
y_D	source width along the y-axis (m)	6.5
y_{rw}	Cartesian coordinate of the receptor well in the y-direction (m)	6.5
z	principal Cartesian coordinate in the vertical direction (m)	6.6
z^*_{rw}	z-coordinate of the receptor well positive downward from the water table(m)	6.6
	GREEK SYMBOLS	
α	van Genuchten soil-specific shape parameter (1/cm)	5.2.2, 5.2.4.1
α_L	longitudinal dispersivity of the aquifer (m)	5.3.8.1, 6.6
α_{Lu}	longitudinal dispersivity in the unsaturated zone (m)	5.2.6
α_{Ref}	reference longitudinal dispersivity, as determined from the probabilistic distribution (m)	5.3.8.1
α_T	horizontal transverse dispersivity (m)	5.3.8.2, 6.5
α_V	vertical transverse dispersivity (m)	5.3.8.2, 6.6
β	van Genuchten soil-specific shape parameter (dimensionless)	5.2.2, 5.2.4.2
γ	van Genuchten soil-specific shape parameter (dimensionless) = $1 - 1/\beta$	5.2.4
η	species-specific nonlinear Freundlich exponent for the unsaturated zone	5.2.9
η^s	Freundlich exponent for the saturated zone (dimensionless)	5.3.13
θ	soil water content (dimensionless)	3.3.2.1
θ_r	residual soil water content (dimensionless)	5.2.4.3
θ_{rw}	angle measured counter-clockwise from the plume centerline (degrees)	6.3
θ_s	saturated soil water content (dimensionless)	5.2.4.4
λ	overall first-order hydrolysis transformation rate(1/y)	3.3.2.2
λ_1	hydrolysis constant for dissolved phase (1/y)	3.3.2.2.2
λ_2	hydrolysis constant for sorbed phase (1/y)	3.3.2.2.1
λ_b^s	biodegradation rate in the saturated zone (1/yr)	5.3.15
λ_c^s	chemical degradation rate in the saturated zone (1/yr)	5.3.14
λ_{bu}	transformation coefficient due to biological transformation (1/y)	5.2.11

LIST OF SYMBOLS AND ABBREVIATIONS (continued)

Symbol	Definition	Section
λ_{cu}	transformation coefficient due to chemical transformation (1/y)	5.2.10
μ	dynamic viscosity of water (N-s/m^2)	5.3.4.4
$\xi_{\ell m}$	stoichiometric fraction of parent m that degrades into daughter ℓ/speciation factor (dimensionless)	3.3.2.3.4
ρ	density of water (kg/m^3)	5.3.4.4
ρ_b	bulk density of the aquifer (g/cm^3)	3.3.2.1, 5.3.3
ρ_{bu}	soil bulk density of the unsaturated zone (g/cm^3)	5.2.5
ϕ	porosity/water content in the unsaturated zone (dimensionless)	3.3.2.2, 5.3.2
ϕ_e	effective porosity of the saturated zone (dimensionless)	6.6

This page intentionally left blank.

1.0 INTRODUCTION

This document provides background information on the parameters and data sources used in **EPA's Composite Model for Leachate Migration with Transformation Products** (EPACMTP). EPACMTP is a subsurface fate and transport model used by EPA's Office of Solid Waste in the RCRA program to establish regulatory levels for concentrations of constituents in wastes managed in land-based units. This document describes the EPACMTP input parameters, data sources and default parameter values and distributions that EPA has assembled for its use of EPACMTP as a ground-water assessment tool. EPA has also developed a complementary document, the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), which presents the mathematical formulation, assumptions and solution methods underlying the EPACMTP. These two documents together are the primary reference documents for EPACMTP, and are intended to be used together.

The remainder of this section describes how this background document is organized. The parameters and data are documented in six main categories, as follows:

- Section 2 describes the Waste Management Unit (Source) Parameters;
- Section 3 describes the Waste and Constituent Parameters;
- Section 4 describes the Infiltration and Recharge Parameters;
- Section 5 describes the Subsurface Parameters;
- Section 6 describes the Ground-water Well Location Parameters; and
- Section 7 provides a list of References

Several appendices provide complete listings of data distributions for a number of the EPACMTP input parameters.

To facilitate the cross-referencing of information between this document and the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), each section begins with a table that lists the parameters described in that section, and provides, for each parameter, a reference to the equation(s) and/or section number in the *EPACMTP Technical Background Document* (U.S. EPA, 2003a) that describes how each parameter is used in the EPACMTP computer code.

This page intentionally left blank.

2.0 WASTE MANAGEMENT UNIT (SOURCE) PARAMETERS

EPACMTP can simulate the subsurface migration of leachate from four different types of waste management units (WMUs). Each of the four unit types reflects waste management practices that are likely to occur at industrial Subtitle D facilities. The WMU can be a landfill, a waste pile, a surface impoundment, or a land application unit. The latter is also sometimes called a land treatment unit. Figure 2.1 presents schematic diagrams of the different types of WMUs modeled in EPACMTP.

Landfill. Landfills (LFs) are facilities for the final disposal of solid waste on land. EPACMTP is typically used to model closed LFs with an earthen cover. LFs may be unlined, or they may have some type of engineered liner, but the model assumes no leachate collection system exists underneath the liner. The LF is filled with waste during the unit's operational life. Upon closure of the LF, the waste is left in place, and a final soil cover is installed. The starting point for the EPACMTP simulation is the time at which the LF is closed, i.e., the unit is at maximum capacity. The release of waste constituents into the soil and ground water underneath the LF is caused by dissolution and leaching of the constituents due to precipitation which percolates through the LF. The type of liner that is present (if any) controls, to a large extent, the amount of leachate that is released over time from the unit. LFs are modeled in EPACMTP as WMUs with a rectangular footprint and a uniform depth. The EPACMTP model does not explicitly account for any loss processes occurring during the unit's active life (for example, due to leaching, volatilization, runoff or erosion, or biochemical degradation), however these processes will be taken into account if the input value for leachate concentration is based on a site-specific chemical analysis of the waste (such as results from a Toxicity Characteristic Leaching Procedure (TCLP) or Synthetic Precipitation Leaching Procedure (SPLP) analysis). The leachate concentration used as a model input is the expected initial leachate concentration when the waste is 'fresh'. Because the LF is closed, the concentration of the waste constituents will diminish with time due to depletion of the landfilled wastes; the model is equipped to simulate this "depleting source" scenario for LFs, but other source options are available, and are explained in Section 2.3.

Surface Impoundment. A surface impoundment (SI) is a WMU which is designed to hold liquid waste or wastes containing free liquid. SIs may be either ground level or below ground level flow-through units. They may be unlined, or they may have some type of engineered liner. Release of leachate is driven by the ponding of water in the impoundment, which creates a hydraulic head gradient across the barrier underneath the unit. The EPACMTP model considers a SI to be a temporary WMU with a finite operational life. At the end of the unit's operational life, we assume there is no further release of waste constituents to the ground water (that is, there is a clean closure of the SI). SIs are modeled as pulse-type sources; leaching occurs at a constant leachate concentration over a fixed period of time equal to the unit's operating life. The EPACMTP model assumes a constant

ponding depth (depth of waste water in SI) during the operational life (see Section 2.2.4).

Waste Pile. Waste piles (WPs) are typically used as temporary storage or treatment units for solid wastes. Due to their temporary nature, they are typically not covered. Similar to LFs, WPs may be unlined, or they may have some type of engineered liner. EPACMTP assumes that WPs have a fixed operational life, after which the WP is removed. Thus, WPs are modeled as pulse-type sources; leaching occurs at a constant leachate concentration over a fixed period of time which is equal to the unit's operating life (see Section 2.5.2).

Land Application Unit. Land application units (LAUs) (or land treatment units) are areas of land receiving regular applications of waste that is either tilled directly into the soil or sprayed onto the soil and then tilled. EPACMTP models the leaching of wastes after they have been tilled with soil. EPACMTP does not account for the losses due to volatilization during or after waste application. LAUs are only evaluated for the no-liner scenario because liners are not typically used at this type of facility. EPACMTP assumes that an LAU is a temporary WMU with a fixed operational life, after which the waste is no longer land-applied. Thus, LAUs are modeled in EPACMTP as a constant pulse-type leachate source, with a leaching duration equal to the unit's operational life (see Section 2.6.2).

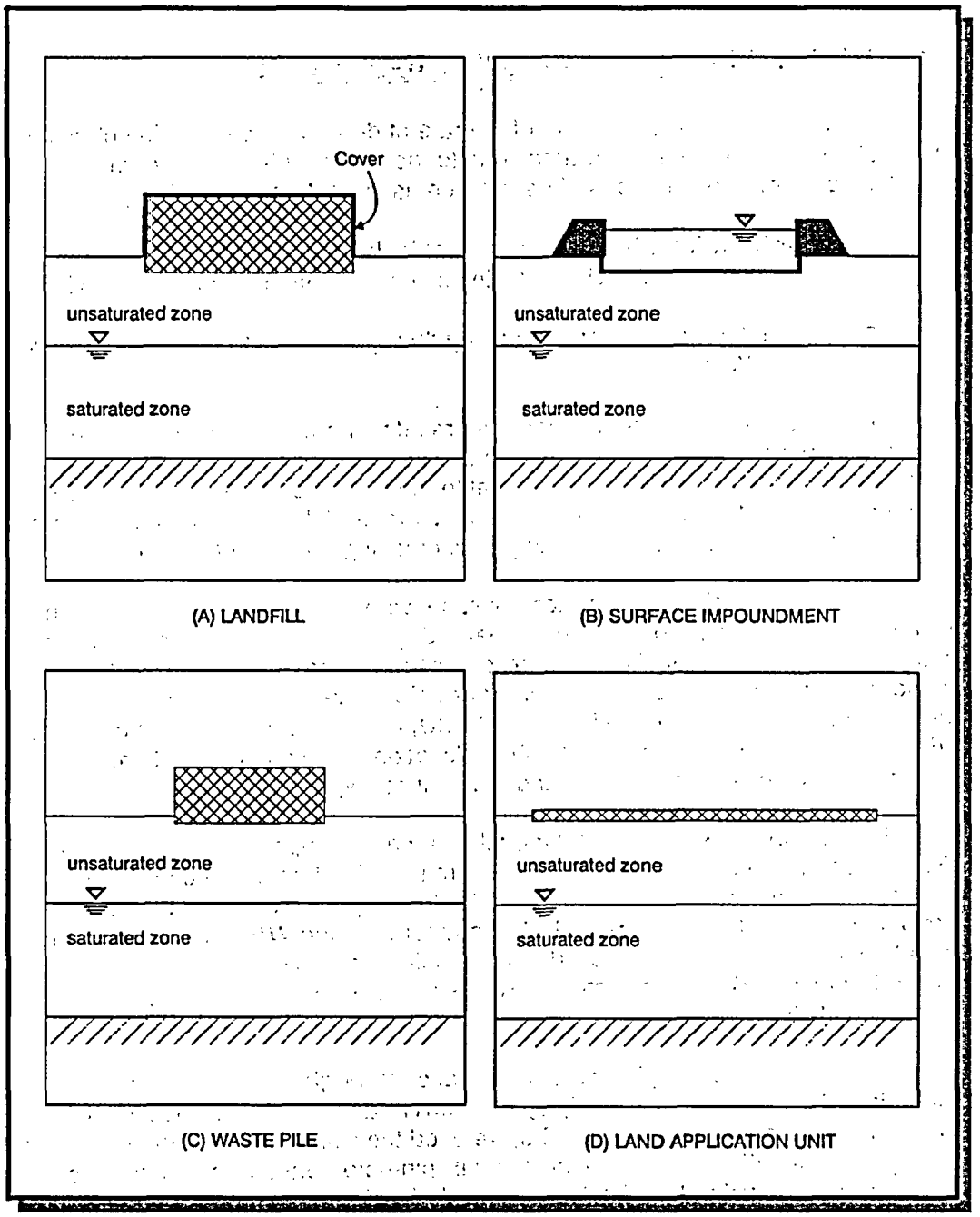


Figure 2.1 WMU Types Modeled in EPACMTP.

APPENDIX A
DETERMINATION OF INFILTRATION AND RECHARGE RATES

A.1 INFILTRATION AND RECHARGE RATES

EPACMTP requires the input of the rate of downward percolation of water and leachate through the unsaturated zone to the water table. The model distinguishes between two types of percolation as infiltration and recharge:

- **Infiltration** (WMU leakage rate) is defined as water percolating through the WMU – including a liner if present – to the underlying soil.
- **Recharge** is water percolating through the soil to the aquifer outside the WMU.

Infiltration is one of the key parameters affecting the leaching of waste constituents into the subsurface. For a given leachate concentration, the mass of constituents leached is directly proportional to the infiltration rate. In EPACMTP, using a different default liner scenario changes the modeled infiltration rate; more protective liner designs reduce leaching by decreasing the rate of infiltration.

In contrast, recharge introduces pristine water into the aquifer. Increasing recharge therefore tends to result in a greater degree of plume dilution and lower constituent concentrations. High recharge rates may also affect the extent of ground-water mounding and ground-water velocity. The recharge rate is independent of the type and design of the WMU; rather it is a function of the climatic and hydrogeological conditions at the WMU location, such as precipitation, evapotranspiration, surface run-off, and regional soil type.

In developing the EPACMTP model and the accompanying databases, the U.S. EPA used several methodologies to estimate infiltration and recharge. We used the HELP model (Schroeder et al, 1994) to compute recharge rates for all units, as well as infiltration rates for LAUs, and for LFs and WPs with no-liner and single-liner designs. For LFs and WPs, composite liner infiltration rates were compiled from leak-detection-system flow rates reported for actual composite-lined waste units (TetraTech, 2001).

For unlined and single-lined SIs, infiltration through the bottom of the impoundment is calculated internally by EPACMTP, as described in Section 4.3.4 of this document. For composite-lined SIs, we used the Bonaparte (1989) equation to calculate the infiltration rate assuming circular (pin-hole) leaks with a uniform leak size of 6 mm^2, and using the distribution of leak densities (number of leaks per hectare) assembled from the survey of composite-lined units (TetraTech, 2001).

Tables A.1 through A.4 summarize the liner assumptions and infiltration rate calculations for LFs, WPs, SIs, and LAUs. The remainder of this appendix provides background on how we used the HELP model in conjunction with data from climate stations across the United States to develop nationwide recharge and infiltration rate

distributions and provides a detailed discussion of how we developed infiltration rates for different default liner designs for each type of WMU.

A.1.1 USING THE HELP MODEL TO DEVELOP RECHARGE AND INFILTRATION RATES

The HELP model is a quasi-two-dimensional hydrologic model for computing water balances of LFs, cover systems, and other solid waste management facilities. The primary purpose of the model is to assist in the comparison of design alternatives. The HELP model uses weather, soil and design data to compute a water balance for LF systems accounting for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. The HELP model can simulate LF systems consisting of various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners.

HELP Versions 3.03 and 3.07 (which include WMU- and liner-specific distributions of infiltration rates) were used to construct the EPACMTP site data files. We started with an existing database of no-liner infiltration rates for LFs, WPs and LAUs. Also existing were recharge rates for 97 climate stations in the lower 48 contiguous United States (ABB, 1995), that are representative of 25 specific climatic regions (developed with HELP version 3.03). We then added five climate stations (located in Alaska, Hawaii, and Puerto Rico) to ensure coverage throughout all of the United States. Figure A.1 shows the locations of the 102 climate stations.

The current version of HELP (version 3.07) was used for the modeling of the additional climate stations for the no-liner scenario. We compared the results of Version 3.07 against Version 3.03 and found that the differences in calculated infiltration rates were insignificant. We also used this comparison to verify a number of counter-intuitive infiltration rates that were generated with HELP Version 3.03. We had observed that for some climate stations located in areas of the country with low precipitation rates, the net infiltration for unlined LFs did not always correlate with the relative permeability of the LF cover. We found some cases in which a less permeable cover resulted in a higher modeled infiltration rate as compared to a more permeable cover. Examples can be seen in the detailed listing of infiltration data that are presented in Tables A.11 to A.14. For instance, Table A.11 shows that for a number of climate stations, including Albuquerque, Denver, and Las Vegas, the modeled infiltration rate for LFs with a silty clay loam (SCL) cover is higher than the values corresponding to silt loam (SLT) and sandy loam (SNL) soil covers. We determined that in all these cases, the HELP modeling results for unlined LFs were correct and could be explained in terms of other water balance components, including surface run-off and evapotranspiration.

Table A.1 Methodology Used to Compute Infiltration for LFs

	No Liner	Single Liner	Composite Liner
Method	HELP model simulations to compute an empirical distribution of infiltration rates for a 2 ft. thick cover of three native soil cover types using nationwide coverage of climate stations. Soil-type specific infiltration rates for a specific site are assigned by using the infiltration rates for respective soil types at the nearest climate station.	HELP model simulations to compute an empirical distribution of infiltration rates through a single clay liner using nationwide coverage of climate stations. Infiltration rates for a specific site were obtained by using the infiltration rate for the nearest climate station.	Compiled from literature sources (TetraTech, 2001) for composite liners
Final Cover	Monte Carlo selection from distribution of soil cover types. 2 ft thick native soil (1 of 3 soil types: silty clay loam, silt loam, and sandy loam) with a range of mean hydraulic conductivities (4.2×10^{-5} cm/s to 7.2×10^{-4} cm/s).	3 ft thick clay cover with a hydraulic conductivity of 1×10^{-7} cm/sec and a 10 ft thick waste layer. On top of the cover, a 1 ft layer of loam to support vegetation and drainage and a 1 ft percolation layer.	No cover modeled; the composite liner is the limiting factor in determining infiltration
Liner Design	No liner	3 ft thick clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec. No leachate collection system. Assumes constant infiltration rate (assumes no increase in hydraulic conductivity of liner) over modeling period.	60 mil HDPE layer with either an underlying geosynthetic clay liner with maximum hydraulic conductivity of 5×10^{-9} cm/sec, or a 3-foot compacted clay liner with maximum hydraulic conductivity of 1×10^{-7} cm/sec. Assumes same infiltration rate (i.e., no increase in hydraulic conductivity of liner) over modeling period.
EPACMTP Infiltration Rate	Monte Carlo selection from HELP generated location- specific values.	Monte Carlo selection from HELP generated location-specific values.	Monte Carlo selection from distribution of leak detection system flow rates.

Table A.2 Methodology Used to Compute Infiltration for SIs

	No Liner	Single Liner	Composite Liner
Method	EPACMTP SI module for infiltration through consolidated sludge and native soil layers with a unit-specific ponding depth from EPA's SI Study (EPA, 2001).	EPACMTP module for infiltration through a layer of consolidated sludge and a single clay liner with unit-specific ponding depth from EPA's SI study.	Bonaparte equation (1989) for pin-hole leaks using distribution of leak densities for units installed with formal CQA programs
Ponding Depth	Unit-specific based on EPA's SI study.	Unit-specific based on EPA's SI study.	Unit-specific based on EPA's SI study.
Liner Design	None. However, barrier to infiltration is provided by layer of consolidated sludge at the bottom of the impoundment, and a layer of clogged native soil below the consolidated sludge. The sludge thickness is assumed to be constant over the modeling period. The hydraulic conductivity of the consolidated sludge is between 1.3×10^{-7} and 1.8×10^{-7} cm/sec. The hydraulic conductivity of the clogged native material is assumed to be 0.1 of the unaffected native material in the vadose zone.	3 ft thick clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec. No leachate collection system. Assumes no increase in hydraulic conductivity of liner over modeling period. Additional barrier is provided by a layer of consolidated sludge at the bottom of the impoundment, see no-liner column.	60 mil HDPE layer with either an underlying geosynthetic clay liner with maximum hydraulic conductivity of 5×10^{-9} cm/sec, or a 3-foot compacted clay liner with maximum hydraulic conductivity of 1×10^{-7} cm/sec. Assumptions: 1) constant infiltration rate (i.e., no increase in hydraulic conductivity of liner) over modeling period; 2) geomembrane liner is limiting factor that determines infiltration rate.
EPACMTP Infiltration Rate	Calculated by EPACMTP based on Monte Carlo selection of unit-specific ponding depth.	Calculated based on Monte Carlo selection of unit-specific ponding depth	Calculated based on Monte Carlo selection of unit-specific ponding depth and distribution of leak densities

Table A.3 Methodology Used to Compute Infiltration for WPs

	No Liner	Single Liner	Composite Liner
Method	HELP model simulations to compute distribution of infiltration rates for a 10 ft. thick layer of waste, using three waste permeabilities (copper slag, coal bottom ash, coal fly ash) and nationwide coverage of climate stations. Waste-type-specific infiltration rates for a specific site are obtained by using the infiltration rates for respective waste types at the nearest climate station.	HELP model simulations to compute distribution of infiltration rates through 10 ft. waste layer using three waste permeabilities and nationwide coverage of climate stations. Infiltration rates for a specific site were obtained by using the infiltration rate for the nearest climate station.	Compiled from literature sources (TetraTech, 2001) for composite liners
Cover	None	None	None
Liner Design	No liner.	3 ft thick clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec, no leachate collection system, and a 10 ft thick waste layer. Assumes no increase in hydraulic conductivity of liner over unit's operational life.	60 mil HDPE layer with either an underlying geosynthetic clay liner with maximum hydraulic conductivity of 5×10^{-9} cm/sec, or a 3-foot compacted clay liner with maximum hydraulic conductivity of 1×10^{-7} cm/sec. 1) same infiltration rate (i.e., no increase in hydraulic conductivity of liner) over unit's operational life; 2) geomembrane is limiting factor in determining infiltration rate.
EPACMTP Infiltration Rate	Monte Carlo selection from HELP generated location-specific values.	Monte Carlo selection from HELP generated location- specific values.	Monte Carlo selection from distribution of leak detection system flow rates

Table A.4 Methodology Used to Compute Infiltration for LAUs

	No Liner	Single Liner	Composite Liner
Method	HELP model simulations to compute an empirical distribution of infiltration rates for a 0.5 ft thick sludge layer, underlain by a 3 ft layer of three types of native soil using nationwide coverage of climate stations. Soil-type specific infiltration rates for a specific site are assigned by using the infiltration rates for respective soil types at the nearest climate station.	N/A	N/A
Liner Design	No liner	N/A	N/A
EPACMTP Infiltration Rate	Monte Carlo selection from HELP generated location specific values.	N/A	N/A

biochemical (biological) oxygen demand (BOD)
The amount of oxygen, divided by the volume of the system, taken up through the respiratory activity of microorganisms growing on the organic compounds present in the sample (e.g. water or sludge) when incubated at a specified temperature (usually 20 °C) for a fixed period (usually 5 days, BOD_5). It is a measure of that organic pollution of water which can be degraded biologically. In practice, it is usually expressed in milligrams O_2 per litre.
1992, *64*, 148

The Science of
CHEMICAL OXYGEN DEMAND

Technical Information Series, Booklet No. 9

By: Wayne Boyles

©Hach Company, 1997. All rights are reserved.

K71.3 7053 Printed in U.S.A.

Contents Page

I. INTRODUCTION 3
Purpose of booklet 3
Background on Oxygen Demand Testing 3
Oxidants used for COD testing 4

II. DICHROMATE CHEMICAL OXYGEN DEMAND 5
Dichromate COD Chemistry 6
Precision and Accuracy 6
Pros and Cons of Dichromate 6
Improving the Dichromate COD Test 6

III. MANGANESE III COD REAGENT DEVELOPMENT AND CHEMISTRY 7
Reagent Preparation 7
Precision and Accuracy 7
Comparative Advantages Mn III COD 8

IV. THEORETICAL OXYGEN DEMAND AND COD TEST CALIBRATIONS 8
Theoretical Oxygen Demand of Potassium Acid Phthalate (KHP)—The Industry Standard 8
Calibrations based upon reference materials other than KHP 8
Theoretical oxygen demand of nitrogen-containing compounds 8
Oxidation Efficiency of Organic Compounds 8

V. CATALYSTS 9

VI. INTERFERENCES 9

VII. COMPARATIVE STUDIES OF COD TEST RESULTS 11
Comparison of the Mn III COD and the Dichromate COD Tests 11
Correlation of the COD and BOD Tests 12
COD Results on Selected Synthetic Organic Compounds 13

VIII. CHEMICAL OXYGEN DEMAND PROCEDURES 13
Sample Handling and Preservation 13
Digestion Procedures 13
Advantages of the Micro Digestion Procedure 14
Safety Notes on the Micro Digestion Procedure 14
Colorimetric Procedures 15
Dichromate COD Tests 15
Manganese III COD Tests 18
Titration Methods 20

IX. BIBLIOGRAPHY 22

I. INTRODUCTION

Recent advances in oxygen demand research have expanded the number of options available for testing. The purpose of this technical bluebook is to 1) provide background information on oxygen demand testing, and 2) discuss the comparative advantages of methods currently available, including the new Hach Manganese III COD Method designed to eliminate hazardous heavy metals waste.

Background on Oxygen Demand Testing

Oxygen demand is an important parameter for determining the amount of organic pollution in water. The test has its widest application in measuring waste loadings of treatment plants and in evaluating the efficiency of treatment processes. Other applications include testing lake and stream water samples for organic pollution. Oxygen demand testing does not determine the concentration of a specific substance; rather, it measures the effect of a combination of substances and conditions. Because oxygen demand is not a pollutant, it poses no direct threat to fish or other life. It can, however, pose an indirect threat to living organisms by reducing the level of dissolved oxygen.

There are three widely-used methods of measuring oxygen demand. Two measure oxygen demand directly: Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). A third method—Total Organic Carbon (TOC)—measures oxygen demand indirectly.

BOD Test

Of the three test methods that determine oxygen demand (BOD, COD and TOC), the BOD test most closely models aerobic waste treatment and the aquatic ecosystem. In this test, microorganisms consume organic compounds for food while consuming oxygen at the same time. The standard BOD test measures the amount of oxygen consumed in a sample over a five-day period. Due to the length of time required to complete the test, results provide historical data only and do not facilitate rapid water quality assessment or optimal process control. The test is limited in some applications such as industrial wastewaters, which often contain heavy metal ions, cyanides, and other substances toxic to microorganisms. When microorganisms become poisoned by toxic substances, they are unable to oxidize waste, in which case the BOD test becomes an ineffective measure of organic pollution.

TOC Test

The Total Organic Carbon (TOC) test uses heat, ultraviolet light, and a strong chemical oxidant (or a combination of these three) to oxidize organic compounds to CO_2 and H_2O. Oxygen demand is measured indirectly by determining the amount of CO_2 produced using infrared spectroscopy, conductivity, or coulometry (an electrochemical technique). The test can take several minutes to several hours to complete, and information obtained from TOC analysis is less useful than information obtained from BOD and COD analysis. Also, the TOC test does not differentiate between compounds with the same number of carbon atoms in different stages of oxidation and will thus produce different oxygen demand results. Because BOD and COD tests directly measure the amount of oxygen required to stabilize a waste sample, results reflect the original oxidation state of the chemical pollutants. This is demonstrated using the following example, where two compounds with the same number of carbon atoms in different oxidation states are oxidized to CO_2 and H_2O.

Oxalic Acid: $C_2H_2O_4 + 1/2\ O_2 \longrightarrow 2\ CO_2 + H_2O$

Ethanol: $C_2H_6O + 3\ O_2 \longrightarrow 2\ CO_2 + 3\ H_2O$

While TOC results are identical for both compounds, the oxygen demand of ethanol is six times greater than oxalic acid, and will thus have a much greater effect on the dissolved oxygen content of a receiving water.

COD Test

The Chemical Oxygen Demand (COD) test uses a strong chemical oxidant in an acid solution and heat to oxidize organic carbon to CO_2 and H_2O. By definition, chemical oxygen demand is "a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant."* Oxygen demand is determined by measuring the amount of oxidant consumed using titrimetric or photometric methods. The test is not adversely affected by toxic substances, and test data is available in 1-1/2 to 3 hours, providing faster water quality assessment and process control.

COD test results can also be used to estimate the BOD results on a given sample. An empirical relationship exists between BOD, COD and TOC. However, the specific relationship must be established for each sample. Once correlation has been established, the test is useful for monitoring and control. Table 1 compares the attributes of BOD, COD and TOC tests.

**Standard Methods for the Examination of Water and Wastewater*, 15th Edition

Table 1: Comparison of COD, BOD and TOC Tests			
Parameter	**COD**	**BOD**	**TOC**
Oxidant Used	K_2Cr_2O7 $Mn_2(SO_4)_3$	Oxidation by microorganisms	• O_2 • $K_2S_2O_8$ • Heat • Combination of the above with various catalysts
Most Suitable Use	Rapid and frequent monitoring of treatment plant efficiency and water quality	Modeling treatment plant process and the effects of organic compounds on the dissolved oxygen content of receiving waters	Measures amount of total organic carbon in samples
Test Completion Time	1-1/2 to 3 hours	5 days (for standard BOD test)	Several minutes to hours
Accuracy and Precision	5 - 10% relative standard deviation; may be higher when samples contain suspended solids; sample homogenization can be important	15% relative standard deviation; not considered highly accurate	5 - 10% relative standard deviation; may be higher when samples contain suspended solids; sample homogenization can be important
Advantages	• Correlates with BOD on waste with constant composition. • Toxic materials do not affect oxidant. • Changes in the COD value between influent and effluent may parallel BOD content and supplement BOD results • Short analysis time	• Most closely models the natural environment when used with the proper "seed"	• Correlates with BOD on waste with constant composition, but not as closely as COD • Short analysis time
Disadvantages	• Interference from chloride ions • Some organic compounds are not oxidized completely	• Toxic materials kill microorganisms • Microorganisms do not oxidize all materials present in waste • Inaccuracies when used with improper "seed" • Lengthy test period	• Requires expensive equipment • Some organic compounds are not oxidized completely • Measures Total Organic Carbon and not oxygen demand

Oxidants Used for COD Testing

Analysts have attempted to use many different oxidants in the COD test procedure. Hach laboratories have experimented with permanganate (in both acidic and basic solutions), cerate, persulfate, periodate, iodate, bromate, perbromate, hypochlorite, perchlorate, ferrate, bismuthate, hydrogen peroxide, ozone, oxygen, hydroxyl radical, vanadate, ultraviolet light, bomb colorimetry, combinations of several oxidants and electrochemical techniques. These approaches have not been suitable due to difficulties in reagent preparation, reagent stability, photosensitivity, low oxidation potential, poor oxidation efficiency, expense, and user protocols that proved too complex.

Several oxidants, however, have proven to overcome most of these difficulties. The most widely used oxidant is potassium dichromate and more recently manganese III sulfate. Table 2 summarizes the attributes of oxidants not widely used for COD testing.

Table 2: Major Oxidants Other than $K_2Cr_2O_7$ and $Mn_2(SO_4)_3$ Used in COD Determinations		
Oxidant	**Advantages**	**Disadvantages**
$KMnO_4$	• Stable for several months, MnO_2 must be excluded • Is used in acidic, neutral and basic media • Manganese is a non-hazardous metal	• Relatively slow-acting and is not quantitative • Results may depend upon sample size • Does not oxidize volatile acids or amino acids • Incomplete oxidation of many organic compounds • Unstable in solution: Forms MnO_2 precipitate which catalyzes reagent decomposition.
$Ce(SO_4)_2$	• More complete oxidation of organic compounds than $KMnO_4$ • More stable than $KMnO_4$	• Incomplete oxidation of many organic compounds • Poor reproducibility • Photometric measurement at 320 nm where incompletely oxidized organic compounds interfere • Relatively expensive
K_2S_2O	• Oxidizes many organic nitrogen-containing compounds more completely than other oxidants • Widely used with TOC instrumentation	• Requires elaborate equipment • More labor intensive • Relatively unstable
KIO_3	• Strong oxidant	• Difficult to use • Questionable accuracy
O_2	• Oxygen consumption measured directly	• Elaborate equipment required

The oxidants described in Table 2 have a number of limitations which are eliminated when $K_2Cr_2O_7$ are used as an oxidant.

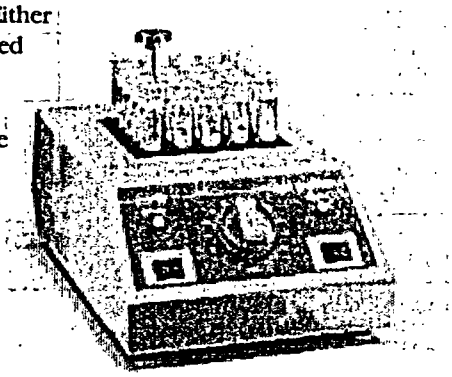
II. DICHROMATE CHEMICAL OXYGEN DEMAND

Dichromate has been used to oxidize organic matter for more than 70 years. It has been preferred over other oxidants because of its superior oxidizing ability on a large variety of samples, and for its ease of use. The test measures the oxygen equivalent of the amount of organic matter oxidized by potassium dichromate in a 50% sulfuric acid solution. Generally, a silver compound is added as a catalyst to promote the oxidation of certain classes of organic compounds. A mercuric compound may be added to reduce the interference from oxidation of chloride ions.

There are two digestion methods used in the COD test: the older Macro Digestion Method, and the Micro Digestion Method. The Macro Digestion Method requires a considerable amount of space, equipment and volume of reagents for each test. Each set-up includes a flask, a glass condenser with hose, a hot plate, a laboratory stand, and clamps. Sample volumes are also relatively large. Because of these inconveniences, the macro method has been virtually replaced by the micro method. The Micro Digestion Method minimizes reagent consumption and reduces the required space and equipment to one reactor block that will digest up to 25 samples at one time. Each test set-up is a self-contained disposable vial, which is inserted into a block heater. Reagent and sample volumes are considerably smaller, which decreases reagent cost and waste volume.

The two-hour digestion time can be reduced if caution is observed. Many types of waste are digested completely in 30 minutes or less at 150 °C, the normal operating temperature. The time of complete digestion can be recognized through experience, or by using a colorimetric reading with the micro method discussed later. In this approach, many consecutive readings are taken on a single sample, allowing a final determination of when the reaction is complete.

After the oxidation step is completed, the amount of dichromate consumed is determined titrimetrically or colorimetrically. Either the amount of reduced chromium (trivalent) or the amount of unreacted dichromate (hexavalent) can be measured. End products of the reaction are carbon dioxide, water, and various states of the chromium ion.



The micro method has several advantages over the macro method, including the capture of volatile organics, small sample size, elimination of cumbersome equipment, and a reduction in the volume of expensive and hazardous reagents.

Dichromate COD Chemistry

When organic matter is oxidized by dichromate in sulfuric acid, most of the carbon is converted to CO_2. Hydrogen present is converted to H_2O. The reaction is illustrated using the primary standard, potassium acid phthalate (KHP), as an example:

$$2\ KC_8H_5O_4 + 10\ K_2Cr_2O_7 + 41\ H_2SO_4 \longrightarrow 16\ CO_2 + 46\ H_2O + 10\ Cr_2(SO_4)_3 + 11\ K_2SO_4$$

Dichromate ions ($Cr_2O_7^{-2}$) form orange-colored solutions. When dichromate is reduced to chromic ion (Cr^{+3}), the solution becomes green. Intermediate valence states may also occur. The standard reduction potential, E° (25 °C vs. Normal Hydrogen Electrode, pH = 0) is about 1.36 volts. The actual potential will vary with temperature, pH, and the ratio of dichromate to chromic ion concentrations according to the following equation:

$$E = E^\circ + \frac{0.0001983\ T}{6} \log \frac{[H^+]\ [Cr_2O_7^{2-}]}{[Cr^{+3}]^2}$$

Precision and Accuracy

A number of samples have been tested using Hach's High Range, Low Range, and Ultra Low Range Dichromate COD vials. Results are given in Table 3 below.

Table 3: Dichromate COD Precision and Accuracy

Sample	Dichromate COD mg/L	Standard Deviation mg/L	Relative Standard Deviation %	Number of Tests *n*
500 mg/L COD	500[1]	1.7	0.3	3
500 mg/L COD + 500 mg/L Chloride	508[1]	1.0	0.1	3
Wastewater Influent	245[1]	6	2.4	5
Wastewater Effluent	45[2]	4.7	2.6	5
Textile Industry	176[1]	4.6	2.6	5
ASTM Synthetic Wastewater Sample	1018[1]	14	1.3	3
Swimming Pool	13[3]	0.6	4.6	3

[1]Hach High Range Dichromate COD Vial
[2]Hach Low Range Dichromate COD Vial
[3]Hach Ultra Low Range Dichromate COD Vial

Pros and Cons of Dichromate

Pros

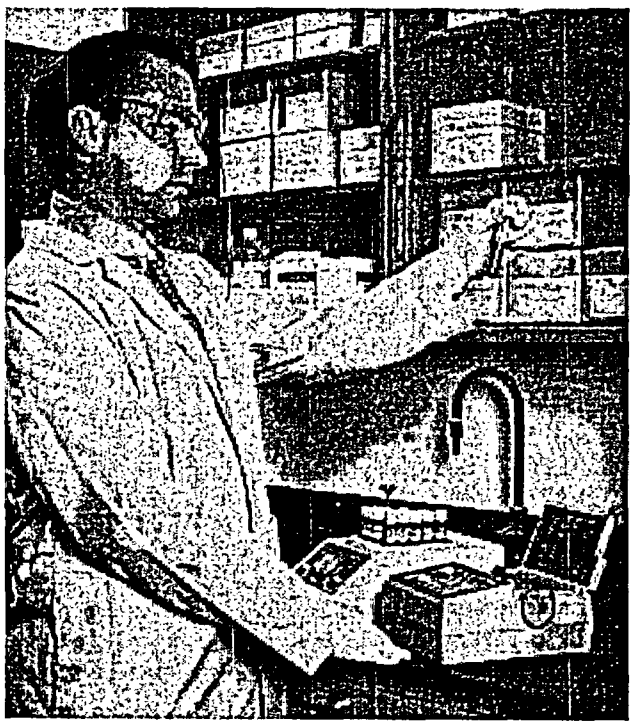
- Dichromate accomplishes a complete oxidation when used with a catalyst and a two-hour digestion period.
- Dichromate is stable at room temperature when protected from exposure to light.

Cons

- Some organic compounds are only partially oxidized.
- Some organic compounds, such as pyridine, are not oxidized.
- There can be interference from inorganic pollutants, mainly chloride ions.
- Reaction temperature is limited by thermal decomposition of the oxidant.
- Dichromate is classified as a carcinogen.

Improving the Dichromate COD Test

Through careful research, many of the disadvantages to the COD test have been overcome or reduced in significance. Incomplete oxidation of aliphatic hydrocarbons, organic acids or alcohols have been improved by using silver ion as a catalyst. Some compounds are not oxidized even with the catalyst. Disposal considerations play an increasingly important role in chemical testing. Although the micro method minimizes the volume of waste generated, the dichromate COD does contain hexavalent chromium, which must be treated as hazardous wastes and mercury.



III. MANGANESE III REAGENT DEVELOPMENT AND CHEMISTRY

A newly developed COD test using Mn III COD oxidizes organic compounds in water without the disposal problems associated with the other method. The chemistry behind the Manganese III COD is unique and not widely known. The following paragraphs discuss the various facets and challenges presented by Mn III chemistry and the process which led to the successful development of the Manganese III COD reagent for wastewater analysis.

Manganese III salts participate in a number of complex chemical equilibria which are largely dependent on acid type and strength. Metastable solutions have been prepared containing up to 40 g/L Mn III. These solutions do not reach equilibrium for several weeks to several months. At equilibrium, the maximum reported level is about 1.6 g/L Mn III in 11 N H_2SO_4 (saturated with $MnSO_4$). Initial experiments with the reagent contained up to 1.1 g/L Mn III.

After several weeks, purple, planar, diamond-shaped crystals were formed. The crystals have been identified as manganosulfuric acid, $H_2\,[Mn_2(SO_4)_4] \bullet 8\,H_2O$. Over time the percentage of vials observed with crystals increased dramatically. The reagent was heated in a reactor block at 150 °C in an attempt to dissolve the crystals which had formed. Reconstitution of the reagent was incomplete, requiring the reformulation of the reagent using a lower concentration of manganese III. The suitability of Mn III for use as a COD test reagent is dependent upon the ability to stabilize Mn III at a concentration high enough to oxidize organic compounds and provide a useful test range.

The solubility of Mn III in sulfuric acid is optimal at a normality of 11. However, for effective oxidation of organic compounds, the normality should be above 12. As the acid strength increases above 11 N, the solubility of Mn III decreases. The optimum reagent composition must balance these two factors: manganese III solubility and reagent acid strength.

The Manganese III COD reagent is stabilized by complexation in sulfuric acid solution where there are several possible Mn III complexes. The predominant species in 11 N H_2SO_4 are $Mn_2(SO_4)_3$ and two hydrated species, $[Mn(H_2O)_5HSO_4]^{2+}$ and $[Mn(H_2O)_5\,(HSO_4)_2]^{+}$.

Reagent stability is also affected by the disproportionation reaction as shown below.

$$2\,Mn^{3+} \longleftrightarrow Mn^{4+} + Mn^{2+}$$

The addition of excess Mn II provides additional stability by forcing the above equilibrium towards Mn III. Consideration must also be given to the decrease in the oxidation potential of the Mn III/Mn II couple due to excess Mn II.

Once reagent strength and stability are determined, reagent and sample volumes can be adjusted. Consideration must be made for optimum sample volume, reagent dilution, and the desired test range.

Reagent Preparation

Reagent preparation methods can be divided into three groups: methods based on chemical oxidation of Mn II; methods based on electrochemical oxidation of Manganese II; and methods based upon dissolution of solid Mn III. In our laboratories, the most frequently used method for laboratory-scale preparations has been the oxidation of manganous sulfate with potassium permanganate, as described by the following equation:

$$2\,KMnO_4 + 8\,MnSO_4 + 8\,H_2SO_4 \longrightarrow 5\,Mn_2\,(SO_4)_3 + K_2SO_4 + 8\,H_2O$$

The Manganese III COD solution has a broad absorption band in the region of 420 to 600 nm, with a maximum absorbance at 510 nm. For comparison, potassium permanganate is an oxidant that has a visual appearance somewhat similar to the Manganese III COD. Both solutions are purple in color, but the spectra are quite different. See Figure 1.

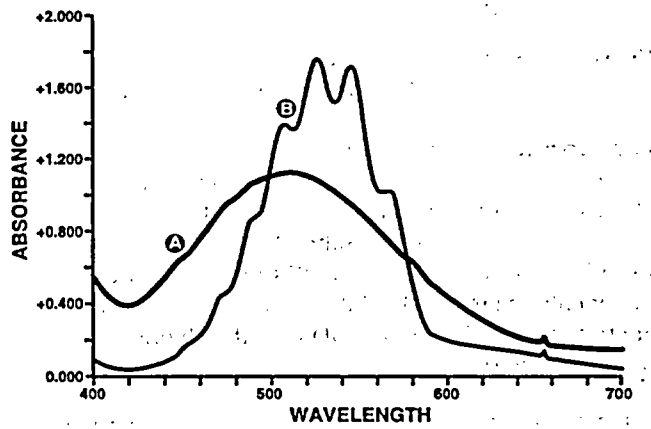


Figure 1.
A: Mn III Reagent blank solution, approximately 0.008 N Mn III
B: Potassium Permanganate solution, approximately 0.001 N, in deionized water.

The Mn III COD Reagent calibration is linear over the range from 0 to 1000 mg/L COD. The working range of the test is 20 to 1000 mg/L COD. The calibration slope is negative. (See the calibration graph in Figure 2.) The reagent has an oxidation efficiency of about 80% for standards prepared from KHP and for typical wastewater samples. When standards and samples have the same oxidation efficiencies, the sample COD recoveries will be 100%. When samples contain components not oxidized to the same extent as KHP, standards can be prepared from reference materials which more closely match the sample. No oxygen demand test will oxidize all organic compounds with 100% efficiency. An alternate approach for difficult-to-oxidize samples is to

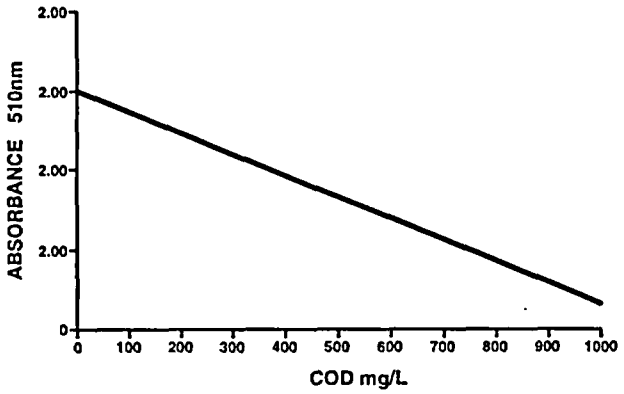


Figure 2.
Maganese III COD Reagent Calibration, Hach DR/3000 at a wavelength of 510 nm and using a Hach Mn III COD Reagent vial as the sample cell (path length = 13.5 mm). The slope is -0.0013 Abs/mg/L; the x-axis intercept is 1185 mg/L; and the correlation coefficient is 0.9997.

increase the digestion time (which can be extended up to 4 hours), so long as a blank is also digested for the same period of time.

The reaction occurring in the Mn III COD reagent vial is best represented by the following equation, where the reagent is reacted with KHP:

$$2\ KC_8H_5O_4 + 30\ Mn_2(SO_4)_3 + 24\ H_2O \longrightarrow 16\ CO_2 + 60\ MnSO_4 + 28\ H_2SO_4 + 2\ KHSO_4$$

Precision and Accuracy

A number of samples have been tested and the precision and accuracy of these results determined. Table 4 contains representative sample results. The 800 mg/L COD standard was tested using the Mn III COD procedure without chloride removal, while the remaining samples were tested using the Mn III COD with the chloride removal procedure.

Table 4: Precision of Mn III COD Test

Sample	Mn III COD mg/L	Standard Deviation mg/L	Relative Standard Deviation %	Number of Tests *n*
800 mg/L COD	797	13	1.6	7
500 mg/L COD + 500 mg/L Chloride	508	3	0.6	4
ASTM Wastewater Influent Reference	1008	7	0.7	4
Wastewater Influent	463	13	2.8	3

Comparative Advantages

- The one-hour digestion period is shorter than other methods.
- Correlates very well with Dichromate COD and BOD test results.
- Is not photosensitive.
- Is stable at room temperature.
- The reagent contains no hazardous metals and generates no hazardous metal waste.

There are three factors that should be noted about the Manganese III COD Procedure. It oxidizes approximately 80% oxidation of most organic compounds. There is interference from some inorganic compounds, mainly chloride ions. And the reaction temperature is limited by thermal decomposition of the oxidant.

IV. THEORETICAL OXYGEN DEMAND AND COD TEST CALIBRATION

Theoretical Oxygen Demand of Potassium Acid Phthalate (KHP) - The Industry Standard

COD testing is based upon the theoretical amount of oxygen required to oxidize organic compounds to CO_2 and H_2O. The most commonly used standard is potassium hydrogen phthalate (KHP). The theoretical oxygen demand of KHP is stated by the following equation:

$$KC_8H_5O_4 + 7.5\ O_2 \longrightarrow 8\ CO_2 + 2\ H_2O + KOH$$

Seven and one-half molecules of oxygen consume one molecule of KHP. On a weight basis, the theoretical oxygen demand for KHP is 1.175 mg O_2 per mg KHP. To prepare a 2000 mg/L stock COD standard solution from KHP, the standard concentration is divided by the theoretical oxygen demand, resulting in the amount of KHP to be dissolved in one liter of deionized water. The equation below demonstrates this for a 2000 mg/L COD standard solution.

$$\frac{2000\ \text{mg/L COD } (O_2)}{1.175\ \text{mg } O_2 / \text{mg KHP}} = 1{,}702\ \text{mg KHP/L}$$

Additional standards can be made by preparing serial dilutions of this stock solution. Test results are expressed as mg/L COD or mg/L O_2. These expressions are equivalent.

Calibrations based upon reference materials other than KHP

Occasionally, samples contain a major sample component which is incompletely oxidized, and results will be lower than expected. It may be beneficial for COD results to closely match the theoretical oxygen demand of the sample. In this situation, calibration standards can be prepared from that sample component. For example: An industrial wastewater sample contains acetone as a major sample component and acetone is incompletely oxidized.

To obtain better results on this sample, a calibration curve can be prepared using acetone as the reference material. To prepare the standard solution, first calculate the theoretical oxygen demand of acetone.

$$C_3H_6O + 4\ O_2 \longrightarrow 3\ CO_2 + 3\ H_2O$$

Four molecules of oxygen consume one molecule of acetone and, on a weight basis, the theoretical oxygen demand for acetone is calculated as follows:

$$\frac{4\ (32\ \text{mg/mM}\ O_2)}{58\ \text{mg / mM acetone}} = \frac{2.21\ \text{mg}\ O_2}{\text{mg acetone}}$$

A 1000 mg/L COD standard can be prepared from acetone as follows:

$$\frac{1000\ \text{mg/L COD}}{2.21\ \text{mg}\ O_2\ /\ \text{mg acetone}} = 452.5\ \text{mg acetone /L}$$

Serial dilutions can be made for additional standards.

Theoretical Oxygen Demand of Nitrogen-Containing Compounds

Most nitrogen-containing compounds yield nitrogen as ammonia after oxidation. This includes heterocyclic nitrogen-containing compounds, and is demonstrated using pyrrole in the example below:

$$C_4H_5N + 4\text{-}1/2\ O_2 \longrightarrow 4\ CO_2 + H_2O + NH_3$$

Four and one half molecules of oxygen consume one molecule of pyrrole. On a weight basis, the theoretical oxygen demand for pyrrole is 2.149 mg O_2 per mg pyrrole.

Heterocyclic compounds containing two or more atoms of nitrogen in a molecule are also easily oxidized. Generally, part of the nitrogen is split off as ammonia and part is split off as diatomic nitrogen. This is demonstrated using Imidazole in the following example:

$$C_3H_4N_2 + 3\ 1/4\ O_2 \longrightarrow 3\ CO_2 + 1/2\ H_2O + NH_3 + N_2$$

Three and one quarter molecules of oxygen consume one molecule of imidazole. On a weight basis, the theoretical oxygen demand for imidazole is 1.507 mg O_2 per mg imidazole.

Oxidation Efficiency of Organic Compounds

The oxidation efficiency for a given organic compound can be easily determined. A COD standard is prepared from the compound of interest and is tested. The result of the test is then divided by the standard value and multiplied by 100 to determine the percent recovery or oxidation efficiency.

The dichromate COD procedure will oxidize most organic compounds with 90 - 100% efficiency. However, some compounds are not oxidized and others are only partially oxidized, such as benzene, toluene, and ethylamines. Examples of compounds that resist oxidation are pyridine, pyridine derivatives and methylamines.

V. CATALYSTS

Straight-chain aliphatic compounds are not effectively oxidized without a catalyst. Several metals that have multiple valence states are generally effective as a catalyst with dichromate. Silver, manganese, mercury, nickel, iron, cobalt and copper have all demonstrated catalytic activity. Silver is the most effective catalyst for the greatest variety of organic compounds, and manganese is reported to have a catalytic activity comparable to silver on some compounds.

The catalytic activity of silver is diminished through the formation of insoluble silver halides when halides are present. These precipitates are partially oxidized, but there is a significant loss of free silver ion which must be available for catalytic activity. When sample chloride is complexed with mercury or removed through other techniques, silver will be an effective catalyst.

Catalysts have not produced significant improvement in recoveries of Manganese III COD and also increase reagent cost. High silver concentrations increase recoveries partially, but not significantly, and disposal problems increase.

VI. INTERFERENCES

Reduced inorganic materials may be oxidized by the COD reagent and constitute a positive interference when present in significant amounts.

Chloride is the most common interference and has the greatest effect on test results. The theoretical oxygen demand of chloride is expressed by the following equation:

$$4\ Cl^- + O_2 + 4\ H^+ \longrightarrow 2\ H_2O + 2\ Cl_2$$

One molecule of oxygen consumes 4 molecules of chloride ions. On a weight basis, the theoretical oxygen demand for chloride is 0.226 mg O_2 per mg Cl^-. A sample containing 1000 mg/L chloride will have a theoretical oxygen demand of 226 mg/L COD. Pure chloride solutions are oxidized quantitatively by COD reagents which do not contain a silver catalyst or a chloride masking agent. Silver ions partially mask chloride ions through the formation of insoluble silver chloride. This results in erratic oxidation of chloride and diminishes the ability of silver to function as a catalyst. When organic matter and chloride are both present in a sample, the oxidation of chloride may also be erratic. This is why the technique of determining the chloride concentration by a separate technique and adjusting the COD result does not always provide accurate results.

When chloride is present with high concentrations of ammonia, organic amines, or nitrogenous matter, the interference is severe. This is due to a series of cyclic changes from chlorine to chloride through the formation of chloramine intermediates. Ammonia, organic amines,

or nitrogenous matter do not interfere when chloride is absent. Organic amines and nitrogenous matter are a source of ammonia nitrogen after oxidation by the COD reagent. The easiest remedy to this problem is to remove sample chloride.

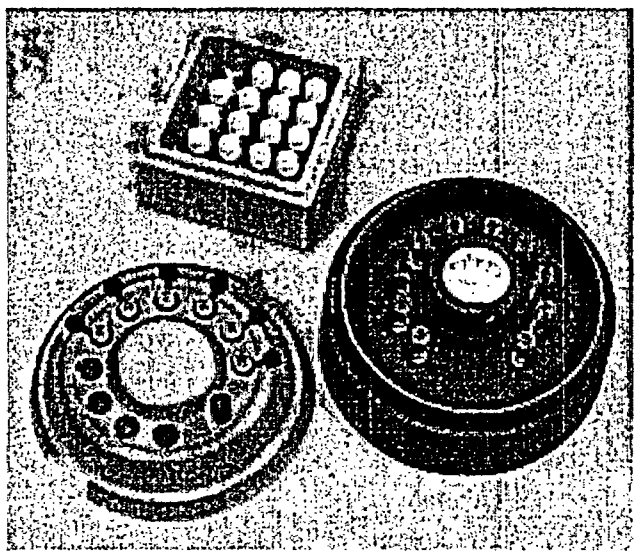
Mercuric sulfate is the most widely used reagent for masking chloride interference and is most effective when the ratio of mercuric sulfate to chloride is 10:1. For example, a 2 mL sample containing 2000 mg/L chloride (4 mg Cl^-) will require 40 mg mercuric sulfate to effectively mask the chloride interference. In some instances, mercuric sulfate may not mask chloride well enough to prevent the combined interference of chloride and high concentrations of ammonia or other nitrogenous compounds. This occurs more often in strong dichromate solutions (high range reagents). One solution to this problem is to dilute the sample to a level where it can be tested using a weaker dichromate solution (low range reagent). The combined interference will usually not be observed with the lower-strength reagent.

Hach Dichromate COD Reagents contain enough mercuric sulfate to eliminate the interference up to 2000 mg/L chloride. The Ultra High Range COD Procedure will eliminate up to 20,000 mg/L chloride, because the sample size used is 0.20 mL rather than the standard 2.00 mL.

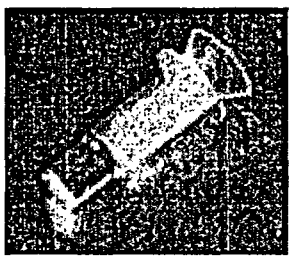
When samples do not contain a significant amount of chloride, it is not necessary for the COD reagent to contain mercuric sulfate. Hach's Dichromate COD2 Reagent vials do not contain mercuric sulfate and can be used for this sample type.

Mercury is very toxic and disposal usually is not a legal option. The only legal method for waste mercury handling is recycling, which can be expensive.

A recent technique for chloride removal was developed in conjunction with the Manganese III COD reagent. The sample is pretreated to remove chloride using a Chloride Removal Cartridge. A Vacuum Pretreatment Device (VPD) controls sample flow rate (see photo). An acidified sample is transferred to the Chloride Removal Cartridge, where a vacuum draws the sample through a glass fiber filter, then through a chloride removal reagent bed, and into a Manganese III COD vial. The filter captures any suspended solids that may be present in the sample. These solids often contain oxidizable organic material and must be returned to the COD vial. Also, if suspended solids are allowed into the reagent reservoir, they will interfere with chloride removal. The reagent bed contains the solid, non-water soluble oxidant, sodium bismuthate. Chloride removal is optimized through the Chloride Removal Cartridge system, while minimizing any effect the oxidant may have on other sample components. The Chloride Removal Cartridge system will remove up to 1000 mg/L chloride.



Vacuum Pretreatment Device



Chloride Removal Cartridge

An historical method for chloride removal is the addition of a reagent to precipitate chloride. This precipitate is separated from the solution by settling, centrifuging or filtration, and a sample aliquot is taken for testing. While chloride is effectively removed from the sample, suspended solids are also removed. These solids often contain oxidizable organic material. The resulting COD is some fraction of the total and is referred to as soluble COD. The most common reagent used for precipitation of chloride is a silver salt.

Nitrite nitrogen interferes with the test and has a theoretical oxygen demand of 1.1 mg O_2 per mg NO_2 - N. Concentrations rarely exceed 1 to 2 mg/L and the interference is considered insignificant. When NO_2 - N concentrations are present at higher levels, the interference can be eliminated by the addition of 10 mg sulfamic acid per mg NO_2 - N. A separate blank must also be prepared containing the same concentration of sulfamic acid.

Other reduced species such as sulfide, or ferrous iron, are usually not present in significant amounts. If necessary, a correction can be made for these interferences. After determining the species concentration using a separate method, there are several ways to make corrections: 1) Determine the theoretical oxygen demand of the species and apply a mathematical correction to the COD result; 2) Prepare a standard from the species of interest, perform a COD test on the standard, and apply a mathematical correction to the result; 3) Spike the sample with the interfering species, perform a COD test on this sample, and apply a mathematical correction to the COD result.

VII. COMPARATIVE STUDIES OF COD TEST RESULTS

Comparison of Mn III COD and Dichromate COD Tests

Wastewater samples were tested using both the dichromate and Mn III COD procedures. Sample data is presented in Table 5.

Table 5: Comparison of Manganese III COD to Dichromate COD

Sample	Sample	Manganese III COD mg/L	Dichromate COD mg/L	Ratio Mn III COD/ Cr COD
WWTP Influent #1	1	428	488	0.88
WWTP Influent #2	1	463	510	0.91
Industrial Influent #1	1	153	169	0.90
Industrial Influent #2	1	234	248	0.94
Industrial Influent #3	1	220	250	0.88
WWTP Influent #3	Day 1	345	523	0.66
	Day 2	316	496	0.64
	Day 3	312	512	0.61
	Day 4	334	443	0.75
	Day 5	344	501	0.69
	Day 6	349	468	0.75
WWTP Effluent #3	Day 1	56	62	0.90
	Day 2	64	63	1.02
	Day 3	62	51	1.22
	Day 4	55	57	0.96
	Day 5	58	63	0.92
	Day 6	59	62	0.95
WWTP Influent #4	Day 1	365	452	0.81
	Day 2	411	553	0.74
	Day 3	406	515	0.79
	Day 4	280	400	0.70
	Day 5	346	478	0.72
	Day 6	348	457	0.76
	Day 7	374	482	0.78
WWTP Effluent #4	Day 1	11*	41	N/A
	Day 2	13*	43	N/A
	Day 3	6*	10	N/A
	Day 4	5*	29	N/A
	Day 5	6*	31	N/A
	Day 6	27	38	0.71
	Day 7	31	35	0.88
Paper Mill Effluent	Day 1	437	465	0.94
	Day 2	421	450	0.94
	Day 3	444	457	0.97
	Day 4	430	444	0.97
	Day 5	429	412	1.04
	Day 6	414	438	0.95
Paper Mill Clarifier Samples	Day 1	881	913	0.96
	Day 2	931	1110	0.84
	Day 3	1174	1268	0.93
	Day 4	775	856	0.91
	Day 5	900	906	0.99
	Day 6	996	1052	0.95

*This data is below the valid test range of the Mn III COD. It is reported here for consistency.

Correlation of the Mn III COD and BOD Tests

An empirical relationship exists between COD and BOD, but the correlation must be established for a specific sample. Once this correlation has been done, COD test results can be used to estimate BOD test results, BOD test dilutions, and BOD performance in the plant. In Table 6 below, Mn III COD (with chloride removal) results are used to estimate BOD test results. The estimated BOD test results are compared to actual BOD test data.

Table 6: Comparison Between Estimated BOD (from COD results) and Actual BOD Test Data

Sample	Mn III COD Result mg/L	Estimated BOD Result mg/L	Actual BOD Result mg/L
Influent #1 - Day 1	365	199	207
Influent #1 - Day 2	411	209	206
Influent #1 - Day 3	406	208	236
Influent #1 - Day 4	280	181	203
Influent #1 - Day 5	346	195	192
Influent #1 - Day 6	348	196	149
Influent #1 - Day 7	374	201	198
Effluent #1 - Day 1	11*	10	11
Effluent #1 - Day 2	11*	13	10
Effluent #1 - Day 3	6*	10	9
Effluent #1 - Day 4	5*	10	10
Effluent #1 - Day 5	6*	10	11
Effluent #1 - Day 6	27	9	8
Effluent #1 - Day 7	31	8	9
Influent #2 - Day 1	345	210	174
Influent #2 - Day 2	316	193	200
Influent #2 - Day 3	312	190	214
Influent #2 - Day 4	334	204	189
Influent #2 - Day 5	344	210	272
Influent #2 - Day 6	349	213	171
Effluent #2 - Day 1	56	15	13
Effluent #2 - Day 2	64	17	14
Effluent #2 - Day 3	62	16	16
Effluent #2 - Day 4	55	14	13
Effluent #2 - Day 5	58	15	18
Effluent #2 - Day 6	59	15	17

*This data is below the valid Mn III COD test range; however, a reasonable BOD test estimate was obtained.

COD Results on Selected Synthetic Organic Compounds

Synthetic compounds were used to prepare standard solutions of known theoretical oxygen demand. The solutions were tested using the dichromate COD and Mn III COD (without chloride removal) test procedures . Five replicates were tested on each compound using each COD procedure. Results are presented in Table 7 below.

Table 7: COD Results on Synthetic Compounds

Sample	Theoretical COD mg/L	Manganese III COD Result mg/L	Manganese III COD Std. Deviation	Dichromate COD Result mg/L	Dichromate COD Std. Deviation
Glycine	500	458	15	512	2
Glucose	500	517	10	495	3
Glutamic Acid	500	418	7	475	2
Dextrin	500	483	6	477	2
Nicotinic Acid	500	10	3	60	3
Tannic Acid	500	422	9	442	1
Acetic Acid	500	122	9	491	2
Lauryl Sulfate Sodium Salt	500	495	6	488	2
Benzoquinone	500	445	3	485	2
Humic Acids Sodium Salt*	100	97	9	104	2

*Estimated theoretical oxygen demand of 1 mg O_2 per mg Humic Acids

VIII. CHEMICAL OXYGEN DEMAND PROCEDURES

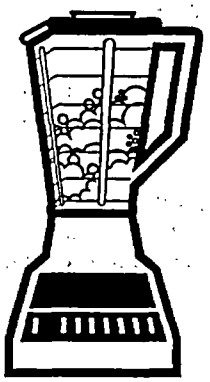
Sample Handling and Preservation

Samples must be representative of the environment or treatment process of interest. Collect samples in clean glass bottles or plastic bottles known to be free of contamination. Biologically active samples should be tested as soon as possible. When settleable or suspended solids are present, the sample should be homogenized prior to testing. Homogenization reduces the size of solids and creates a more uniform sample solution. It may also be helpful to stir the sample, using a magnetic stir plate and stir bar, while taking sample aliquots for analysis. Some loss of volatile sample components may occur during homogenization, but in most samples this is insignificant. The benefits of testing a homogenous sample are significant. Homogenization should be done prior to acid preservation. If this is not possible, necessary safety precautions should be taken. Samples not immediately tested should be preserved with concentrated sulfuric acid to a pH of 2 or less. This will require about 2 mL of concentrated sulfuric acid per liter of sample. Acid-preserved samples are stable for up to 28 days when refrigerated at 4 °C. When the sample COD exceeds the range of the COD procedure used, run the test with COD vials of the appropriate range or dilute the sample into the range of the test. Dilution water should be high quality deionized water free of organic compounds. Dilution water quality becomes increasingly important at lower COD concentrations.

DIGESTION PROCEDURES

There are two COD digestion procedures: the micro digestion method and the macro digestion method. The macro digestion procedure requires large volumes of reagent, bulky glassware, and considerably more space for sample digestion. Because the classic technique is described in other sources, it will not be discussed further here.

COD reagents contain strong oxidants (hexavalent chromium, manganese III sulfate) in strong sulfuric acid solution. During the course of digestion, these reagents oxidize organic carbon compounds to CO_2 and H_2O.



The Micro COD Digestion

Apparatus used in the micro digestion method consists of a COD Reactor with a 25-vial capacity. A typical COD reactor is shown in Figure 3. Using this digestion technique, it is possible to test 25 samples while using a minimum of laboratory bench space. The Hach COD Reactor will maintain a temperature of 150 ± 2 °C, which is more accurate than most laboratory ovens. Hach Company strongly recommends that digestions be performed only in the COD reactor. Please note that, "Severe damage of most culture tube closures from oven digestion introduces a potential source of contamination and increases the probability of leakage. Use an oven for culture-tube digestion only when it has been determined that 2-hour exposure at 150 °C will not damage caps."* Caps on Hach COD Reagent vials are specially designed to provide a positive seal when used in the COD Reactor. They will not withstand temperatures above 120 °C, which will be present if an oven is used for digestion. The caps reach a temperature of about 85 °C when used with the COD Reactor, even though the digestion mixture maintains 150 °C. This temperature difference provides the refluxing action necessary for the recovery of volatile organics.

Micro digestion has the following advantages:

- Small reagent volumes mean lower cost for reagent disposal.
- Recovery of volatile compounds is uniform and higher because of the closed container.
- Prepared vials are easy to handle and take a minimum of time to use.
- Digestion requires minimum space and equipment.
- Requires less analyst attention.

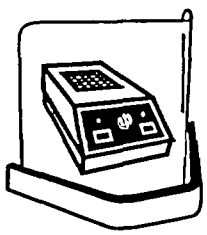


FIGURE 3.
Hach COD Reactor

Micro Digestion Method

1. Turn on the COD Reactor and preheat to 150 °C.

2. Homogenize 100 ml of sample for 30 seconds in a blender.

3. Remove the cap of a COD Reagent vial and transfer the appropriate amount of sample into the vial.

The Dichromate Ultra Low Range, Low Range, and High Range COD products require 2.00 mL of sample. The Dichromate High Range Plus COD requires 0.20 mL and the Manganese III COD reagent uses 0.50 mL of sample (0.60 mL with the Chloride Removal Cartridge).

4. Replace the vial cap tightly. Hold the vial by the cap and invert several times over a sink to mix. (CAUTION! Dichromate COD vials will become very hot during mixing.)

5. Place the vials into the pre-heated COD Reactor. Heat the vials for 1 hour (Mn III COD Reagent) or 2 hours (Dichromate COD Reagents).

6. Remove the vials from the reactor and cool to room temperature.

7. Determine COD results either colorimetrically or by titration.

Note: See the Dichromate COD or Manganese III COD Procedures for specific details pertaining to the digestion procedure.

Safety Notes for the Micro Digestion Method

The micro digestion method is relatively safe for the following reasons:

- Small quantities of reagent are used.
- The apparatus is compact and durable.
- Pipetting and measurement of hazardous reagents has been eliminated.
- The Hach COD Reactor is safety-fused to shut down at 180 °C. This will ensure that sample and reagent will not overheat.
- The reacted sample is measured directly in the COD vial, eliminating the need for sample/reagent transfer.

As with any procedure involving chemical analysis, the analyst should observe certain precautions when using the micro digestion method:

- Use the exact volume of sample called for in the procedure. A larger sample will dilute the acid concentration and lower the boiling point in the mixture. This will increase the pressure in the vial and may cause it to burst or leak. The vials have been tested using pure water at 185 °C (about 20 to 30 times greater pressure than the normal reaction mixture) for seven hours without damage, but they cannot be guaranteed as pressure vessels.
- Place a safety shield in front of the reactor while heating the vials. In the unlikely event of vial breakage, this precaution will minimize any resulting hazard.
- WEAR SAFETY GLASSES OR GOGGLES. When mixing the sample and reagent, hold the vial away from the face and body. A great deal of heat is generated, which can crack even borosilicate glass in some instances.

**Standard Methods for the Examination of Water and Wastewater*, 15th Edition, p5-14

COLORIMETRIC DETERMINATION

Procedures for COD measurement

The measurement of COD test results is done using colorimetric and titrimetric procedures. Colorimetric procedures are easier and quicker to run and are generally more accurate. However, when samples are turbid or colored, or if a spectrophotometer is not available, a titrimetric procedure should be used. Titrimetric procedures require a higher degree of operator skill and take longer to perform.

Colorimetric Procedures

The micro COD test vial used for this digestion also serves as a cuvette for colorimetric measurement. Use with a test tube adapter in a Hach spectrophotometer or other comparable model. Tests have shown that the optical properties of COD vials are very good. The variation in vial absorbance from batch to batch is less than 0.004 units. A Hach DR/4000 and test tube adapter are shown in Figure 4.

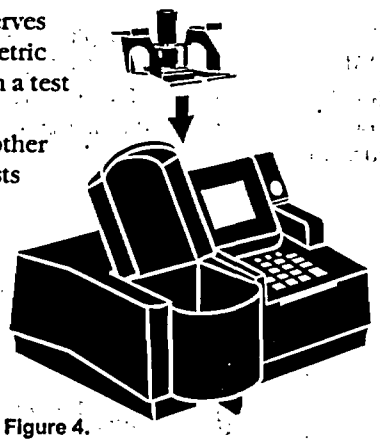


Figure 4.
Hach DR/4000 and Test Tube Adapter

Colorimetric measurements allow the digestion to be monitored periodically for completeness. This means that easy-to-digest samples can be analyzed with confidence in a short period of time. Typical time study curves are shown in Figure 5. They clearly demonstrate that COD determinations made for process control purposes can be conducted in a shorter digestion time than specified in the procedure. For samples which are difficult to oxidize, the digestion time can be extended up to four hours if a blank is also run for the same period of time.

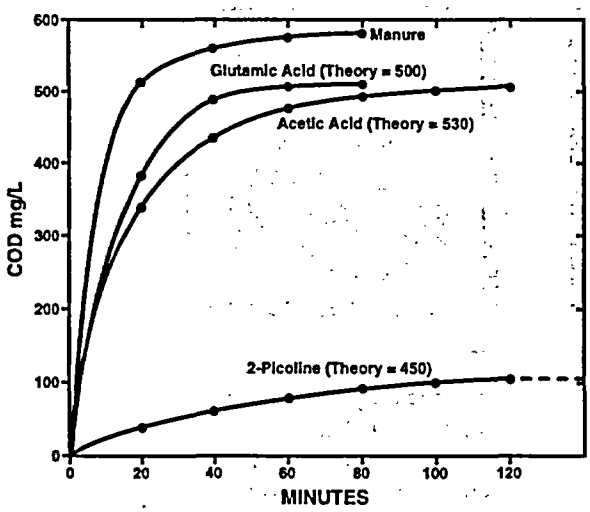


Figure 5. Typical Digestion Curves - COD vs. Time

A reagent blank must be prepared from each new lot of vials. This is done by carrying a sample of high-purity deionized water through the digestion process. The blank is used to zero the spectrophotometer and can be reused until a new lot of reagent is introduced. It must, however, be monitored for degradation. To monitor the blank, fill a clean, empty COD vial with 5 mL of deionized water. Set the instrument to absorbance mode and the appropriate wavelength. Zero the instrument with the deionized water blank and measure the reagent blank absorbance. When the absorbance changes by approximately 0.010 from its initial value, a new blank must be run. Dichromate COD Reagent blanks are photosensitive and must be stored in the dark. Manganese III COD Reagent blanks are not photosensitive.

Hach provides Dichromate COD vials in four ranges, Ultra Low Range (0-40 mg/L), Low Range (0-150 mg/L), High Range (0-1500 mg/L), and High Range Plus (0-15,000 mg/L). The Manganese III COD is available in the 20-1000 mg/L range.

Dichromate COD Tests

Colorimetric Measurement for the Ultra Low Range COD (0-40 mg/L Range)
(Using a Hach DR/4000)

The Hach Ultra Low Range COD test is the lowest range and highest sensitivity COD test available. Results are measured at a wavelength of 350 nm. The maximum sensitivity is at 345 nm, but the test measurement is made at 350 nm for instrumentation considerations. The calibration line for this test has a negative slope. The amount of hexavalent chromium remaining after digestion is measured and it decreases as the COD concentration increases. High quality, organic-free, deionized water is required for blanks and dilution water with this test range. Figure 6 shows several scan overlays of COD standards at various concentrations tested.

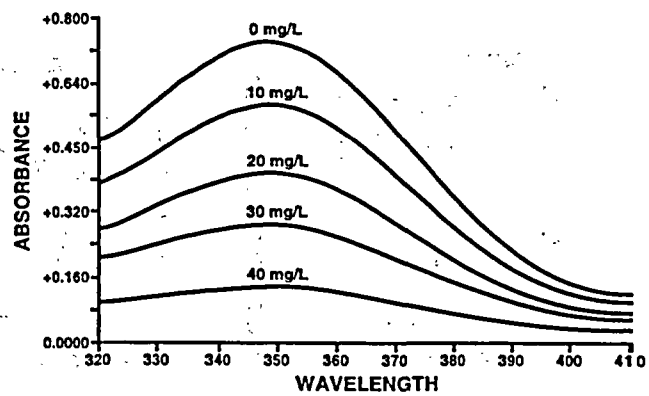
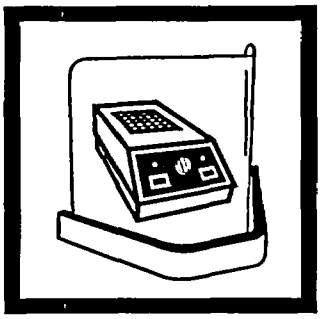
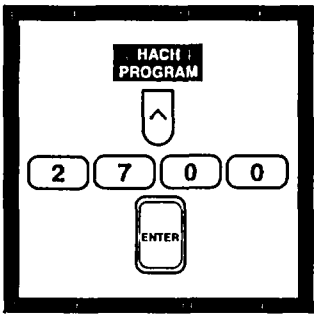


Figure 6. Ultra Low Range COD scan using standards at 0, 10, 20, 30, 40 mg/L COD.

Colorimetric Measurement for the Ultra Low Range COD Test (0-40 mg/L)
An example of a completely illustrated, easy-to-follow procedure from Hach.



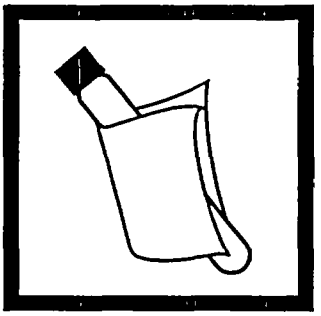
1. Perform the digestion according to given instructions.



2. Press the soft key under HACH PROGRAM. Select the stored program number for ultra low range COD by pressing 2700 with the numeric keys.
Press: ENTER

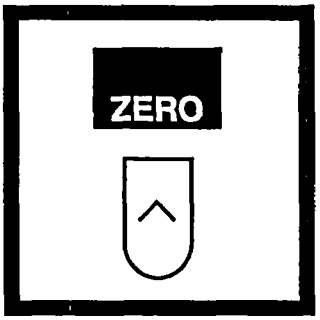
3. The display will show: HACH PROGRAM: 2700 COD, ULR. The wavelength (λ), 350 nm, is automatically selected.

4. Insert the Test Tube Adapter into the sample cell module by sliding it under the thumb screw and into the alignment grooves. Fasten with the thumb screw.

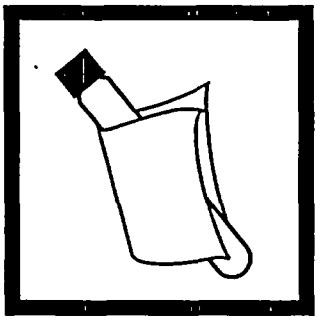


5. Clean the outside of the blank with a towel.

6. Place the blank into the adapter with the Hach logo facing the front of the instrument. Close the light shield.



7. Press the soft key under ZERO. The display will show: 0.0 mg/L COD.



8. Clean the outside of the sample vial with a towel.

9. Place the sample vial into the adapter. Close the light shield. Results in mg/L COD (or chosen units) will be displayed.

Accuracy Check

Standard Solution Method.

Check the accuracy of the 0 to 40 mg/L range with a 30 mg/L standard. Using Class A glassware, prepare a 1000-mg/L solution by diluting 850 mg of dried (120 °C, overnight) potassium acid phthalate (KHP) in 1000 mL of organic-free deionized water. Prepare a 30 mg/L dilution by diluting 3.00 mL of this solution into a 100.0 mL volumetric flask. Dilute to volume with deionized water, stopper, and invert 10 times to mix.

Method Performance Precision

Standard: 30.0 mg/L COD

Program	95% Confidence Limits
2700	29.9 - 30.1 mg/L COD

Estimated Detection Limit

Program	EDL
2700	0.2 mg/L COD

Sensitivity

Program Number: 2700

Portion of Curve	ΔAbs	ΔConcentration
Entire Range	0.010	-0.52 mg/L

COLORIMETRIC MEASUREMENT FOR THE LOW RANGE COD (0-150 mg/L RANGE)

(Using a Hach DR/4000: Please note—procedure is fully illustrated with icons in the instrument manual.)

The Hach Low Range COD is measured at 420 nm. The test range is 0-150 mg/L COD. The COD concentration increases as the concentration of hexavalent chromium decreases. This results in a calibration line with a negative slope. The optimum test range is about 20 to 150 mg/L COD.

Procedure

1. Perform the digestion according to given instructions.

2. Press the soft key under HACH PROGRAM. Select the stored program number for Low Range COD by pressing 2710 with the numeric keys. Press: ENTER

3. The display will show: HACH PROGRAM: 2710 COD, LR. The wavelength (λ), 420 nm, is automatically selected.

4. Insert the Test Tube Adapter into the sample cell module by sliding it under the thumb screw and into the alignment grooves. Fasten with the thumb screw.

5. Clean the outside of the blank with a towel.

6. Place the blank into the adapter with the Hach logo facing the front of the instrument. Close the light shield.

7. Press the soft key under ZERO. The display will show: 0.0 mg/L COD.

8. Clean the outside of the sample vial with a towel.

9. Place the sample vial into the adapter. Close the light shield. Results in mg/L COD (or chosen units) will be displayed.

Accuracy Check

Standard Solution Method

Check the accuracy of the 0 to 150 mg/L range with a 100 mg/L KHP standard. Prepare by dissolving 85 mg of dried (120 °C, overnight) potassium acid phthalate (KHP) in 1 liter of deionized water. Use 2 mL as the sample volume. Or dilute 10 mL of 1000-mg/L COD Standard Solution to 100 mL to produce a 100-mg/L standard.

To adjust the calibration curve using the reading obtained with the 100-mg/L standard solution, press the soft keys under OPTIONS< MORE then STD:OFF. Press ENTER to accept the displayed concentration, the value of which depends on the selected units. If an alternate concentration is used, enter the actual concentration and press ENTER to return to the read screen.

Method Performance Precision

Standard: 100.0 mg/L COD

Program	95% Confidence Limits
2710	99.4 - 100.6 mg/L O_2

Estimated Detection Limit

Program	EDL
2710	1.1 mg/L COD

Sensitivity

Program Number: 2710

Portion of Curve	ΔAbs	ΔConcentration
Entire Range	0.010	3.45 mg/L

COLORIMETRIC MEASUREMENT FOR THE HIGH RANGE COD (0-1500 mg/L RANGE) AND HIGH RANGE PLUS (0-15000 mg/L RANGE)

(Using a Hach DR/4000: Please note—procedure is fully illustrated with icons in the instrument manual.)

Hach's High Range and High Range Plus COD are the highest test ranges available from Hach Company. The chemistry and calibration data are identical for both tests. High Range Plus COD is designed to eliminate the dilution step normally required for COD samples which have concentrations from 1500 mg/L up to 15,000 mg/L. When the High Range Plus vial is manufactured, dilution water is added directly to the High Range COD Reagent to accomplish a 1 to 10 dilution when 0.20 mL of sample is added to the reagent vial. The results are measured at 620 nm, and the calibration line has a positive slope. The amount of trivalent chromium is measured, and its concentration increases as the COD concentration increases.

Procedure

1. Perform the digestion according to given instructions.

2. Press the soft key under HACH PROGRAM. Select the stored program number for High and High Range Plus COD by pressing 2720 with the numeric keys. Press: ENTER

3. The display will show: HACH PROGRAM: 2720 COD, HR, HR Plus. The wavelength (λ), 620 nm, is automatically selected.

4. Insert the Test Tube Adapter into the sample cell module by sliding it under the thumb screw and into the alignment grooves. Fasten with the thumb screw.

5. Clean the outside of the blank with a towel.

6. Place the blank into the adapter with the Hach logo facing the front of the instrument. Close the light shield.

7. Press the soft key under ZERO. The display will show: 0.0 mg/L COD.

8. Clean the outside of the sample vial with a towel.

9. Place the sample vial into the adapter. Close the light shield. Results in mg/L COD (or chosen units) will be displayed. When High Range Plus COD vials are used, multiply the displayed value by ten.

Accuracy Check

Standard Solution Method

0-1500 mg/L range: Check the accuracy of the 0 to 1,500 range by using either a 300 mg/L or 1000 mg/L COD Standard Solution. Use 2 mL of one of these solutions as the sample volume; the expected result will be 300 or 1000 mg/L COD respectively.

Or, prepare a 500-mL standard by dissolving 425 mg of dried (120 °C, overnight) KHP in 1000 mL of deionized water.

To adjust the calibration curve using the reading obtained with the 100-mg/L standard solution, press the soft keys under OPTIONS< MORE then STD:OFF. Press ENTER to accept the displayed concentration, the value of which depends on the selected units. If an alternate concentration is used, enter the actual concentration and press ENTER to return to the read screen.

0-15,000 mg/L range: Check the accuracy of the 0 to 15,000 mg/L range by using a 10,000 mg/L COD Standard Solution. Prepare the 10,000 mg/L solution by dissolving 8.500 g of dried (120 °C, overnight) KHP in 1 liter of deionized water. Use 0.2 mL of this solution as the sample volume; the expected result will be 10,000 mg/L COD (display x 10).

To adjust the calibration curve using the reading obtained with 1000 mg/L COD Standard Solution, press the soft keys under OPTIONS< MORE then STD:OFF. Press ENTER to accept the value and return to the screen. The instrument will only allow adjustment if the entered concentration is within 10% of the measured concentration.

Method Performance Precision

0-1500 mg/L range

Standard: 1000 mg/L COD

Program	95% Confidence Limits
2720	998 - 1002 mg/L COD

0-15,000 mg/L range

Standard: 10,000 mg/L COD

Program	95% Confidence Limits
2720	9980 - 10,020 mg/L COD

Estimated Detection Limit

Program	EDL
2720 (0 - 1500 mg/L)	3 mg/L COD
2720 (0 - 15,000 mg/L)	30 mg/L COD

Sensitivity

Program Number: 2720

Portion of Curve	ΔAbs	ΔConcentration
Entire Range	0.010	-23.5 mg/L

MANGANESE III COD TEST

Colorimetric Measurement for the Manganese III COD (20 to 1000 mg/L COD)

(Using a Hach DR/4000: Please note—procedure is fully illustrated with icons in the instrument manual.)

The Hach Manganese III COD Procedure can be run with or without the chloride removal pretreatment. If chloride is absent or does not present a significant interference, the pretreatment steps can be omitted. The working range of the test is 20 to 1000 mg/L COD. The test is measured at 510 nm, and the calibration line has a negative slope. When manganese III is measured spectrophotometrically, its concentration decreases as the COD concentration increases. High quality, organic-free deionized water is required for blanks and dilution water. Figure 7 shows scans of COD standards tested using the Mn III COD Reagent.

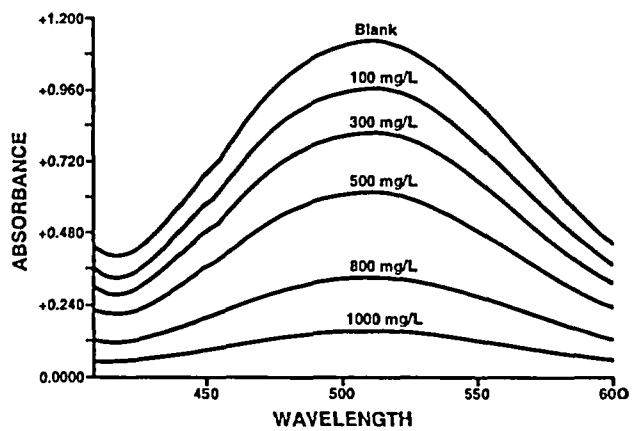


Figure 7. Overlay scans of standards with concentrations of (blank) 0, 100, 300, 500, 800, and 1000 mg/L COD, which were tested using the Mn III COD Reagent.

Manganese III COD Procedure without Chloride Removal Pretreatment

(Using a Hach DR/4000: Please note—procedure is fully illustrated with icons in the instrument manual.)

Procedure

1. Press the soft key under HACH PROGRAM. Select the stored program number for Manganese III COD by pressing 2730 with the numeric keys.

2. The display will show: HACH PROGRAM: 2730 COD, Mn III. The wavelength (λ), 510 nm, is automatically selected.

3. Homogenize 100 mL of sample for 30 seconds in a blender.

4. Pipet 0.50 mL of sample into a Mn III COD vial. Cap and invert several times to mix.

5. Prepare a blank by substituting 0.50 mL of deionized water for the sample. Cap and invert several times to mix.

6. Place the vials in the COD reactor which has been preheated to 150 °C. Digest for 1 hour.

7. Remove the vials and place them in a cooling rack for two minutes to air cool. Then cool the vials to room temperature in a cool water bath or running tap water. This usually takes about 3 minutes.

8. Remove the vials from the water and wipe with a clean, dry paper towel.

9. Insert the COD Vial Adapter into the sample cell module of the DR/4000 by sliding it under the thumb screw and into the alignment grooves. Fasten with the thumb screw.

10. Place the blank into the sample cell compartment. Close the light shield.

11. Press the soft key under ZERO. The display will show: 0 mg/L COD

12. Place the sample vial in the adapter. Close the light shield. Results in mg/L COD will be displayed.

MANGANESE III COD WITH CHLORIDE REMOVAL PRETREATMENT

(Using a Hach DR/4000 Instrument: Please note—procedure is fully illustrated with icons in the instrument manual.)

The Manganese III COD procedure with chloride removal is nearly identical to the procedure without chloride removal. However, there are some differences. To remove chloride from samples using the Chloride Removal Cartridge and Vacuum Pretreatment Device, it is necessary to make the sample solution acidic prior to filtering through the Chloride Removal Cartridge. This process results in a small but consistent volume change. The change does not alter the calibration line slope, but does cause a slight offset. This makes it necessary to prepare a separate blank to zero the instrument for all tests where the chloride removal pretreatment is used.

Procedure

1. Press the soft key under HACH PROGRAM. Select the stored program number for Manganese III COD by pressing 2730 with the numeric keys.

2. The display will show: HACH PROGRAM: 2730 COD, Mn III. The wavelength (λ), 510 nm, is automatically selected.

3. Homogenize 100 mL of sample for 30 seconds in a blender.

4. Using a TenSette® Pipet or a pipet and safety bulb, pipet 9.0 mL of homogenized sample into an empty glass mixing cell.

5. Using an automatic dispenser or TenSette Pipet, add 1.0 mL of concentrated sulfuric acid to the mixing cell.

6. Cap the cell tightly and invert it several times. The solution will become hot. Cool to room temperature before proceeding.

7. Prepare a blank by repeating steps 4 - 6 above, using deionized water for the sample.

8. If not already on, turn on the COD Reactor and heat to 150 °C.

9. Label each Mn III COD vial and remove the cap. Place the vials in one of the numbered holes in the Vacuum Pretreatment Device base.

10. Place the VPD top on the base. Insert a fresh Chloride Removal Cartridge directly above each Mn III COD vial. Plug any open holes in the Vacuum Pretreatment Device top using the stoppers provided.

11. Turn the vacuum pump on and adjust the vacuum regulator valve on top of the Vacuum Pretreatment Device top until the internal gauge reads 20 inches of water column (WC).

12. Pipet 0.60 mL of each acidified sample into a Chloride Removal Cartridge. Pipet 0.60 mL of acidified blank into another Chloride Removal Cartridge. It should take 30 to 45 seconds to draw liquid through the Chloride Removal Cartridge into each vial.

13. Close the vacuum regulator valve completely to achieve full vacuum. (Full vacuum is 20 to 25 inches of mercury and must be read on a separate gauge, usually one attached directly to the vacuum pump.) After one minute of full vacuum, open the regulator valve to release the vacuum.

14. Turn the pump off. Remove the Vacuum Pretreatment Device top and set it beside the base.

15. Use forceps to remove the filter from the top of each Chloride Removal Cartridge. Place the filter in the corresponding Mn III COD vial.

16. Remove the Mn III COD vial from the vacuum chamber and replace the original cap tightly. Invert several times to mix.

17. Place the vials in the COD reactor, which has been preheated to 150 °C. Digest for 1 hour.

18. Remove the vials and place them in a cooling rack for two minutes to air cool. Then cool the vials to room temperature in a cool water bath or running tap water. This usually takes about 3 minutes.

19. Remove the vials from the water and wipe with a clean, dry paper towel.

20. Insert the COD Vial Adapter into the sample cell module of the DR/4000 by sliding it under the thumb screw and into the alignment grooves. Fasten with the thumb screw.

21. Place the blank into the sample cell compartment. Close the light shield.

22. Press the soft key under ZERO. The display will show: 0 mg/L COD

23. Place the sample vial in the adapter. Close the light shield. Results in mg/L COD will be displayed.

Accuracy Check

Standard Solution Method

Prepare an 800 mg/L COD Standard Solution by adding 0.6808 g of dried (120 °C, overnight) potassium acid phthalate (KHP) to one liter of deionized water. Use 0.50 mL of this solution (0.60 mL for the chloride removal procedure) as the sample volume. The result should be 800 ± 24 mg/L COD. An 800 mg/L COD Standard Solution can also be purchased directly from Hach.

To adjust the calibration curve using the reading obtained with the 800 mg/L COD Standard Solution, press the soft keys under OPTIONS MORE then STD:OFF. Press ENTER to accept the value and return to the read screen. The instrument will only allow adjustment if the entered concentration is within 10% of the measured concentration.

Method Performance Precision

(data is for Manganese III COD without the chloride removal procedure)

Standard: 500 mg/L COD

Program	95% Confidence Limits
2730	497 - 503 mg/L COD

Estimated Detection Limit

Program	EDL
2730	4 mg/L COD

Sensitivity

Program Number: 2730

Portion of Curve	Abs	Concentration
Entire range	0.010	8 mg/L

Titration Methods

Two titrimetric techniques are widely used in COD testing: the macro and micro techniques. Because macro techniques have limitations similar to those of the macro digestion procedures, they will not be considered further.

The titration procedure is well established for use with the Dichromate COD Reagent. Hach has adapted this procedure for use with the Low Range (0 to 150 mg/L), High Range (0 to 1500 mg/L), and the High Range Plus (0 to 15,000 mg/L) COD Reagents.

When titration is used for measurement, the amount of hexavalent chromium remaining after digestion is determined. There are two ways of doing this. In both cases, the initial amount of hexavalent chromium must be known. The final hexavalent chromium level is then subtracted from the initial level to determine the amount of hexavalent chromium reduced during the digestion. This difference is used to calculate the COD. The initial amount is known either through calculation (because primary grade potassium dichromate is readily available) or by standardizing the bulk solution before running the individual tests.

The amount of dichromate is usually determined by direct titration using ferrous ammonium sulfate (FAS) as the titrant and ferroin (1,10 phenanthroline ferrous sulfate) as the indicator. The apparatus used with the macro procedure is shown in Figure 8.

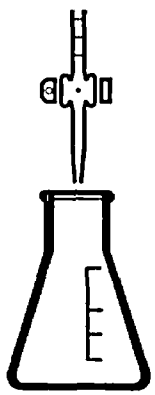


Figure 8. Apparatus Used with Macro Procedure

During the course of the titration, the titrant (Fe^{2+}) reacts instantly with hexavalent chromium (Cr^{6+}) to form trivalent chromium (Cr^{3+}) and ferric ion (Fe^{3+}), as shown below:

$$3\ Fe^{2+} + Cr^{6+} \longrightarrow 3\ Fe^{3+} + Cr^{3+}$$

At the end of the titration, there is no hexavalent chromium present for this reaction to occur and the titrant reacts with the indicator to form an orange-brown color. The indicator, 1,10 phenanthroline, forms an intense color with Fe^{2+} (ferrous ion), but does not react with Fe^{3+} (ferric ion). This end point could also be detected using a potentiometric system.

Other titrants and indicators have been used. One of these titrants is hydroquinone with diphenylamine indicator.

Back titration techniques are also used to determine the amount of hexavalent chromium consumed in the COD digestion. With this technique, a measured amount of reducing agent ions, such as Fe^{2+} or I^-, are added to the digested mixture. The reducing agent consumes the remaining hexavalent chromium after digestion, and excess or unreacted reducing agent titrated. This technique indirectly determines the amount of hexavalent chromium left in the digested solution. Several combinations of reducing agent and titrant have been used with this technique, including ferrous ion with potassium permanganate, iodide with thiosulfate, and oxalate or formate with permanganate.

Micro Titration Procedure

Micro titration procedures use small reagent volumes, require a minimum of space, and are easy to perform. They offer an alternative to colorimetric measurement procedures when samples are highly colored or turbid, or when a spectrophotometer is not available. The test requires more operator skill and a greater amount of time to perform than colorimetric procedures.

Micro Buret Titration

1. After digestion, cool the vial to room temperature. Carefully remove the cap of a vial. Rinse the inside wall with less than 1 mL of deionized water.

2. Add a small Teflon stirring bar and one drop of the appropriate Ferroin Indicator Solution. When using the Low Range COD Digestion Reagent Vials, use Low Range Ferroin Indicator Solution. When using High Range or High Range Plus COD Digestion Reagent Vials, use High Range Ferroin Indicator Solution.

3. Place the vial on the titration stand. Turn on the magnetic stirrer.

4. Titrate with the appropriate Ferrous Ammonium Sulfate Solution (FAS) until the sample color changes sharply from greenish-blue to orange-brown. When using the Low Range COD Digestion Reagent Vials, use 0.0125 N FAS. When using High Range or High Range Plus COD Digestion Reagent Vials, use 0.125 N FAS. Record the mL of titrant required. The mL required for the prepared sample is value B. The mL required for the blank is value A.

5. Pipet 2.00 mL of Potassium Dichromate Standard Solution into an empty vial. When using the Low Range COD Digestion Reagent Vials, use a 0.025 N solution. When using High Range or High Range Plus COD Digestion Reagent Vials, use a 0.25 N solution. Add 3 mL of concentrated sulfuric acid to the vial. Swirl to mix. Wait for the solution to cool until the vial is comfortable to touch.

6. Add one drop of Ferroin Indicator Solution selected in step 2.

7. Add a stir bar and titrate with Ferrous Ammonium Sulfate Standard Solution selected in step 4 until the color changes from greenish-blue to orange-brown. Record the number of mLs required. This is value C.

8. Determine the mg/L COD according to the following equation:

$$\text{COD mg/L} = \frac{(A - B) \times 2000 \times M}{C}$$

Where:

A= mL used in titration of reagent blank

B= mL used in titration of prepared sample

C= mL used in titration of standard solution in step 7

M= 0.1 when using Low Range COD Digestion Reagent Vials

M= 1 when using High Range COD Digestion Reagent Vials

M= 10 when using High Range Plus COD Digestion Reagent Vials

For example, when using Low Range COD Reagent vials:

A=3.95 mL

B=2.00 mL

C=4.00 mL

M=0.1

$$\text{COD mg/L} = \frac{(3.95\text{-}2.00) \times 2000 \times 0.1}{4.00} = 97.5$$

Bibliography

Axen, E.; Morrison, G. M. Intern. *A Mercury-Free Microwave Method for the Chemical Oxygen Demand Analysis of Sewage;* J. Anal. Chem. 1995, 59, 69-78.

Ballinger, D.; Lloyd, A.; Morrish, A. *Determination of Chemical Oxygen Demand of Wastewater without the Use of Mercury Salts*; Analyst 1982, 107, 1047-1053.

Barek, J.; Berka, A. CRC Critical Reviews in Anal. Chem. *The Use of Trivalent Manganese Compounds in Titrimetry*; 1980, 55-95.

Belkin, S.; Brenner, A.; Abeliovich A. *Effect of Inorganic Constituents on Chemical Oxygen Demand-I. Bromides are Unneutralizable by Mercuric Sulfate Complexation*; Wat. Res. 1992, 26 (12), 1577-1581.

Belkin, S.; Brenner, A.; Abeliovich A. *Effect of Inorganic Constituents on Chemical Oxygen Demand-II. Organic Carbon to Halogen Ratios Determine Halogen Interference*; Wat. Res. 1992, 26 (12), 1577-1581

Burns, E. R.; Marshall, C. *Correction for the Chloride Interference in the Chemical Oxygen Demand Test*; Journal WPCF 1965, 37 (12), 1716-1721.

Byerly, John J.; Fouda, Safaa A.; Rempel, Garry L. J. Chem. Soc., Dalton Trans. 1975, 1, 1329-1338.

Canelli, E.; Mitchell D. G.; Pause R. W. *an Improved determination of Chemical Oxygen Demand in Water and Waste by a Simplified Acid Dichromate Digestion*; Wat. Res. 1976, 10, 351-355.

Chudoba, J.; Dalesicky J. *Chemical Oxygen Demand of Some Nitrogenous Heterocyclic Compounds*; Wat. Res. 1973, 7, 663-668.

de Casseres, K. E.; Best, D. G.; May, B. D. *Determination of COD by a Mercury-Free Open-Tube Method*; Wat. Pollut. Control 1984, 416-419.

Dobbs, R. A.; Williams R. T. *Elimination of Chloride Interference in the Chemical Oxygen Demand Test*; Anal. Chem. 1963, 35 (8), 1064-1067.

Favre, T. L. F.; Hage, R.; Van der Helm-Rademaker, K.; Koek, J. H.; Martens, R. J.; Swarthoff, T.; van Vliet, M. R. P. U. S. Patent 5 246 621, 1993.

Germirli, F.; Orhon, D.; Artan, N. *Assesement of the Initial Inert Soluble COD in Industrial Wastewaters*; Wat. Sci. Tech. 1991, 23, 1077-1086.

Gorbachev, S. V.; Shpitalískii Ye. Ye. *Production of Trivalent Manganese*; Zh. Obshch. Khim. 1940, 10 (22), 1961-1967.

Greenberg, A. E.; Connors, J.; Jenkins, D. *Standard Methods for the Examination of Water and Wastewater*; APHA 1981, 489-490.

Hawkins, J.; Lloyd, A. *The Application of Robotics in the Water Industry and the Development of a BOD Robot*; Wat. Sci. Tech. 1989, 21, 937-945.

Hejzlar, Josef; Kopacek, Jiri *Determination of Low Chemical Oxygen Demand Values in Water by the Dichromate semi-micro Method*; Analyst 1990, 115, 1463-1467.

Himebaugh, Ronald R.; Smith, Michael J. *Semi-Micro Tube Method for Chemical Oxygen Demand*; Anal. Chem. 1979, 51 (7), 1085-1087.

Ivanov, N. A.; Dodova, L. I. *Potentiometric Determination of Some Valence Forms of Manganese*; Comptes rendes de liAcademie bulgare des Sciences 1976, 29 (9), 1305-1308.

Jardim, Wilson F.; Rohwedder, Jarbas J. R. *Chemical Oxygen Demand (COD) Using Microwave Digestions*; Wat. Res. 1989, 23, 1069-1071.

Jirka, A. M.; Carter, M. J. *Micro Semi-Automated Analysis if Surface and Wastewaters for Chemical Oxygen Demand*; Anal. Chem. 1975, 47 (8), 1397-1402.

Jones, Bonnie M.; Sakaji, Richard H.; Daughton, Christian G. *Comparison of Macrocolorimetric and Macrotitrimetric Methods for Chemical Oxygen Demand of Oil Shale Wastewaters*; Anal. Chem. 1985, 57, 2334-2337.

Kharabadze, N. I. *Aspects of Producing Sulfates of Tri- and Tetravalent Manganese*; Elektrokhim. Margantsa 1963, 2, 255-265.

Kim, Byung R. *Effect of Ammonia on COD Analysis*; Journal WPCF 1989, 61, 614-617.

Klein, L. *The Strength of Sewage: Some Comparative Results*; Proceedings of Inst. Sewage Purification 1941, 174-191.

Lee, C. M.; Macalady, D. L. *Towards a Standard Method for the Measurement of Organic Carbon in Sediments*; Intern. J. Environ. Anal. Chem. 1989, 35, 219-225.

Lloyd, A. *Simpified Procedure for the Determination of Chemical Oxygen Demand Using Silver Nitrate to Suppress Chloride Interference*; Analyst 1982, 107, 1316-1319.

Lowden, G. F. *Applications of Analytical Techniques to Industrial Effluents*; Proc. Analyt. Div. Chem. Soc. 1976, 44-45.

Mamais, D.; Jenkins, D.; Pitt *P. ,A Rapid Physical-Chemical Method for the Determination of Readily Biodegradable Soluble COD in Municipal Wastewater*; Wat. Res. 1993, 27 (1), 195-197.

Mandal, S.K., Sant B.R. *Manganese (IV) as an Oxidometric Reagent in Sulfuric Acid*; Talanta 1976, 23, 485-487.

Martinez, J. B.; Rios, B. R. *Electolysis with Silent Discharge of Mn II Salts*; An. Real Soc. Espan. Fis. Quim. 1949, B, 519-532.

Martinez, J. Beltran; Rios, B. Rodriguez An. Real Soc. Espan. Fis. Quim. 1949, 519-532.

Matsumoto, H.; Miyazima, S. *Investigations on the Water Pollution Index. IV. Relationship between COD Mn Values and Chemical Structure of Phenolic Compounds*; Eisei Kagaku 1984, 30, 222-228.

McMillan *Higher Oxidation States of Silver*; J. A. Chem. Rev. 1962, 62, 65-80.

Moore, W. A.; Kroner, R. C.; Ruchhoft, C. C., *Dichromate Reflux Method for Determination of Oxygen Consumed*; Anal. Chem. 1949, 21 (8), 953-957.

Moore, W. A.; Ludzack, F. J.; Ruchhoft *Determination of Oxygen Consumed Values of Organic Waste*; C. C. Anal. Chem. 1951, 23 (9), 1297-1300.

Moore, W. A.; Ruchhoft, C. C. *Sewage and Industrial Wastes;* 1951, 23, 705-712.

Moore, W. A.; Walker, W. W. *Determination of Low Chemical Oxygen Demands of Surface Waters by Dichromate Oxidation*; Anal. Chem. 1956, 28 (2), 164-167.

Ruttanagosrigit, W.; Boyd, C. E. J. *Measurement of Chemical Oxygen Demand in Waters of High Chloride Concentration*; World Aquaculture Soc. 1989, 20 (3), 170-172.

Selim, R. G.; Lingane, J.J. *Coulometric Titration with Higher Oxidation States of Manganese. Electrolytic Generation and Stability of +3 Manganese inSulfuric Acid Media*; Coulometry of Mn 1959, 21, 536-544.

Selvapathy, P.; Jogabeth, J. S. *A New Catalyst for the COD Determination*; Indian J. Environ. Hlth. 1991, 33 (1), 96-102.

Sem, M. Z. *Electrooxidation of Manganous Salts and Some Compounds Obtained Thereby*; Zeitschrift für Electrochemie 1915, 21 (17/18), 426-437.

Sherigara, B. S.; Mamatha, M. R.; Pinto, I.; Bhat, K. I. *Potentiometric Studies with Manganese(III) Compounds in Solution: Determination of Thiocyanates in Metal salts and Complexes*; J. Electrochem Soc. India 1994, 43, 7-17.

Soto, M.; Veiga, M. C.; Mendez, R.; Lema, J. M. *Semi-Micro C.O.D. Determination Method for High-Salanity Wastewater*; Environmental Technology Letters 1989, 10, 541-548.

Stone, A. T.; Morgan, J. J. *Reduction and Dissolution of Manganese 9III) and Manganese (IV) Oxides by Organics. 1. Reaction with Hydroquinone*; Environ. Sci. Technol. 1984, 18 (6), 450-456.

Suwyn, M. A.; Hamm, R. E. *The Mechanism of Oxidation of Oxalate with trans-1,2-Diaminocyclohexanetetraacetonemanganate(III) in Aqueous Solution*; Inorg. Chem. 1967, 6 (1), 142-145.

Suwyn, M. A.; Hamm, R. E. A *Kinetic and Equilibrium Study of the Reaction between Ethylenediaminetetraacetomanganate(III) and Azide;* Inorg. Chem. 1967, 6 (12), 2150-2154.

Thompson, K. C.; Mendham, D.; Best D.; de Casseres, K. E. *Simple Method for Minimising the Effect of Chloride on the Chemical Oxygen Demand Test Without the Use of Mercury Salts;* Analyst 1986, 111, 483-485.

Wagenknecht, J. H.; Coleman, J. P.; Hallcher, R. C.; McMackins, D. E.; Rogers, T. E.; Wagner, W. G. J. Applied Electrochem. 1983, 13, 535-540.

Water Analysis Handbook, 2nd ed.; Hach Company, 487-505.

Watts, R. J.; Adams, V. D. *The Elimination of Sulfer Dioxide Interference in the Low Level Chemical Oxygen Demand Analysis;* Wat. Res. 1983, 17 (6), 715-718.

Zink-Nielsen, I. *Intercalibration of Methods for Chemical Analysis of Sediments;* Vatten 1977, 1, 14-20.

About the Author

Wayne Boyles obtained B.S. Degrees in Chemistry and Biology from the University of Colorado at Denver and the University of Northern Colorado. He worked for 25 years as an analytical chemist in the water and wastewater industries, the electronics industry, and as a research chemist at Hach Company, where he developed several chemical oxygen demand procedures and products.

QUATERNARY RESEARCH 43, 221–231 (1995)

Groundwater Isotopic Evidence for Paleorecharge in U.S. High Plains Aquifers

ALAN R. DUTTON

Bureau of Economic Geology, The University of Texas at Austin, University Station, Box X, Austin, Texas 78713-7508

Received May 16, 1994

Compositions of δD, $\delta^{18}O$, ^{14}C, and ^{3}H are distinct in unconfined and confined groundwaters beneath the nonglaciated U.S. High Plains and reflect differences in average paleoclimatic conditions between the Holocene and the Middle to Late Wisconsinan. δD and $\delta^{18}O$ are more depleted in confined groundwaters than in unconfined groundwaters beneath the southern and central Plains but are more enriched in confined than in unconfined groundwaters beneath the northern Plains. The range in stable isotopic composition of meteoric water north-to-south across the High Plains was apparently smaller during the Middle to Late Wisconsinan than it has been during the Holocene. The greater δD and $\delta^{18}O$ depletion of confined groundwater beneath the southern and central Plains agrees with isotopic and noble gas data on other paleowaters that suggest Middle to Late Wisconsinan recharge temperatures were cooler than average Holocene temperatures by 5 to 8°C. The greater δD and $\delta^{18}O$ enrichment of confined groundwater beneath the northern High Plains adds to previously reported evidence for stable isotope enrichment in glacial age precipitation across the northern Plains to the eastern United States. Additional research is needed to evaluate how patterns and mechanisms of moisture transport and other climatic variables might explain isotopic composition of paleorecharge during the last glacial period. ©1995 University of Washington.

INTRODUCTION

Climatic change during the Late Quaternary has been inferred from the isotopic composition and noble gas content of groundwater in Africa (Srdoč *et al.*, 1982; Dray *et al.*, 1983; Andrews *et al.*, 1994), Europe (Rozanski, 1985; Moser *et al.*, 1989; Stute and Deak, 1989), North America (Perry *et al.*, 1982; Claassen, 1986; Phillips *et al.*, 1986; Plummer *et al.*, 1990; Stute *et al.*, 1992; Plummer, 1993), and Australia (Jacobson *et al.*, 1989). Comparison of isotopic compositions of dated groundwater in unconfined and confined aquifers thus can supplement paleoclimatic inferences based on pollen and other fossils, δD of tree cellulose, geomorphology, and geochemistry of sediments and cements. Such isotopic evidence is not found in all aquifer systems containing old groundwater. For an isotopic record of paleoclimate to be preserved and identified requires (1) isotopic composition of paleorecharge to have been distinct from Holocene isotopic composition, (2) paleoclimatic conditions to have persisted long enough for recharge of one isotopic composition to replace older groundwaters in both unconfined and deeper confined aquifers, and perhaps in an intervening confining layer, (3) the unconfined aquifer to have been flushed by Holocene recharge with an unique isotopic composition, and (4) transport or recharge rates to be too low during the past 11,000 to 18,000 years to have replaced the isotopically distinct paleowater in the confined aquifers with Holocene water. Just how a distinct isotopic composition of paleowater relates to specific climatic variables and moisture transport patterns can be ambiguous for many reasons (Gat, 1983; Grootes, 1993).

Paleorecharge temperature estimated from Wisconsinan-age groundwaters in west-central North America appears cooler than average Holocene temperature by 5 to 8°C (Claassen, 1986; Phillips *et al.*, 1986; Stute *et al.*, 1992). Dutton and Simpkins (1989) and Parkhurst *et al.* (1992) found that stable isotopic composition is stratified beneath the southern and central High Plains, respectively, with δD and $\delta^{18}O$ more depleted in the confined aquifers than in the unconfined aquifers. Dutton and Simpkins (1989) lacked groundwater age data and could not determine whether isotopic stratification is caused by an elevation effect or a climatic effect, because both are functions of temperature.

The purpose of this study is to interpret relative groundwater ages, distinguish vertical and lateral flow paths, and evaluate paleoclimatic implications of isotopic stratification of groundwater beneath the U.S. High Plains. Little is known about the age, isotopic composition, or hydrologic history of unconfined and confined groundwaters beneath the nonglaciated High Plains (Fig. 1). Nonhydrologic data on paleoclimatic conditions are sparse in this region (Galloway, 1983; Baker and Waln, 1985; Holliday, 1987). This study provides new ^{14}C and tritium data, draws together previous reports of isotopically distinct groundwaters, and extends the isotopic comparison of unconfined and confined aquifers to the

0033-5894/95 $6.00
Copyright © 1995 by the University of Washington.
All rights of reproduction in any form reserved.

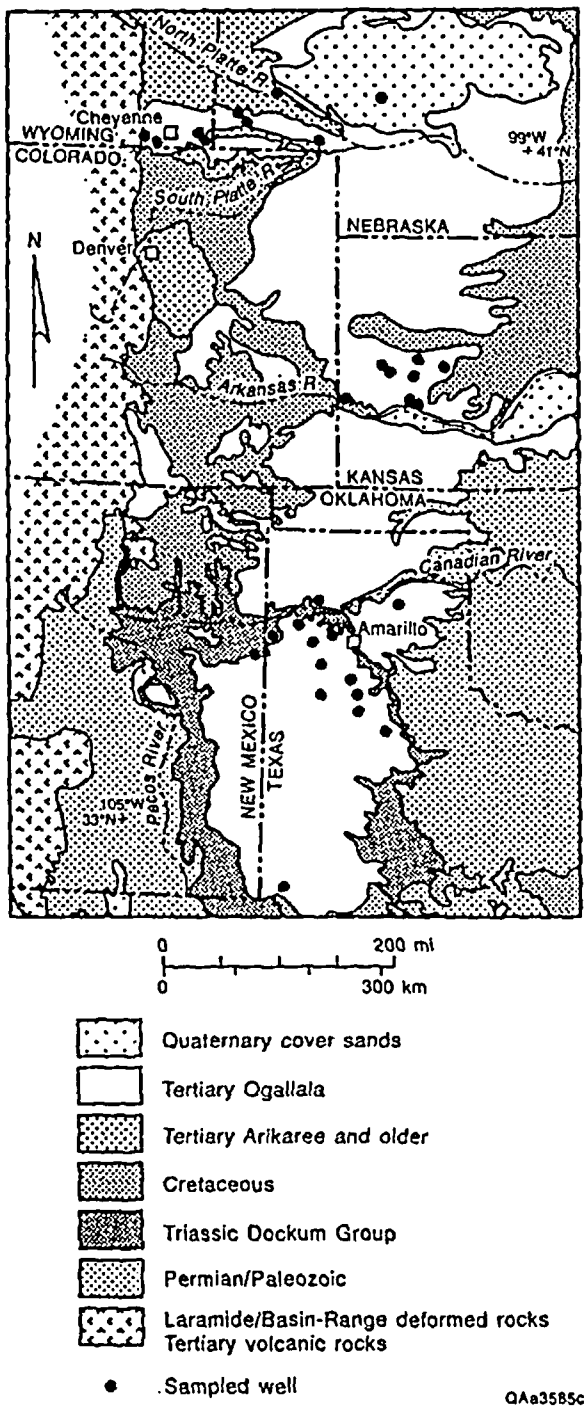


FIG. 1. Simplified geologic map of U.S. High Plains showing sampled wells in southern, central, and northern High Plains. Extent of the High Plains essentially the same as the Ogallala Formation (Osterkamp *et al.*, 1987). Gangplank refers to High Plains between the South Platte and North Platte Rivers. Quaternary surficial deposits not everywhere differentiated.

central and northern High Plains. The approach is to compare age and isotopic composition of groundwaters from paired wells in unconfined and confined aquifers. The 18 wells in confined aquifers from which samples were taken in this study (Figs. 1 and 2) probably represent 5–10% of available wells in confined aquifers in the three study areas. These wells were chosen to lie along presumed horizontal flow paths in the confined aquifers. To compare isotopic composition and groundwater age, wells in the unconfined aquifer were chosen for sampling that were close to the wells in the confined aquifer. The 14 sampled wells in the unconfined aquifer constitute fewer than 0.01% of drilled wells in the extensively developed High Plains aquifer.

HYDROGEOLOGIC SETTING

The High Plains in the midwestern United States (Fig. 1) is underlain by Tertiary and Quaternary alluvial fan, fluvial, lacustrine, and eolian deposits that formed when the Rocky Mountains eroded. Recharge to unconfined and confined aquifers in the Tertiary and Quaternary formations undoubtedly changed during the Pliocene to

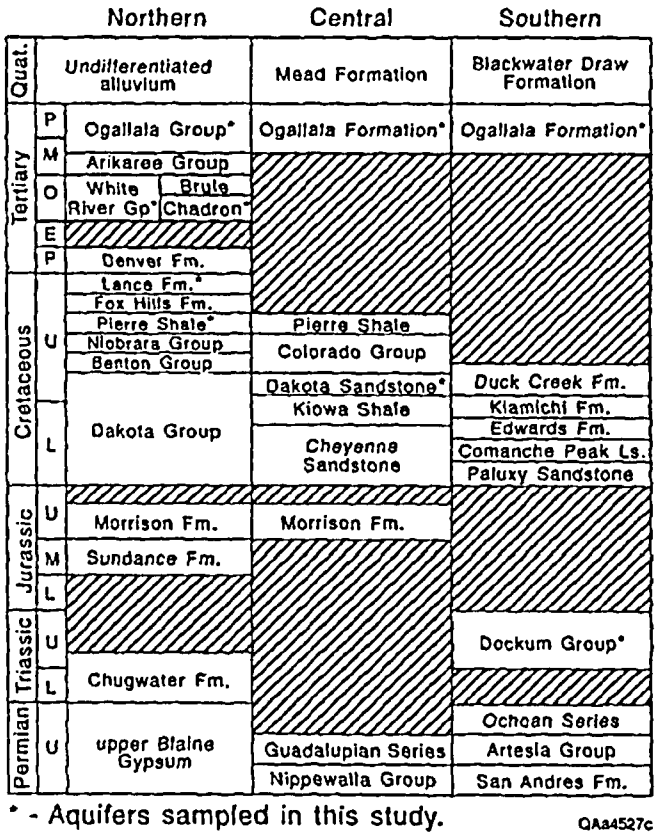


FIG. 2. Generalized correlation chart of stratigraphic units in northern, central, and southern High Plains. Based on Hills and Kottlowski (1983) and Kent *et al.* (1988).

Pleistocene when erosion of Pecos, Arkansas, and South Platte Rivers divided the southern and central High Plains from the Rocky Mountains (Gustavson and Finley, 1985; Osterkamp *et al.*, 1987). Erosion has not completely separated the northern High Plains from the Rocky Mountains in southeastern Wyoming and the Nebraska Panhandle: "At this place [the Gangplank], as nowhere else, you can step off the Great Plains directly onto a Rocky Mountain summit" (McPhee, 1986, p. 54). Hydrologic history of the northern High Plains might differ from that of the southern and central High Plains.

Groundwater flow in both unconfined and confined aquifers is generally from west to east parallel to the regional slope of ground surface (Gutentag *et al.*, 1984). The principal productive part of the unconfined High Plains aquifer lies in the lower part of the Ogallala Formation (Fig. 2). Recharge to the unconfined aquifer beneath the southern High Plains is focused through playa basins (Nativ and Smith, 1987; Osterkamp and Wood, 1987; Nativ and Riggio, 1989; Mullican *et al.*, 1994).

Groundwater resources in confined aquifers are sparsely developed except where the Ogallala is thin or absent. Beneath the southern Plains, the principal confined aquifer lies in sandstone in the lower part of the Triassic Dockum Group (Fig. 2), confined by upper Dockum mudstone (Dutton and Simpkins, 1989). A groundwater divide separates the confined aquifer from its outcrop in the Pecos and Canadian River valleys (Fig. 3). The hydrologic divide resulted from the mostly Pliocene excavation of the Pecos and Canadian River valleys (Gustavson and Finley, 1985).

Beneath the central Plains, the Cretaceous Dakota Sandstone composes the principal confined aquifer and is confined by Upper Cretaceous shales and carbonates (Belitz and Bredehoeft, 1988). Confined groundwater south of the Arkansas River flows eastward, but north of the Arkansas River it flows northeastward (Fig. 4). Less than 15% of recharge in the Colorado Piedmont flows under the Arkansas River to reach the confined part of the aquifer, where model results suggest that vertical

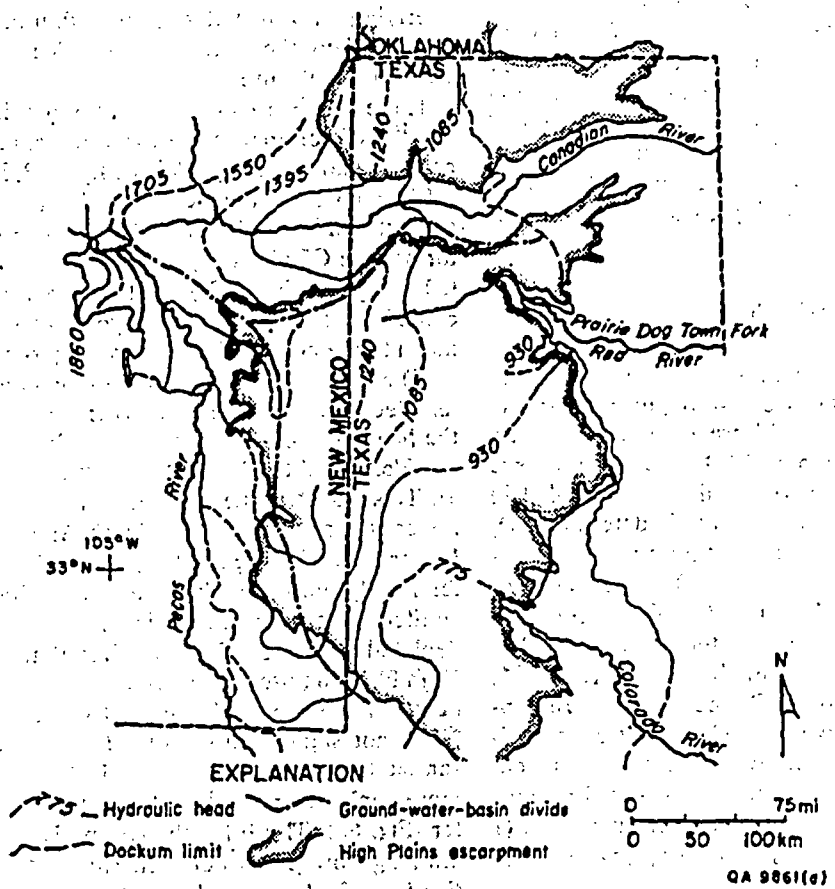


FIG. 3. Hydraulic head (meters above sea level) of groundwater in lower Dockum Group in southern Plains areas. Most of the 1056 water-level measurements used in contouring are from Dockum Group outcrop; only 77 are from the confined aquifer beneath the southern High Plains. Dashed-line contours signify areas of little well control. Symbol for High Plains escarpment is shaded on the High Plains side (see Fig. 1). Modified from Dutton and Simpkins (1989).

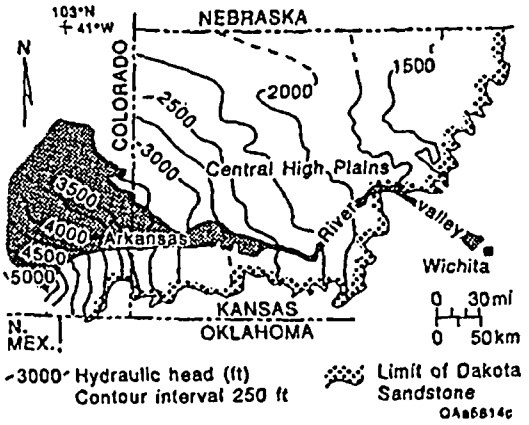


FIG. 4. Potentiometric surface of groundwater in Dakota Sandstone in central Plains area. Most of the ~570 water-level measurements are from the Arkansas River valley and its headwaters in the Colorado Piedmont (shaded area); less than 170 measurements are from the confined aquifer beneath the central High Plains. Modified from Macfarlane (1993).

leakage through confining beds accounts for at least 10% of total flow (Davisson *et al.*, 1993; Macfarlane, 1993).

Beneath the northern Plains, confined aquifers lie in an unconformable succession of Cretaceous to Tertiary rocks that underlie the Ogallala Formation (Swinehart *et al.*, 1985). Confined groundwater flows mostly eastward (Lowry and Christ, 1967) but flow paths probably bend north and south toward discharge areas in the North Platte and South Platte River valleys, where upward flow is possible.

METHODS

Most wells had been pumping nearly continuously for weeks before sampling; other wells were pumped for several hours to purge a few well-bore volumes of water. Waters to be analyzed for δD, $\delta^{18}O$, and tritium were filtered through 0.45-μm cartridge filters and sealed in sample bottles without other treatment. To determine δD, water samples were reacted with hot zinc metal to generate hydrogen gas; to determine $\delta^{18}O$, water samples were equilibrated with CO_2. δD and $\delta^{18}O$ are reported relative to standard mean ocean water (SMOW). Laboratory measurements are reproducible within 1.4 to 5‰ for δD and 0.09 to 0.3‰ for $\delta^{18}O$; these errors are consistent with differences between two laboratories of 5.2‰ in δD and 0.5‰ in $\delta^{18}O$. Tritium was determined on electrolytically enriched water samples by low-level proportional counting; results are reported as tritium units (1 TU is 1 ^3H atom/10^{18} H atoms) with a typical error of ±0.1 TU.

Dissolved inorganic carbon for ^{14}C and $\delta^{13}C$ analyses was collected by direct precipitation using a 30% ammonium hydroxide solution saturated with $SrCl_2$ (Hassan, 1982). The $SrCO_3$ slurry was decanted from carboys and later filtered and washed in the laboratory with negligible exposure to the atmosphere. The $SrCO_3$ powder was analyzed by liquid scintillation counting for ^{14}C and mass spectrometry for $\delta^{13}C$. ^{14}C is reported as uncorrected percentage modern ^{14}C activity (pmc) and $\delta^{13}C$ relative to Peedee belemnite (PDB).

RESULTS

Average ^{14}C differs significantly between unconfined (^{14}C of 55.3 ± 24.2 pmc) and confined groundwaters (^{14}C of <3.7 ± 3.6 pmc). There is no significant regional difference in ^{14}C between unconfined groundwaters beneath the southern High Plains (average of 40.3 pmc, standard deviation of ±13.8 pmc), central High Plains (66.7 ± 6.2 pmc), and northern High Plains (69.3 ± 34.1 pmc). Tritium was above background in half of the samples from the unconfined High Plains aquifer, and in these it ranged from 6.4 to 32.2 TU (Table 1). Nativ and Smith (1987) found that tritium in groundwater in the southern High Plains aquifer was between 4.2 and 73 TU where the overlying unsaturated zone was thin but between 0 and 2.8 TU where the water table was deep, reflecting greater vertical travel time.

There also is no significant regional difference in average ^{14}C of confined groundwaters beneath the southern, central, and northern Plains (4.1 ± 3.8, 5.5 ± 4.7, and <1.7 ± 1.1 pmc, respectively). Tritium was below background in all samples from the confined aquifers except for sample C5 (Table 1), which also had elevated nitrate (20.8 mg/liter $N-NO_3$). Data from this well were excluded on the suspicion that younger water was moving down to the confined aquifer owing to well construction.

δD and $\delta^{18}O$ from both unconfined and confined aquifers decrease from south to north across the High Plains, the heaviest isotopic composition being from the southern Plains and the lightest from the northern Plains (Fig. 5). This matches the pattern of isotopic composition of meteoric water in central North America (Taylor, 1974; Lawrence and Wright, 1991). Isotopic compositions differ locally, however, between unconfined and confined aquifers. In the southern Plains, δD averages 19‰ more depleted in the confined aquifer than in the overlying High Plains aquifer (Figs. 6a and 7). δD is 20 to 26‰ more depleted in two paired samples from the confined aquifer; δD is not significantly more depleted in a third paired sample (Fig. 6a). In the central Plains, δD is 12 to 28‰ more depleted in confined than in unconfined groundwater (Fig. 6b). The little change in δD and $\delta^{18}O$ along 75-km-long flow paths between sampled wells in the confined aquifer beneath the central Plains, however, is not statistically significant given the small sample size (Fig. 8). In the northern Plains, δD is essentially identical in the paired samples from confined and unconfined aquifers

TABLE 1

Tritium, ^{14}C, $\delta^{13}C$, δD, and $\delta^{18}O$ Isotopic Composition of High Plains Ground Waters

Sample ID	Latitude	Longitude	Unit[a]	Depth (m)	Sample date	Tritium (TU)	^{14}C (pmc)	$\delta^{13}C$ (‰)	δD (‰)	$\delta^{18}O$ (‰)	Well sets
					Southern High Plains						
S1a	35.538	102.289	Do	131.1	12/17/84	—	—	—	−66, −68	−9.1, −9.3	
S1b	35.538	102.289	Do	131.1	6/18/91	—	2.7 ± 0.2	−3.8	−68	−10.1	
S2a	35.121	103.021	Do	24.4	3/12/85	—	—	−4.2	−48, −46	−6.8, −6.9	
S2b	35.121	103.021	Do	24.4	6/19/91	—	1.5 ± 0.2	−7.1	−50	−7.48	
S3a	34.983	103.367	Do	304.8	3/18/85	—	—	−7.6	−73, −72	−10.7, −10.7	
S3b	34.983	103.367	Do	304.8	6/20/91	—	4.8 ± 0.2	−8.7	−59	−8.6, −8.4	
S4a	35.122	102.502	Do	265.8	3/12/85	—	—	−4.4	−76	−10.8	1
S4b	35.122	102.502	Do	265.8	6/19/91	0.00 ± 0.09	12.3 ± 0.2	−8.7	−70, −73	−11.7	1
S4c	35.122	102.502	Do	265.8	8/19/92	—	13.1 ± 0.2	−8.7	−67	−10.5	1
S5a	34.854	102.347	Do	291.1	11/27/84	—	—	—	−54, −55	−7.4, −7.4	3
S5b	34.854	102.347	Do	291.1	6/19/91	0.00 ± 0.09	3.1 ± 0.2	−7.9	−58	−7.96	3
S6a	34.734	101.864	Do	253.0	11/30/84	—	—	—	−74, −75	−10.7, −10.8	
S6b	34.734	101.864	Do	253.0	6/20/91	−0.14 ± 0.09	2 ± 0.1	−8.5	−78, −82	−11.7	
S7a	34.546	101.769	Do	252.4	3/13/85	—	—	−5.4	−73, −71	−10.4	2
S7b	34.546	101.769	Do	252.4	6/21/91	0.09 ± 0.09	4.9 ± 0.3	−9.6	−68	−9.5	2
S8a	32.244	102.647	Do	365.8	3/15/85	—	—	−9.6	−47, −49	−7.5, −7.3	
S8b	32.244	102.647	Do	365.8	6/21/91	—	<1	−9.7	−51, −47	−7.2, −7.2	
S9	34.854	102.347	Do	—	11/27/84	—	—	—	−67, −70	−9.6, −9.6	
S10	34.883	102.317	Do	246.0	4/27/84	—	—	—	−80	−11.2	
S11	34.904	102.317	Do	282.2	4/27/84	—	—	—	−83	−11.8	
S12	34.896	102.181	Do	224.6	4/27/84	—	—	—	−85	−12.7	
S13	34.833	102.344	Do	252.1	4/30/84	—	—	—	−71	−9.9	
S14	34.793	102.331	Do	290.2	4/27/84	—	—	—	−67	−9.1	
S15	34.558	101.774	Do	244.1	3/13/85	—	—	—	−75, −73	−10.6	
S16	35.015	101.752	Do	—	11/28/84	—	—	—	−55, −55	−7.5, −7.5	
S17	34.775	101.869	Do	244.8	4/24/84	—	—	—	−62	−9.1	
S18	34.439	101.881	Do	244.1	4/25/84	—	—	—	−50	−6.6	
S19	35.271	102.565	Og	76.2	8/18/92	0.01 ± 0.09	61.1 ± 0.4	−6.0	−38	−6.57	
S20	—	—	Og	109.4	8/18/92	−0.02 ± 0.09	32.4 ± 0.2	−6.9	−54	−8.24	
S21	35.515	100.963	Og	140.2	8/17/92	0.82 ± 0.09	20.8 ± 0.7	−7.3	−42	−6.73	
S22	34.449	102.295	Og	114.6	8/19/92	1.50 ± 0.09	46.5 ± 0.4	−7.6	−34	−6.39	
S23	33.918	101.375	Og	110.6	8/20/92	−0.04 ± 0.09	45.2 ± 0.5	−8.4	−41	−6.86	
S24	34.202	101.708	Og	98.5	8/20/92	5.39 ± 0.18	35.7 ± 0.3	−8.0	−31	−5.35	
					Central High Plains						
C1	38.045	102.011	Da	103.6	11/ 5/91	−0.11 ± 0.09	11.8 ± 0.2	−8.0	−88	−12.8	
C2	38.478	101.362	Da	320.0	11/ 6/91	0.02 ± 0.09	2.1 ± 0.1	−8.4	−92	−12.2	1
C3	37.947	100.973	Da	213.1	11/ 9/91	−0.02 ± 0.09	6.4 ± 0.2	−7.1	−87	−11.8	2
C4	38.471	100.399	Da	346.9	11/ 8/91	−0.03 ± 0.09	1.8 ± 0.2	−7.1	−96	−13	
C5	38.313	100.893	Da	304.8	11/ 7/91	5.56 ± 0.18	21.1 ± 0.2	−8.2	−52	−7.93	
C6	38.478	101.362	Og	48.2	11/ 6/91	6.44 ± 0.21	72.6 ± 0.9	−7.6	−64	−9.5, −9.6	1
C7	38.476	100.911	Og	65.2	11/ 8/91	0.92 ± 0.10	60.2 ± 0.8	−4.3	−64	−9.7, −9.5	
C8	37.921	100.987	Og	133.2	11/ 9/91	0.0 ± 0.09	67.4 ± 1.0	−5.8	−75	−10.4	2
					Northern High Plains						
N1	41.095	104.909	La	285.9	11/13/91	—	3.1 ± 0.5	−12.0	−107	−14.4	1
N2	41.155	104.116	La	277.4	11/13/91	—	2.2 ± 0.3	−7.4	−100	−13.2	2
N4	41.591	102.879	Ch	262.7	11/14/91	—	2.2 ± 0.3	−12.8	−98, −97	−13.7	
N3	41.582	103.674	P	237.7	11/16/91	—	<0.6	−8.9	−89, −92	−13	3
N5	41.093	102.523	WR	147.8	11/22/91	—	<0.6	−16	−98	−13.4	
N6	41.185	104.973	Og	57.3	11/12/91	−0.06 ± 0.09	107 ± 1	−12.3	−110, −108	−14.3	1
N7	41.177	104.067	Og	34.1	11/12/91	6.39 ± 0.23	88.3 ± 1	−11.1	−106	−14.2	2
N8	41.717	103.661	Og	98.8	11/15/91	0.0 ± 0.09	47.9 ± 1	−8.9	−114, 112	−15.2, −15.4	3
N9	—	—	Og	—	11/15/91	—	—	—	−99	−13.8	
N10	41.648	101.369	Og	185.3	11/23/91	32.2 ± 1.10	34 ± 0.5	−8.8	−78	−11	

[a] Do-Dockum, Og-Ogallala, Da-Dakota, La-Lance, Ch-Chadron, P-"transitional" Pierre, WR-White River.
— Not measured.

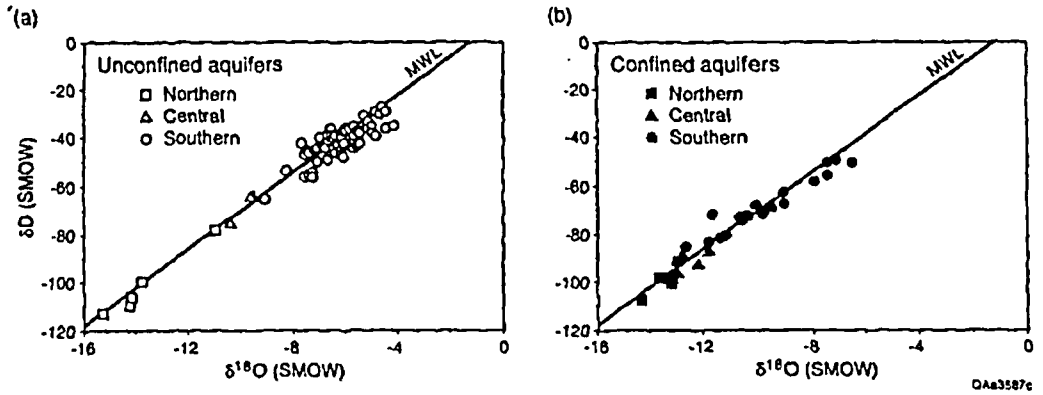


FIG. 5. δD and $\delta^{18}O$ in (a) unconfined and (b) confined ground water beneath the High Plains. Data given in concentration units. MWL is meteoric water line defined by $\delta D = 8\,\delta^{18}O + 10$ (Craig, 1961). Data from southern High Plains in (a) from Nativ and Smith (1987).

nearest the mountain front (set 1 of Fig. 6c; Fig. 9). Although the change in $\delta^{18}O$ is not statistically significant, δD becomes slightly more enriched eastward along the Gangplank—by 6‰ 75 km from the mountain front (set 2) and by 20 to 25‰ 110 km from the mountain front (set 3).

DISCUSSION

Key questions raised by these results are: (1) Does groundwater age constrain interpretation of the sources of confined groundwater? (2) What does isotopic stratification imply about paleoclimate? (3) What does residence time of isotopically distinct waters suggest about persistence of paleohydrologic or paleoclimatic conditions? (4) Does comparative hydrogeology of the southern, central, and northern High Plains reflect differences in hydrologic history?

Ages and Sources of Confined Groundwater

As discussed below, vertical recharge probably is superposed on lateral flow within the unconfined and confined aquifers. This means that there is mixing of groundwaters of varying ages along flow paths in both unconfined and confined aquifers. In addition, hydrodynamic dispersion results in mixing of successive pore volumes (Domenico and Robbins, 1985). Back-calculation of the effects of isotopic dilution and exchange for individual samples, therefore, would not uniquely estimate groundwater age. For the present purpose, ^{14}C and ^{3}H activities suffice to show that confined groundwater is significantly older than unconfined groundwater. Based on comparison with other studies (e.g., Phillips *et al.*, 1986), however, it is reasonable to assume that (1) age of unconfined groundwaters in the High Plains aquifer is generally less than 1000 yr and locally younger than 50 yr, and (2) isotopically distinct confined groundwaters are approximately 15,000 to 35,000 yr old and recharged during the last Pleistocene glaciation.

The assumed age of 15,000 to 35,000 yr is considerably younger than the (Pliocene) age of the hydrologic divide bounding the Pecos River valley (Fig. 3), suggesting that underflow from the Dockum Group outcrop in New Mexico was not the source of water in the confined aquifer beneath the southern High Plains. Vertical leakage, therefore, is the most likely source of water in the confined aquifer. Quantities of water moving in short but slow flow paths across regional confining layers can be large (Bredehoeft *et al.*, 1988). Climatic effects acting on the water that recharged the unconfined aquifer during the Middle to Late Wisconsinan, rather than an elevation effect acting across the Pecos Plains, must account for the isotopically light water now in the confined aquifers (Dutton and Simpkins, 1989). Senger and Fogg (1987) simulated a vertical travel time of approximately 310,000 yr downward across the confining layer beneath the southern High Plains. Their model results suggest that more than 90% of flow in the confined aquifer is derived from vertical leakage. Vertical hydraulic conductivity was set very low in model calibration (9×10^{-9} cm/sec). A 10- to 20-fold larger value of vertical hydraulic conductivity would allow even more leakage and give a vertical travel time of 15,000 to 35,000 yr. The decrease in ^{14}C activities along the northwest-to-southeast flow path in the confined aquifer (Figs. 3, 7) might reflect downward flow of groundwater across the confining layer and lateral transport in the confined aquifer. The greater ^{14}C activity in one sample at the east end of the transect (4.9 pmc, Fig. 7) might reflect more cross-formational flow near the High Plains escarpment (Senger and Fogg, 1987).

Davisson *et al.* (1993) also estimated that confined groundwater beneath the central High Plains is 15,000 to 40,000 yr old. Higher ^{14}C activities nearer the Arkansas River valley (6.4 and 11.8 pmc, Fig. 8) might reflect a shorter travel time and greater vertical leakage downward across the thin part of the confining layer. Lower

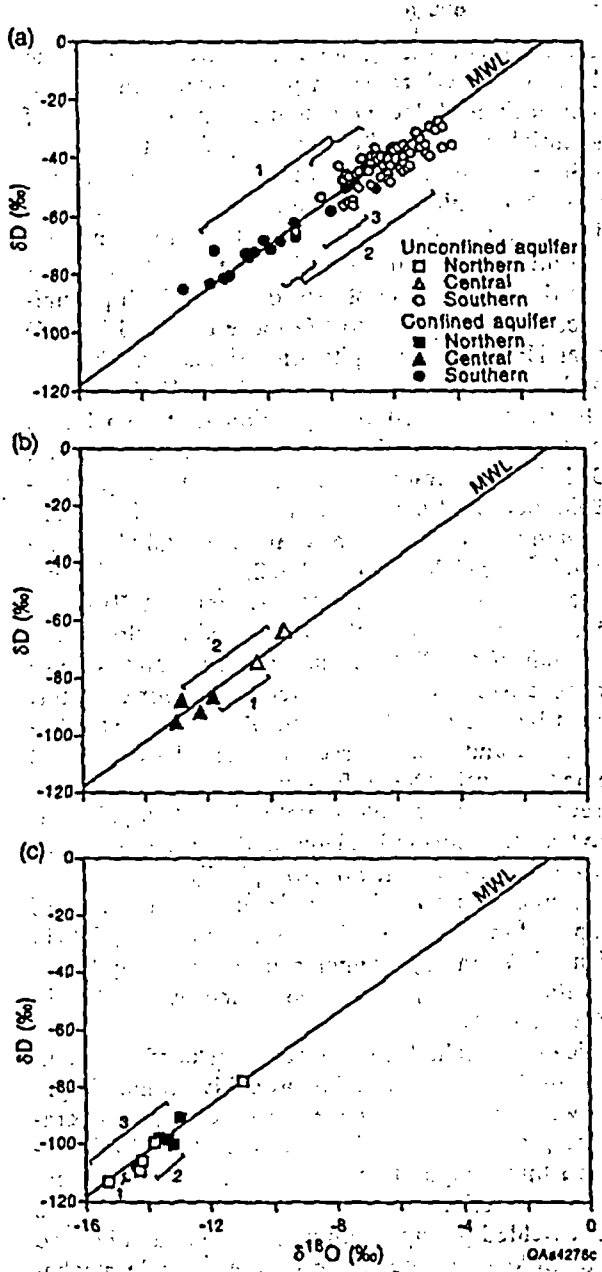


FIG. 6. δD and $\delta^{18}O$ in unconfined and confined groundwater from beneath (a) southern, (b) central, and (c) northern High Plains. MWL as defined in Figure 5. Numerals refer to paired wells (brackets). Data on unconfined aquifer in (a) from Nativ and Smith (1987), including their sample 59 (set 1 unconfined aquifer comparison), sample 53 (set 2), and sample 50 (set 3).

^{14}C activities farther to the northeast might reflect greater horizontal travel time (Fig. 4) and less vertical leakage across the thick part of the confining layer.

^{14}C activity in confined aquifers decreases from west to east beneath the northern High Plains (Fig. 9). These confined groundwaters were probably emplaced by both focused recharge at the western limit of the northern High Plains and by downward leakage from the unconfined aquifer all along the Gangplank. The difference in ^{14}C activity between confined (2.2 to 3.1 pmc, Fig. 9) and unconfined groundwaters (88.3 to 107 pmc) nearest the mountain front reflects a long vertical travel time even in proximal-facies, coarse-grained Tertiary deposits.

Isotopic Stratification and Paleoclimate

The small variation in δD and $\delta^{18}O$ along flow paths within the confined aquifers does not appear to record short-term paleoclimatic changes. Instead, the variation most likely reflects vertical leakage and the paleoisotopic composition of the unconfined aquifer that was the source of water. Beneath the southern Plains, for example, the band of isotopically depleted confined groundwater coincides with the area where the confining layer is thinnest and probably allows the greatest leakage (Dutton and Simpkins, 1989). Beneath the central and northern Plains, the possible trends in δD in confined groundwater might reflect mixing of groundwater that was recharged in the Colorado Piedmont or water that was recharged near the mountain front, respectively, and water that leaked downward from the High Plains aquifer.

The fact that δD and $\delta^{18}O$ in confined groundwater are more enriched beneath the northern Plains but more depleted to the south, compared to groundwater in the unconfined High Plains aquifer, suggests that the gradient in isotopic composition of meteoric water across the northern to southern Plains was less during the Middle to Late Wisconsinan than during the Holocene (Fig. 5a). The δD isopleths of meteoric water (Taylor, 1974) appear to have been shifted farther north across the northern Plains and farther south across the southern Plains. Other confined groundwaters in the southwest United States have similarly depleted $\delta^{18}O$ as those from the southern and central

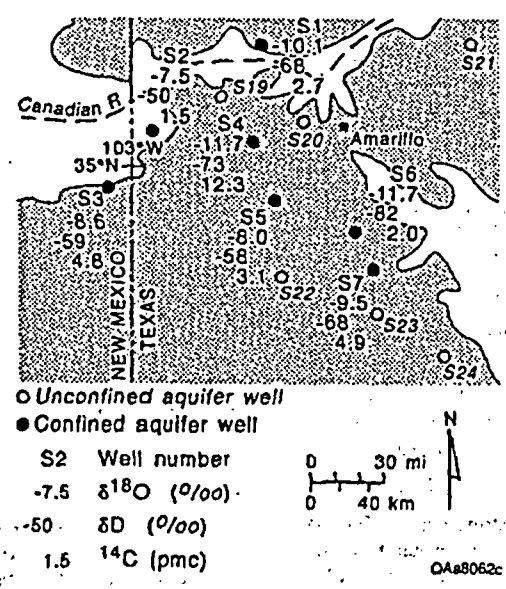


FIG. 7. Distribution of $\delta^{18}O$, δD, and ^{14}C is confined groundwater in Dockum Group beneath the southern High Plains (shaded area).

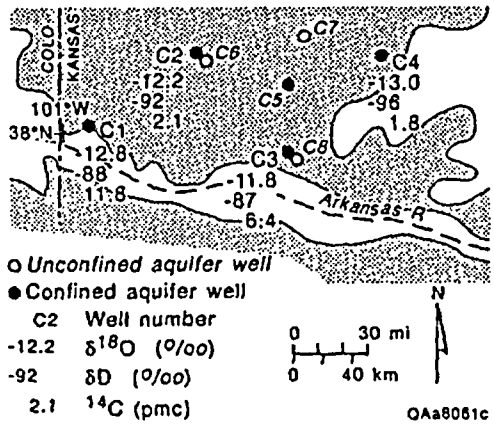


FIG. 8. Distribution of $\delta^{18}O$, δD, and ^{14}C in confined groundwater in Dakota Group beneath the central High Plains (shaded area).

Plains, and have been interpreted on the basis of stable isotopic composition and dissolved noble gas data as reflecting a Wisconsinan paleorecharge temperature 5 to 8°C cooler than average Holocene temperature (Claassen, 1986; Phillips *et al.*, 1986; Stute *et al.*, 1992). Some aspect of the last glaciation is the most likely explanation for the inferred narrow range in isotopic composition of meteoric water, including: (1) temperature difference between the moisture source and the precipitation area, (2) distance from ocean source(s), (3) jet stream and surface wind trajectories, (4) paleoisotopic composition of sources of moisture in Pacific and Atlantic Oceans and Gulf of Mexico, (5) differences in seasonal precipitation, and (6) an "amount effect," in which isotopic composition tends to be more depleted in large precipitation events (Dansgaard, 1964; Gat, 1983; Phillips *et al.*, 1986; Lawrence and White, 1991).

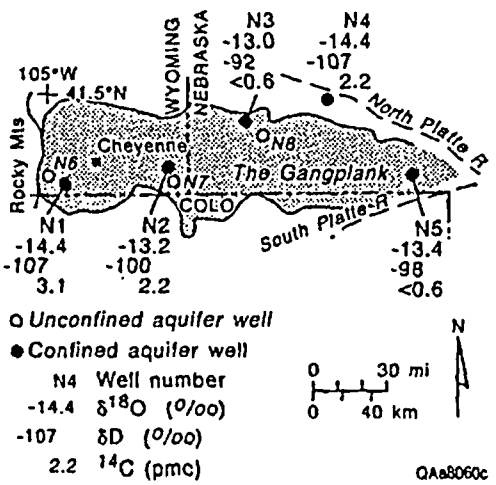


FIG. 9. Distribution of $\delta^{18}O$, δD, and ^{14}C in confined groundwater in confined aquifers beneath the northern High Plains (shaded area). Gangplank refers to High Plains between the South Platte and North Platte Rivers.

In addition to confined groundwaters from beneath the Gangplank, other Wisconsinan paleowaters are isotopically heavier than Holocene precipitation. The degree of isotopic enrichment possibly decreases from the eastern United States west to the northern Plains. Siegel (1991) concluded that a plume of dilute, isotopically enriched groundwater in the glaciated Plains of Iowa is a mixture of glacial meltwater that had a $\delta^{18}O$ of $-20‰$ and precipitation that had a $\delta^{18}O$ of -6 to $-5‰$. Such precipitation would have been 2 to 5‰ more enriched in $\delta^{18}O$ than local Holocene precipitation. Similar subglacially recharged groundwater in western New York was inferred to have received precipitation that also had a heavier-than-Holocene isotopic composition (Siegel, 1992; D. I. Siegel, personal communication, 1994). Plummer (1993) identified paleowater from the Floridan aquifer system in the southeastern Atlantic coastal plain with maximum $\delta^{18}O$ enrichment of 0.7 to 2.3‰ relative to local Holocene groundwater. Yapp and Epstein (1977) found δD of 14,000- to 22,000-yr-old fossil wood cellulose from near the limit of the Wisconsinan ice front that is 20 to 30‰ more enriched than Holocene meteoric water. Agreement between the δD record of dated wood cellulose in Alaska and isotopic records from the Greenland ice cap and Atlantic Ocean foraminifera (Epstein, 1993) gives credence to the cellulose method. Not all paleowaters between the northern Plains and the east coast of North America, however, are isotopically heavier than Holocene precipitation; other confined groundwaters are more depleted in $\delta^{18}O$ than Holocene recharge by 2‰ in north-central Wyoming (Plummer *et al.*, 1990), by 5‰ in northern Illinois (Perry *et al.*, 1982), and by 3 to 8‰ in Iowa (Siegel, 1991).

Isotopically enriched groundwaters in confined aquifers beneath the northern Plains probably do not simply reflect a warmer-than-Holocene paleorecharge temperature in the proglacial area. Yapp and Epstein (1977) hypothesized that evaporation from cold, isotopically enriched seawater of the North Atlantic during the glacial maximum yielded precipitation more enriched in δD and $\delta^{18}O$ than Holocene precipitation. One possible mechanism bringing moisture from the North Atlantic across the northern Plains is suggested by paleoclimate simulations (Kutzbach and Wright, 1985; COHMAP Members, 1988) that showed a weak anticyclonic circulation between two jet streams at the time of glacial maximum (~18,000 yr). Simulations suggest that anticyclonic circulation was strongest in winter months, but was overwhelmed by strong westerly air flow during summer months (Kutzbach and Wright, 1985; Kutzbach and Guetter, 1986). Alternatively, Siegel (1991, 1992) interpreted isotopically enriched groundwater in the glaciated areas as evidence of either a mild, proglacial climate or the influx of moist tropical air. Climatic simulations also indicate that southerly air flow from the Gulf of Mexico

across the continental interior was possible and that precipitation near the ice front might have been above average (J. E. Kutzbach, personal communication, 1994). These simulations may or may not support Siegel's (1991, 1992) interpretation. The confined aquifers beneath the nonglaciated southern and central High Plains, however, record isotopically depleted, not enriched, meteoric water between Siegel's (1991, 1992) study areas in Iowa and New York and source areas in the Gulf of Mexico and Pacific Ocean.

Persistence of Paleohydrologic Conditions

In general, the climatic imprint on the isotopic composition of confined groundwater must have been made by downward flow of water, either regionally, as in the southern High Plains, or locally, as perhaps at the west side of the northern High Plains. Whether water moved into the confined aquifers by vertical leakage or by horizontal transport from an aquifer outcrop, climatic conditions must have persisted long enough for Wisconsinan groundwater to replace older water in the confined aquifers. If confined groundwater beneath the High Plains is 15,000 to 35,000 yr old, then two to four pore volumes might have passed through the heterogeneous strata during the last glacial age from about 73,000 to 11,000 yr ago (Dansgaard *et al.*, 1969). Hydrodynamic dispersion increases the effective time and number of pore volumes needed for complete displacement of an older groundwater (Davidson and Airey, 1982; Domenico and Robbins, 1985) and makes the temporal records of ^{14}C and stable isotopic composition imprecise. The last pore volume to move into confined aquifers during the past 15,000 to 35,000 yr would not have completely displaced older groundwater. Since the end of the Pleistocene enough time has elapsed for recharge to replace Wisconsinan groundwater in the unconfined aquifers but not in the deeper, confined aquifers.

Model of Tertiary Recharge in Southern and Central Plains

The late Pleistocene to Holocene record of groundwater flow in the northern Plains might serve as an analog for Tertiary groundwater flow in the southern and central Plains. Before the erosion of the Pecos Plains and Colorado Piedmont (Fig. 1), both unconfined and confined aquifers in the southern and central Plains might have been recharged at high elevations near the Rocky Mountains. By the late Pliocene, recharge at the foothills of the southern Rocky Mountains was largely captured by the Pecos River, and downward vertical leakage became the major source of recharge to the confined aquifer beneath the southern High Plains. Beneath the central High Plains, flow of recharge from near the Rocky Mountains into the confined aquifer probably has been greatly reduced; 85% of the total recharge now is lost across the Colorado Piedmont and upper Arkansas River valley by discharge from local- and intermediate-scale groundwater flow systems (Davisson *et al.*, 1993; Macfarlane, 1993).

CONCLUSIONS

The isotopic composition of dated, confined groundwater can shed light on regional paleoclimate. The depleted δD and $\delta^{18}O$ composition of confined groundwater beneath the southern and central High Plains agrees with the isotopic composition of other Middle to Late Wisconsinan groundwaters from the southwestern United States and might indicate paleorecharge temperature 5 to 8°C cooler than average Holocene temperature in that region. Isotopic compositions of confined groundwater beneath the northern High Plains, Iowa, New York, and Florida and wood cellulose in Wisconsinan-dated trees are more enriched than Holocene meteoric waters. Isopleths of isotopic composition of meteoric water were shifted, decreasing the range in isotopic composition of paleorecharge across the U.S. High Plains relative to its Holocene range. Further study is needed to map the effect of moisture transport patterns and other climatic variables on the isotopic composition of paleorecharge water.

A distinct isotopic record being preserved in confined groundwater implies that hydrologic and climatic conditions persisted long enough for a water mass of one isotopic composition to replace an older water mass in unconfined and deeper confined aquifers. Because of aquifer dispersion, the isotopic record in confined groundwater beneath the High Plains averages climatic effects over several pore volumes recharged during 60,000 yr of the Middle to Late Wisconsinan. During the past 11,000 yr, recharge under a warm and dry climate in the High Plains has replaced unconfined groundwater but not deeper confined groundwater. Comparative hydrogeology suggests that groundwater flow beneath the northern High Plains might serve as an analog for the hydrology of the southern and central High Plains during the Tertiary.

ACKNOWLEDGMENTS

Research was supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS Award 14-08-0001-G1885. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. Marvin Christ, Alan Fryar, Jim Goeke, Allen Macfarlane, Steve Sibray, and Don Whittemore helped arrange sampling. Allen Macfarlane, Niel Plummer, Don Siegel, Don Whittemore, and Warren Wood reviewed the manuscript and along with Philip Bennett, Alan Fryar, and Jim Lawrence provided helpful suggestions. Publication is authorized by the Director, Bureau of Economic Geology, University of Texas at Austin.

REFERENCES

Andrews, J. N., Fontes, J.-C., Aranyossy, J.-F., Dodo, A., Edmunds, W. M., Joseph, A., and Travi, Y. (1994). The evolution of alkaline groundwaters in the continental intercalaire aquifer of the Irhazer Plain, Niger. *Water Resources Research* 30, 45–61.

Baker, R. G., and Wain, K. A. (1985). Quaternary pollen records from the Great Plains and central United States. *In* "Pollen records of Late-Quaternary North American Sediments" (Bryant, V. M., Jr., and Holloway, R. G., Eds.), pp. 191–203. American Association of Stratigraphic Palynologists, Dallas, TX.

Belitz, Kenneth, and Bredehoeft, J. D. (1988). Hydrodynamics of Denver Basin: Explanation of subnormal fluid pressures. *American Association of Petroleum Geologists Bulletin* 72, 1334–1359.

Bredehoeft, J. D., Back, William, and Hanshaw, B. B. (1988). Regional ground-water flow concepts in the United States: Historical perspective. *In* "Recent Trends in Hydrogeology" (Narasimhan, T. N., Ed.), pp. 297–316. *Geological Society of America Special Paper* 189.

Claassen, H. C. (1986). Late-Wisconsinan paleohydrology of the west-central Amargosa Desert, Nevada, U.S.A. *Chemical Geology* 58, 311–323.

COHMAP Members (1988). Climatic changes of the last 18,000 years: Observations and model simulations. *Science* 241, 1043–1052.

Craig, Harmon (1961). Isotopic variations in meteoric waters. *Science* 133, 1702–1703.

Dansgaard, W. (1964). Stable isotopes in precipitation. *Tellus* 16, 436–468.

Dansgaard, W., Johnsen, S. J., Møller, J., and Langway, C. C., Jr. (1969). One thousand centuries of climatic record from Camp Century on the Greenland ice sheet. *Science* 166, 377–381.

Davidson, M. R., and Airey, P. L. (1982). The effect of dispersion on the establishment of a paleoclimatic record from groundwater. *Journal of Hydrology* 58, 131–147.

Davisson, M. L., Smith, D. K., Macfarlane, P. A., Whittemore, D. O., Hudson, G. B., and Caffee, M. (1993). Isotopic indications of age and flow characteristics of ground water in the Dakota aquifer, eastern Colorado through central Kansas. *Geological Society of America, Abstracts with Programs* 25, 145 [Abstract].

Dray, M., Gonfiantini, R., and Zuppi, G. M. (1983). Isotopic composition of groundwater in the southern Sahara. *In* "Palaeoclimates and Palaeowaters: A Collection of Environmental Isotope Studies," Panel Proceedings Series, pp. 187–199. International Atomic Energy Agency, Vienna.

Domenico, P. A., and Robbins, G. A. (1985). The displacement of connate water from aquifers. *Geological Society of America Bulletin* 96, 328–335.

Dutton, A. R., and Simpkins, W. W. (1989). Isotopic evidence for paleohydrologic evolution of ground-water flow paths, Southern Great Plains, U.S.A. *Geology* 17, 653–656.

Epstein, Samuel (1993). The D/H ratio of hydrogen in plant remains which grew 8 to 12 × 10^3 years B.P. on the north slope of Alaska. *Geological Society of America Abstracts with Programs* 23, A456 [Abstract].

Galloway, R. W. (1983). Full-glacial southwestern United States: Mild and wet or cold and dry? *Quaternary Research* 19, 236–248.

Gat, J. R. (1983). Precipitation, groundwater, and surface waters; control of climatic parameters on their isotopic composition and their utilization as palaeoclimatological tools. *In* "Palaeoclimates and Palaeowaters: A Collection of Environmental Isotope Studies," Panel Proceedings Series, pp. 3–12. International Atomic Energy Agency, Vienna.

Grootes, P. M. (1993). Interpreting continental oxygen isotope records. *In* "Climate Change in Continental Isotopic Records" (P. K. Swart, K. C. Lohman, J. McKenzie, and S. Savin, Eds.), pp. 37–46. American Geophysical Union, Geophysical Monograph 78.

Gustavson, T. C., and Finley, R. J. (1985). "Late Cenozoic Geomorphic Evolution of the Texas Panhandle and Northeastern New Mexico—Case Studies of Structural Controls on Regional Drainage Development." Bureau of Economic Geology Report of Investigations 148. University of Texas, Austin.

Gutentag, E. D., Heimes, F. J., Krothe, N. C., Luckey, R. R., and Weeks, J. B. (1984). "Geohydrology of the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming," Professional Paper 1400-B. U.S. Geological Survey.

Hassan, A. (1982). "Methodologies for Extraction of Dissolved Inorganic Carbon for Stable Carbon Isotope Studies: Evaluation and Alternatives." Water Resources Investigations 82–6. U.S. Geological Survey.

Hills, J. M., and Kottlowski, F. E. (1983). "Southwest/Southwest Mid-Continent Region: Correlation of Stratigraphic Units of North America (COSUNA) Project," Correlation Chart Series. American Association of Petroleum Geologists.

Holliday, V. T. (1987). Re-examination of late-Pleistocene boreal forest reconstruction for the southern High Plains. *Quaternary Research* 28, 238–244.

Jacobson, G., Calf, G. E., Jankowski, J., and McDonald, P. S. (1989). Groundwater chemistry and palaeorecharge in the Amadeus Basin, Central Australia. *Journal of Hydrology* 109, 237–266.

Kent, H. C., Couch, E. L., and Knepp, R. A. (1988). "Central and Southern Rockies Region: Correlation of Stratigraphic Units of North America (COSUNA) Project," Correlation Chart Series. American Association of Petroleum Geologists.

Kutzbach, J. E., and Wright, H. E., Jr. (1985). Simulation of the climate of 18,000 years BP: Results for the North American/North Atlantic/European sector and comparison with the geologic record of North America. *Quaternary Science Reviews* 4, 147–187.

Kutzbach, J. E., and Guetter, P. J. (1986). The influence of changing orbital parameters and surface boundary conditions on climate simulations for the past 18,000 years. *Journal of the Atmospheric Sciences* 43, 1726–1759.

Lawrence, J. R., and White, J. W. C. (1991). The elusive climate signal in the isotopic composition of precipitation. *In* "Stable Isotope Geochemistry: A Tribute to Samuel Epstein" (H. P. Taylor, Jr., J. R. O'Neil, and I. R. Kaplan, Eds.), Special Publication 3. pp. 169–185. The Geochemical Society.

Lowry, M. E., and Christ, M. A. (1967). "Geology and Ground-Water Resources of Laramie County, Wyoming." Water-Supply Paper 1834. U.S. Geological Survey.

Macfarlane, P. A. (1993). "The Effect of Topographic Relief and Hydrostratigraphy on the Upper Part of the Regional Ground-Water Flow System in Southeastern Colorado and Western and Central Kansas, with Emphasis on the Dakota Aquifer." Unpublished Ph.D. dissertation, University of Kansas.

McPhee, J. A. (1986). "Rising from the Plains." Farrar, Straus, Giroux, New York.

Moser, H., Wolf, M., Fritz, P., Fontes, J.-C., Florkowski, T., and Payne, B. R. (1989). Deuterium, oxygen-18, and tritium in Stripa groundwater. *Geochimica et Cosmochimica Acta* 53, 1757–1763.

Mullican, W. F., III, Fryar, A. E., and Johns, N. D. (1994). Vertical transport of contaminants through perched aquifers to the Ogallala aquifer, Pantex Plant area, southern High Plains, Texas. *In* "Toxic Substances and the Hydrologic Sciences" (A. R. Dutton, Ed.), pp. 547–562. American Institute of Hydrology.

Nativ, Ronit, and Riggio, Robert (1989). Meterologic and isotopic characteristics of precipitation events with implications for ground-water recharge, southern High Plains. *Atmospheric Research* 23, 51–82.

Nativ, Ronit, and Smith, D. A. (1987). Hydrogeology and geochemistry of the Ogallala aquifer, southern High Plains. *Journal of Hydrology* 91, 217–253.

Osterkamp, W. R., Fenton, M. M., Gustavson, T. C., Hadley, R. F., Holliday, V. T., Morrison, R. B., and Toy, T. J. (1987). Great Plains. *In* "Geomorphic systems of North America" (W. L. Graf, Ed.), Centennial Special Vol. 2, pp. 163–210. Geological Society of America, Boulder, CO.

Osterkamp, W. R., and Wood, W. W. (1987). Playa-lake basins on the southern High Plains of Texas and New Mexico: I. hydrologic, geomorphic, and geologic evidence for their development. *Geological Society of America Bulletin* 99, 215–223.

Parkhurst, D. L., Christenson, S., and Breit, G. N. (1992). "Ground-Water-Quality Assessment of the Central Oklahoma Aquifer, Oklahoma: Geochemical and Geohydrologic Investigations," Open-File Report 92-642. U.S. Geological Survey.

Perry, E. C., Jr., Grundl, T., and Gilkeson, R. H. (1982). H, O, and S isotopic study of the groundwater in the Cambrian–Ordovician aquifer system of northern Illinois. *In* "Isotope Studies of Hydrologic Processes" (E. C. Perry, Jr., and C. W. Montgomery, Eds.), pp. 35–43. Northern Illinois Univ. Press, DeKalb, IL.

Phillips, F. M., Peeters, L. A., Tansey, M. K., and Davis, S. N. (1986). Paleoclimatic inferences from an isotopic investigation of groundwater in the Central San Juan Basin, New Mexico. *Quaternary Research* 26, 179–193.

Plummer, L. N. (1993). Stable isotope enrichment in paleowaters of the southeast Atlantic coastal plain, United States. *Science* 262, 2016–2020.

Plummer, L. N., Busby, J. F., Lee, R. W., and Hanshaw, B. B. (1990). Geochemical modeling of the Madison aquifer in parts of Montana, Wyoming, and South Dakota. *Water Resources Research* 26, 1981–2014.

Rozanski, K. (1985). Deuterium and oxygen-18 in European groundwaters—links to atmospheric circulation in the past. *Chemical Geology* 52, 349–363.

Senger, R. K., and Fogg, G. E. (1987). Regional underpressuring in deep brine aquifers, Palo Duro Basin, Texas. 1. Effects of hydrostratigraphy and topography. *Water Resources Research* 23, 1481–1493.

Siegel, D. I. (1991). Evidence for dilution of deep, confined ground water by vertical recharge of isotopically heavy Pleistocene water. *Geology* 19, 433–436.

Siegel, D. I. (1992). Isotopic evidence from regional ground water and calcite cements that Late Wisconsin continental ice lobes were sustained by tropical air masses. *Geological Society of America Abstracts with Programs* 24, A240 [Abstract].

Srdoč, D., Obelić, B., Horvatinčić, N., Sliepčević, A., Stichler, W., Moser, H., and Geyh, M. A. (1982). Isotope analyses of groundwaters of the North African Plain. *Catena* 9, 253–263.

Stute, M., and Deak, J. (1989). Environmental isotope study (^{14}C, ^{13}C, ^{18}O, D, noble gases) on deep groundwater circulation systems in Hungary with reference to paleoclimate. *Radiocarbon* 31, 902–918.

Stute, M., Schlosser, P., Clark, J. F., and Broecker, W. S. (1992). Paleotemperatures in southwestern United States derived from noble gases in ground water. *Science* 256, 1000–1003.

Swinehart, J. B., Souders, V. L., DeGraw, H. M., and Diffendal, R. F., Jr. (1985). Cenozoic paleogeography of western Nebraska. *In* "Cenozoic Paleogeography of West-Central United States" (R. M. Flores, and S. S. Kaplan, Eds.), Rocky Mountain Paleogeography Symposium 3, pp. 209–299. Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section.

Taylor, H. P., Jr. (1974). The application of oxygen and hydrogen isotope studies to problems of hydrothermal alterations and ore deposition. *Economic Geology* 69, 843–883.

Yapp, C. J., and Epstein, Samuel (1977). Climatic implications of D/H ratios of meteoric water over North America (9500–22,000 B.P.) as inferred from ancient wood cellulose C–H hydrogen. *Earth and Planetary Science Letters* 34, 333–350.

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE COMMISSION

In the Matter of:	)	
	)	
	)	Docket No. 70-3103-ML
LOUISIANA ENERGY SERVICES, L.P.	)	
	)	ASLBP No. 04-826-01-ML
(National Enrichment Facility)	)	
	)	

Deposition of:

GEORGE A. HARPER

ROGER L. PEERY

witnesses of lawful age, taken on behalf of the Nuclear Information & Resource Service and Public Citizen, pursuant to notice, in the New Mexico Environment Department, Office of the Secretary, Conference Room, Harold Runnels Building, 1190 St. Francis Drive, Santa Fe, New Mexico, on Friday, September 17, 2004, at 9:00 a.m., before Carol Oppenheimer, Notary Public, when were present:

APPEARANCES:

On behalf of Nuclear Information & Resource Service and Public Citizen:

LINDSAY A. LOVEJOY, JR., ESQ.

618 Paseo del Peralta, Unit B

Santa Fe, New Mexico 87501

On behalf of the Louisiana Energy Services, L.P.:

JAMES R. CURTISS, ESQ.

MARTIN J. O'NEILL, ESQ.

Winston & Strawn, LLP

1400 L Street, N.W.

Washington, D.C. 20005-3502

On behalf of the Nuclear Regulatory Commission:

LISA CLARK, ESQ.

Nuclear Regulatory Commission

Also Present:

GEORGE R. (RANDY) CAMPBELL

Lockwood Greene

ROD KRICH

National Enrichment Facility

JOHN W. LAWRENCE, ESQ.

National Enrichment Facility

GEORGE RICE

Expert Witness, Groundwater Hydrologist

MARK S. STRUM

Framatome ANP, Inc.

ALAN TOBLIN

Advanced Technologies and Laboratories
International, Inc.

ABE ZEITOUN, Ph.D.

Advanced Technologies and Laboratories
International, Inc.

I N D E X

WITNESS	EXAMINATION
George A. Harper and	
Roger L. Peery	
Examination by Mr. Lovejoy	6
Nuclear Information & Resource Service and Public Citizen	

EXHIBITS	PAGE	DESCRIPTION
NIRS-HP-1	6	Peery resume
NIRS-HP-2	6	Harper resume
NIRS-HP-3	58	Study Report, Liquid Effluent Disposition, 8/5/03
NIRS-HP-4	62	Study Report, Liquid Effluent Disposition, 8/22/03
NIRS-HP-5	65	Draft Report of Preliminary Subsurface Exploration, 10/8/03
NIRS-HP-6	71	Hydrologic Investigation 11/19/03
NIRS-HP-7	79	Walker to Harper, 3/1/04, LES-168
NIRS-HP-8	81	Walker to Harper, 3/1/04, LES-170
NIRS-HP-9	83	Walker to Harper, 3/1/04, LES-172
NIRS-HP-10	88	GL to Harper, 4/6/04
NIRS-HP-11	102	Lockwood Greene to Krich, 5/11/04
NIRS-HP-12	103	Figure for groundwater discharge permit app, LES-186
NIRS-HP-13	104	LES Boring & Monitor Well Survey Data

EXHIBITS	PAGE	DESCRIPTION
NIRS-HP-14	105	Potential for Radioactivity Concentration in Runoff from UBC Storage Pad
NIRS-HP-15	108	Water Balance Tables for National Enrichment Facility Basins
NIRS-HP-16	109	Excerpts from Environmental Report

1 P R O C E E D I N G S

2 Whereupon,

3 GEORGE A. HARPER

4 ROGER L. PEERY

5 having been first duly sworn, were called as a witnesses

6 herein, and were examined and testified as follows:

7 MR. LOVEJOY: Good morning. Can we mark as

8 Exhibits 1 and 2 these two resumes, please.

9 (The documents referred to were

10 marked for identification as

11 Exhibits NIRS-HP 1 and 2.)

12 EXAMINATION

13 BY MR. LOVEJOY:

14 Q Okay. For identification, Mr. Peery, is

15 Exhibit 1 your own resume?

16 A (Mr. Peery) Yes, it is.

17 Q And, Mr. Harper, is Exhibit 2 your own resume?

18 A (Mr. Harper) Yes, it is.

19 Q Okay. Mr. Peery, I take it from looking at

20 your resume, Exhibit 1, that you're now associated with

21 John Shomaker & Associates, a hydrology firm in

22 Albuquerque. Is that right?

23 A (Mr. Peery) That's correct.

24 Q And I've just gotten this right now. Can you

25 just tell me for the record what your education is in

1 scientific fields related to --

2 A (Mr. Peery) I have a bachelor of science in

3 geology and a master's in water resources.

4 Q Okay. And since 1992, how have you been

5 employed?

6 A (Mr. Peery) Since 1992, I've been employed at

7 John Shomaker & Associates as a hydrogeologist.

8 Q And what kind of tasks have you undertaken

9 there?

10 A (Mr. Peery) I have been involved with

11 environmental investigations, development of monitoring

12 wells, networks, logging of holes, remediation of

13 environmental sites, water resources work related to well

14 siting, evaluation of water supply, groundwater flow

15 modeling, water planning, regional water planning as well

16 as municipal water planning.

17 Q Have you had occasion to testify as an expert?

18 A (Mr. Peery) Yes, I have.

19 Q Can you name the times, please?

20 A (Mr. Peery) I can give you rough times. I

21 don't remember exactly.

22 Q That's fine.

23 A (Mr. Peery) I believe last year I testified in

24 front of the Office of the State Engineer hearing

25 examiners related to a water rights issue. And I believe

1 another time in front of the New Mexico Office o State
2 Engineer related to a water issue. That was around 2000.
3 I've also testified in front of the Planning and Zoning
4 Commission and the county commissioners of Santa Fe. That
5 was probably 1995-ish in front of the Socorro County
6 commissioners, I believe, 2000. Sandoval County
7 commissioners, I testified before them on several
8 occasions in the late '90s and 2003 and probably somewhere
9 in early 2000 also.
10 Q Okay. How large an office is Shomaker &
11 Associates?
12 A (Mr. Peery) We're currently about 14 people,
13 including support staff.
14 Q Okay. And what tasks, if any, have you been
15 assigned to undertake with respect to the LES proposal for
16 an enrichment plant?
17 A (Mr. Peery) To look at the site hydrogeology
18 and to look at water supply issues.
19 Q When you say, look at hydrogeology, what do you
20 mean? What have you been asked to do?
21 A (Mr. Peery) Review available data from site
22 reports and permit applications that LES has submitted,
23 and I've also looked at other scientific reports from
24 nearby WCS facility.
25 Q Okay. Have you been asked to direct or design

1 any exploration efforts?

2 A (Mr. Peery) No, I have not.

3 Q Have you been asked to undertake any data

4 gathering efforts, apart from reviewing reports that have

5 been prepared?

6 A (Mr. Peery) No.

7 Q When did you first undertake work on matters

8 involving LES?

9 A (Mr. Peery) I think we signed a contract with

10 LES approximately three months ago.

11 Q We being Shomaker & Associates.

12 A (Mr. Peery) Shomaker & Associates.

13 Q Okay. Mr. Harper, would you identify Exhibit

14 2?

15 A (Mr. Harper) I already have.

16 Q You did. Okay. So it's still your resume.

17 A (Mr. Harper) Still my resume.

18 Q Okay. Would you please describe your

19 scientific and engineering education.

20 A (Mr. Harper) I have a bachelor of science in

21 civil engineering and a master's of science in civil

22 engineering from the University of Massachusetts at

23 Amherst. I'm a registered professional engineer in three

24 states: Maine, New Hampshire and Massachusetts. And I've

25 worked in the nuclear industry for 25 years, mostly in the

1 environmental area.

2 Q What, if any, training have you had in the

3 sphere of hydrology?

4 A (Mr. Harper) My master's in flow mechanics and

5 hydraulics. As you'll see in my resume, I've taken

6 various hydrology seminars and training courses over the

7 years. I'm also a FERC-approved hydrologist, as my resume

8 documents, and I've done a lot of hydrology and hydraulics

9 work during my career.

10 Q What is involved in becoming a FERC-approved

11 hydrologist?

12 A (Mr. Harper) I've been on two of the DM safety

13 committees where by through my experience and record, they

14 have approved me to act as a hydrologist on DM safety

15 studies.

16 Q Have you ever testified as an expert witness on

17 matters of hydrology?

18 A (Mr. Harper) Partially. I testified back in

19 the early 1990s before the Vermont Public Utilities

20 Commission on site characterization issues associated with

21 a potential low-level waste facility in Vermont, and my

22 testimony covered all types of environmental issues,

23 including hydrology and groundwater.

24 Q Okay. Is that the only instance you've

25 testified as expert in hydrology?

1 A (Mr. Harper) Correct.

2 Q And where are you employed now?

3 A (Mr. Harper) I'm with Areva Framatome out of

4 Marlborough, Massachusetts. We provide all types of

5 services to the nuclear industry in the United States and

6 throughout the world.

7 Q Now, you used the term Areva, A-R-E-V-A. Is

8 that an acronym?

9 A (Mr. Harper) No. It's our parent company name

10 in France.

11 Q And is Areva the parent of Framatome?

12 A (Mr. Harper) Correct.

13 Q Is Areva a public company?

14 A (Mr. Harper) It is in the process of becoming

15 publicly traded in Europe.

16 Q Does Areva have any corporate relationship with

17 LES or any of the partners that make up LES?

18 A (Mr. Harper) Not to my knowledge.

19 Q Is the work that Framatome is doing for LES

20 under contractual arrangement?

21 A (Mr. Harper) Yes, it is.

22 Q Do you know how long ago that contract was

23 made?

24 A (Mr. Harper) Yes. The original contract

25 with -- was actually with Urenco back in early 2002.

1 Q Okay. Can you -- let's start with you, Mr.
2 Harper. Can you please tell me what conclusions or
3 opinions you're going to be expressing in this proceeding?
4 A (Mr. Harper) I'll be -- I'm here to discuss
5 the three basins that have been designed for the facility,
6 the septic system, potential sources of contamination of
7 liquids that flow into those basins or the septic systems,
8 groundwater monitoring, the New Mexico groundwater
9 discharge permit application that LES has submitted, and
10 the UF_6 feed pump composition.
11 Q The feed composition, did you say?
12 A (Mr. Harper) Yes.
13 Q All right. You're here to testify on those
14 subjects. Well, do you have any expert conclusions that
15 you're going to provide the Atomic Safety and Licensing
16 Board in this case?
17 A (Mr. Harper) Yes, I do.
18 Q What are those? You can go down these subjects
19 if you like.
20 A (Mr. Harper) Okay. Well, in regards to the
21 basins, my conclusion is that the basins have been
22 engineered to the extent to preclude any significant
23 release of contamination to the soils underneath the
24 basins and also to the groundwater; that the groundwater
25 monitoring program has been -- as outlined in the

1 groundwater discharge permit -- in the environmental
2 report is adequate to monitor the groundwater for the
3 facility. And I guess that's it.
4 Q Those are the only conclusions you're going to
5 testify to.
6 A (Mr. Harper) That come to mind right now, yes.
7 Q Well, if in the course of today's testimony
8 something else comes to mind, can you let me know?
9 A (Mr. Harper) Sure.
10 Q Okay. And, Mr. Peery, what conclusions --
11 rather let's start a little earlier. What subject areas
12 are you here to testify about, are you going to be
13 testifying before the Board about?
14 A (Mr. Peery) I'll be testifying about the
15 characterization that was performed at the site, the
16 geologic -- type of geologic characterization. I'll be
17 discussing the absence of shallow groundwater at the
18 system; hydraulic properties of the formations at the
19 site; and the absence of fracturing or fast-flow paths,
20 you might -- as referred to yesterday in the Chinle.
21 Q When you say the absence of fast-flow paths, is
22 it your conclusion that there are no fast-flow paths in
23 the Chinle?
24 A (Mr. Peery) My conclusion is there's no
25 evidence to support that there are any fractures that are

1 fast-flow paths in the Chinle.

2 Q Okay. On the other matters that you're going

3 to be testifying about, what conclusions have you reached?

4 A (Mr. Peery) I'm sorry. What other matters are

5 you addressing?

6 Q You said you were going to testify about the

7 characterization at the site, the absence of shallow

8 groundwater, the hydraulic properties of the formations.

9 A (Mr. Peery) Can we go through those one at a

10 time, please?

11 Q Please.

12 A (Mr. Peery) The first one, adequacy of the

13 characterization of the site, the conclusions I reached on

14 that is that the investigation was what would normally be

15 done for site investigation, industry standard for

16 evaluating whether or not there's shallow groundwater

17 present, and also looking at the developed properties of

18 the aquifer at the approximately 220-foot zone.

19 Q What about that aquifer?

20 A (Mr. Peery) What do you mean?

21 Q You just said, and also about the aquifer in

22 the 220-zone. What's your conclusion about that?

23 A (Mr. Peery) That the aquifer is present under

24 confined conditions; that it has a very low hydraulic

25 conductivity, very low permeability.

1 Q Okay. You spoke of the absence of shallow
2 groundwater. What is your conclusion in that regard?
3 A (Mr. Peery) My conclusion is that based on 14
4 borings that were advanced at the site, that there is no
5 shallow groundwater present at the site. All of the
6 borings were advanced through the shallow sediments,
7 basically alluvial type and Quaternary age sediments, to
8 the top of the redbed which is the Chinle, and there is no
9 evidence to suggest that any water was there.
10 There was one report of moisture present in one
11 of the borings that was performed as part of the
12 geotechnical investigation, and the presence of just
13 someone logging a cutting as moist is not an indication
14 that there's groundwater present. Normally cuttings are
15 logged in sort of a relative fashion: very dry, dry,
16 moist, slightly moist, moderately moist, very moist,
17 saturated. And there was no indication of very moist or
18 saturated sediments in any of the boreholes.
19 In fact, that borehole that I mentioned was the
20 only one where moist sediments were actually mentioned.
21 Another boring -- I believe it was B-2 -- had report of
22 slight moisture at a zone from 6 to 14 feet, but that's
23 way above the redbeds, and we had very dry sediments
24 reported on either side of it.
25 Q So you just -- I'm sorry. Go ahead.

1 A (Mr. Peery) Also, nine of the borings were
2 left open overnight to see if any water would accumulate
3 in the borings, and none was noted.
4 Q When you talk about shallow groundwater,
5 what -- can you quantify that?
6 A (Mr. Peery) Well, I guess it's a relative
7 term, depending where you are in New Mexico, but at this
8 specific site, the shallow groundwater would normally be
9 referred to in the upper sediments, above the Chinle
10 formation.
11 Q And can you quantify the depth of that? Does
12 that vary a whole lot over the site?
13 A (Mr. Peery) It varies from around 22 feet to
14 about 55 feet, if I recall.
15 Q Uh-huh. Can you tell us exactly how the report
16 of moisture in one of the holes that you spoke of -- what
17 data was that based on?
18 A (Mr. Peery) It was based on the field
19 geologist's interpretation of the materials that came off
20 the log from a split-spoon sample.
21 Q And what drilling methods were used?
22 A (Mr. Peery) It was a hollow-stem auger.
23 Q Do you know whether the cuttings themselves
24 that came up were being logged or recorded in any way when
25 that hole was made?

1 A (Mr. Peery) I don't have firsthand knowledge
2 of that, but as a geologist who has performed logging of
3 numerous holes, you always log everything that comes up
4 the hole, whether it's a core, a split-spoon or the
5 cuttings, to verify everything you see coming out of the
6 hole.
7 Q Did you check the logs of the cuttings to see
8 if there was any mention of moisture?
9 A (Mr. Peery) The mention of moisture was for a
10 specific zone, and so I assume it's -- everything over
11 that entire zone was logged as moist, the cuttings and
12 the --
13 Q What was -- what's the name of -- the
14 designation of this hole that we're talking about?
15 A (Mr. Peery) I believe that one was B-2.
16 Q B-2. Okay.
17 A (Mr. Peery) From the geotechnical borings.
18 Q And what was the depth of the zone? What was
19 the vertical extent of the zone?
20 A (Mr. Peery) Approximately 31 to 40 feet, if I
21 recall correctly. And it's important to point out that
22 when you have a formation like the Chinle, which is
23 predominantly a shale or clay material, that you have a
24 significant amount of porosity in that material, and
25 therefore having moist samples is not an unusual thing to

1 find in the Chinle or any formation for that matter above
2 the water table in the vadose zone.
3 The fact that you have such a high porosity in
4 the fine-grain materials, it allows it to hold onto water
5 quite readily, but it doesn't allow water to move quickly
6 through that sediment or to develop necessarily a
7 saturated zone.
8 Q So the moisture, if we can call it that, was in
9 a zone of the Chinle. Is that correct?
10 A (Mr. Peery) Uh-huh.
11 Q Can you describe the -- this is sedimentary
12 rock. Is that right?
13 A (Mr. Peery) Yes.
14 Q And what's the nature of it in the zone that
15 was moist?
16 A (Mr. Peery) Nature of it's a high-density,
17 highly plastic clay.
18 Q Okay. You said that you're also going to be
19 testifying about the hydraulic properties of the
20 formations. Can you say what your conclusions are in that
21 regard?
22 A (Mr. Peery) Yes. My conclusions regarding the
23 Chinle is that it has a very low permeability based on
24 data from the nearby WC site, which is a very similar
25 hydrogeologic setting in that it has the same sediments

1 overlying the redbeds, the Chinle present, and water is
2 found at the same 220-foot zone that I described.
3 The Chinle has very low permeability. Data
4 from the WCS site reflects permeabilities on the order of
5 1 times 10 to the minus 8 or minus 9 centimeters per
6 second, which is a very low permeability. And also you
7 couple that with the fact that the borings into the
8 redbeds at the LES site are reported as very dry indicates
9 that there's very limited opportunity for water to move
10 vertically downward, in addition to the fact that the
11 permeabilities recorded at WCS indicate what the Chinle
12 would be in that regional area.
13 Q And what was your source for the information
14 about permeabilities of the WCS site?
15 A (Mr. Peery) Various reports starting, I
16 believe, with Rainwater, '93 or '96, and a recent geologic
17 report for the site.
18 Q Can you identify that any more?
19 A (Mr. Peery) I believe it was a 2003 geology
20 report for the site, but I don't remember the exact title.
21 Q And how had permeability data been obtained for
22 use in those reports?
23 A (Mr. Peery) Primarily the permeability data
24 related to the Chinle is from laboratory permeabilities,
25 and normally when you get laboratory permeabilities, the

1 way the samples are collected, you often will see some
2 increased permeability, because the sample is collected by
3 pounding a split-spoon into the sediments, so therefore
4 you can get some more damage to the material that you're
5 trying to sample, so it tends to potentially give you some
6 higher permeability readings than you might otherwise have
7 gotten.
8 Q Isn't it a fact that you could also get lower
9 permeability readings than you might get in a field test,
10 using a lab test?
11 A (Mr. Peery) I would say that's dependent on
12 the nature of the material that you're sampling.
13 Q If there were any fractures or fast-flow paths
14 in the Chinle and one used a lab sample to test
15 permeability, isn't it quite possible that you'd miss the
16 fast-flow paths with the sample you took?
17 A (Mr. Peery) The boreholes that were sampled
18 and logged, no. I would say no. You would see those as
19 you drilled down and collect your samples.
20 Q Would they be present in the -- well, strike
21 that.
22 When you're conducting a lab test, you actually
23 extract a piece of the formation, and you subject it to
24 permeability tests of that piece of rock in the lab. Is
25 that right?

1 A (Mr. Peery) Uh-huh. That's correct.

2 Q And can you tell me the size of the sample that

3 was taken for testing in the WCS site?

4 A (Mr. Peery) No, I don't recall. Normally

5 those kind of samples would be on the order of an inch-

6 and-a-half diameter split-spoons, but I don't know exactly

7 what was used.

8 Q So if there were fractures at a rate of, say,

9 five inches apart in the rock body, there's no assurance

10 that you would capture that characteristic in a sample, is

11 there?

12 A (Mr. Peery) Possibly not. I should point out

13 again, though, the fact that the Chinle sediments are

14 reported as dry to very dry is strong evidence that there

15 isn't a fast-flow fracture path there. If there were, you

16 would expect to see those sediments having quite a bit of

17 moisture in boreholes.

18 Q You said that there's no evidence of fast-flow

19 paths or fractures. And were you referring to the Chinle

20 formation --

21 A (Mr. Peery) Yes.

22 Q --when you spoke. And did you look for such

23 evidence?

24 A (Mr. Peery) Yes, I did.

25 Q And can you tell me what you did?

1 A (Mr. Peery) Well, the evidence that I did look
2 for was the logging of the moisture content, both at the
3 LES facility and at the WCS facility, and then I looked at
4 the permeability data from the WCS facility, and -- with
5 the intent that if there were very high permeabilities in
6 the lab samples, that that would indicate some sort of
7 fast-flow path fracturing or something, but I didn't see
8 any of that.
9 Q Did you --
10 A (Mr. Peery) And let me add something else.
11 Q Please.
12 A (Mr. Peery) The aquifer that I described at
13 the zone of 220 foot is -- has a very low permeability.
14 It was reported from a slug test at the LES site to have a
15 permeability or hydraulic conductivity of 3.7 times 10 to
16 the minus 6 centimeters per second, which is very low. In
17 fact, water levels recover quite slowly there, indicating
18 also that it is -- it's a poor aquifer, if you want to
19 call it that.
20 If there were fracturing in the Chinle -- and
21 the Chinle being a more clay unit than the siltstone
22 present at the 220-ish-foot depth, we would expect those
23 fractures to continue on down into the aquifer that's
24 present at 220 feet, and that would increase the
25 permeability. That aquifer would be -- it would have had

1 much higher permeabilities than what were documented from
2 field testing.
3 Q And what was the figure you gave us? Was it
4 3.7 times 10 to the minus 7?
5 A (Mr. Peery) Ten to the minus 6 centimeters --
6 Q Minus 6? Okay.
7 A (Mr. Peery) -- per second.
8 Q Okay. Why do you say you would expect the
9 fracturing to be present at depth also?
10 A (Mr. Peery) Well, it's -- geologically
11 speaking, it's very difficult to fracture an upper part of
12 a formation without some movement that fractures the lower
13 portion of the formation.
14 Q In your work for LES, did you talk to anybody
15 about how the investigation plans for the LES site had
16 been developed, and, you know, what choices had been made
17 in designing that investigation?
18 A (Mr. Peery) Before I asked them about that, I
19 reviewed the available reports, which gave a description
20 of how the investigation was designed and developed, and
21 then coupled with that, I've had some recent talk with
22 them about how it was designed.
23 Q Who did you have these discussions with?
24 A (Mr. Peery) Actually my discussions were with
25 George Harper on that.

1 Q Okay. And you say the available reports.
2 Which were those that you reviewed?
3 A (Mr. Peery) There was a preliminary subsurface
4 investigation report and then the hydrogeologic report,
5 both for the LES facility.
6 Q And who did the first one?
7 A (Mr. Peery) I don't recall.
8 Q And --
9 A (Mr. Peery) It might have been Lockwood
10 Greene, but I'm not positive.
11 Q And who did the second one?
12 A (Mr. Peery) Cook-Joyce did the second one.
13 Q And what your discussion with Mr. Harper about
14 the planning for those investigations?
15 A (Mr. Peery) Well, my discussion was that I
16 thought they took a reasonable approach to identify the
17 subsurface conditions at the site. What they did was they
18 built a grid and drilled holes on a grid, rather than just
19 sort of randomly walking around, drilling holes. They
20 actually came up with a plan and followed it to get the
21 site information.
22 And subsequent to that, when George Harper and
23 I talked, he said they came up with that plan and also
24 used Cook-Joyce because they had done so much work at the
25 nearby WCS facility and had a lot of experience with the

1 subsurface conditions in the area.

2 Q What were the dimensions of the grid?

3 A (Mr. Peery) I think the -- as I recall -- and

4 George Harper would probably be better to ask. But as I

5 recall, it was -- borings were on a three-by-three grid at

6 1,000-foot spacing. But George could probably address

7 that more accurately.

8 Q Was that accurate?

9 A (Mr. Harper) The three-by-three grid and the

10 1,000-foot spacing is approximately what I recollect.

11 Q Okay. Did you -- did it occur to you in your

12 work that there might have been some other investigations

13 carried out?

14 A (Mr. Peery) At the LES site?

15 Q Yes.

16 A (Mr. Peery) No, it did not.

17 Q Okay.

18 A (Mr. Peery) And I guess I should state my

19 reason for that.

20 Q All right.

21 A (Mr. Peery) I've done a significant amount of

22 work in Lea County related to the Lea County Regional

23 Water Plant, and during our investigation and

24 hydrogeologic study for that plant, I didn't recall any

25 activity in that area, both by my driving through the area

1 or in documents that we uncovered when we were putting
2 together our plan.
3 Q You didn't encounter any other activities?
4 That's what you're saying?
5 A (Mr. Peery) Yes. Like I didn't see anything
6 when I drove by the site, so -- there was nobody drilling
7 at the site while I was performing the Lea County plan, so
8 I didn't see anything happening there and I didn't find
9 anything in written documentation.
10 Q Well, did it occur to you that there might have
11 been certain efforts undertaken which were not?
12 MR. CURTISS: I think he's answered the
13 question no.
14 MR. LOVEJOY: Well, I think there's some
15 confusion here. He's said that he was there and nobody
16 was doing anything else.
17 THE WITNESS: (Mr. Peery) No. That's not
18 exactly what I said. I said -- you asked me if I had --
19 could you restate the question?
20 BY MR. LOVEJOY:
21 Q Well, the question is: In examining the work
22 that was done to investigate the LES site, did it occur to
23 you that there might have been certain efforts undertaken
24 which had not been undertaken?
25 A (Mr. Peery) And I said no.

1 Q Yes.

2 A (Mr. Peery) And I gave my reasons for that,
3 both visual -- having been by the site, I didn't see
4 anything happening -- and doing research for my Lea County
5 study, that didn't turn up any documentation, so, no. It
6 didn't occur to me that there would have been other work
7 done at the site.

8 Q Okay. Well, as a scientist, did it occur to
9 you that there might have been some efforts undertaken
10 which were not undertaken, that would have made the
11 investigation better?

12 A (Mr. Peery) Could you --

13 Q Is my question clear now?

14 A (Mr. Peery) No. It's not clear to me. I'm
15 sorry.

16 Q Okay. Well, did it occur to you, as you
17 examined the work done at the site, that there might have
18 been some different or additional drilling done, that
19 might have satisfied you more about knowledge of the
20 subsurface?

21 A (Mr. Peery) Well, I'm sort of at a little bit
22 of a loss for your question. I'm not sure if you're
23 asking whether or not I think that there was data
24 performed that I didn't evaluate or if --

25 Q No.

1 A (Mr. Peery) -- I would have evaluated it
2 differently.
3 Q I'm asking if you might have evaluated it
4 differently, if you were there to design the exploration.
5 MR. CURTISS: Let me just clarify the question.
6 I think the witness has said that in reviewing the
7 information that was adduced from the investigation, he
8 indicated that provided an adequate basis for the
9 characterization of the site. And if the question is,
10 Should more have been done, I would advert to his answer
11 to your earlier question, that the information that was
12 performed was adequate.
13 BY MR. LOVEJOY:
14 Q So let me just ask you. Did anything occur to
15 you that you think should have been done which was not
16 done?
17 A (Mr. Peery) No. And, in fact, when I started
18 my testimony, I said I thought the investigation was
19 formed in an adequate way and would generally be
20 considered industry standard for performing a site
21 investigation.
22 Q Okay. Did you consider at all whether there
23 might have some slant drilling done at the site?
24 A (Mr. Peery) No. That's not generally industry
25 standard for site investigations.

1 Q Why do you -- what's the basis for that
2 statement, that it's not industry standard?
3 A (Mr. Peery) The basis for that is, I guess, my
4 experience as a hydrogeologist over the last 16 years.
5 It's very unusual to perform any sort of slant drilling on
6 sites. Most everything is done by vertical drilling,
7 whether it's for leaky gas station sites, sites associated
8 with contamination in mining industries that I've been
9 involved with, and just about every environmental project
10 I've been involved with was only done vertical boreholes
11 in wells.
12 Q Has most of the work that you've had experience
13 with involved identifying the extent of contamination that
14 has taken place?
15 A (Mr. Peery) No. Some of my work has been
16 going to sites to see if there is contamination first, and
17 if there is, then to develop a program to define the
18 extent and nature of that contamination.
19 Q Did it occur to you that efforts might have
20 been undertaken to identify the age of any of the
21 groundwater found at the LES site?
22 A (Mr. Peery) No, I didn't. That's generally
23 not an activity that's undertaken, and I'm not sure
24 specifically what groundwater you're referring to.
25 Q But it didn't occur to you with respect to any

1 of it.

2 A (Mr. Peery) Well, what I did is I evaluated

3 the water quality data for the deep aquifer at 220 feet,

4 and the total dissolved solids concentration of that water

5 exceeds 6,000 milligrams per liter, which indicates it's

6 not a particularly young water. In order for water to get

7 that concentration of total dissolved solids, it has to

8 spend a fair amount of time in the aquifer in order to

9 dissolve the minerals into the water, so it indicates a

10 pretty slow movement through the aquifer and a long

11 residence time, so it didn't seem to me reasonable to try

12 to do any age-dating of a water of that nature.

13 Q How old was that water?

14 A (Mr. Peery) I don't know how old it is, but it

15 has to be -- I mean, it is not recent. It's old water.

16 Geologically speaking, it's a hard thing to quantify, but

17 it is --

18 Q Can you tell us what you mean when you say it's

19 old water?

20 A (Mr. Peery) Oh, tens of thousands of years or

21 more.

22 Q Did you examine, in your work for LES, the

23 plans for construction of the facility?

24 A (Mr. Peery) No. Some of the documentation was

25 provided to me, but that's outside my area of expertise.

1 Q So you didn't look at the sewage system or the
2 various discharge lagoons that were planned to be
3 constructed.
4 A (Mr. Peery) I know where they are physically
5 on the map and have read about the discharge of the septic
6 and the stormwater detention lagoon and the UBC and the
7 TEEB basins, but in regards to looking at actual design of
8 facility, I didn't look at it in that manner.
9 Q And you didn't involve yourself in trying to
10 estimate where water might go if it entered those basins?
11 That was outside your assignment?
12 A (Mr. Peery) Not exactly. I did look at the
13 basins, just in regard to particularly the unlined basin
14 and what might happen with that. But the lining of basins
15 and calculating anything that could potentially happen
16 through basins is outside -- lined basins is outside my
17 area of expertise.
18 Q Okay. What work did you do with respect to the
19 unlined basin?
20 A (Mr. Peery) I just looked at it in terms of
21 what kind of water it would receive.
22 Q The quantity? Quality? What were you looking
23 at?
24 A (Mr. Peery) Just where the run-off was coming
25 from.

1 Q Did you seek to quantify the amount that might
2 enter that basin?
3 A (Mr. Peery) No. It was included in the
4 reports. I didn't try to quantify --
5 Q It was in the data you had?
6 A (Mr. Peery) Uh-huh.
7 Q Well, did you try to project where that water
8 might end up if it entered that basin?
9 A (Mr. Peery) I didn't do any calculations on
10 that. The sight hydrogeology would indicate that the
11 water from an unlined basin would just have to move out
12 into the alluvial sediments, if you will, and there
13 wouldn't really be an opportunity for it to migrate the
14 Chinle and contaminate anything else because of the low
15 permeabilities at the site. But I didn't attempt to look
16 at where the water might end up in terms of its horizontal
17 extent.
18 And one of the primary reasons is evaporation
19 rates. Evapo-transpiration rates are so high in this
20 area, they're on the order of about 65 inches per year, so
21 even water that infiltrates into the shallow alluvium has
22 a relatively limited opportunity to migrate, as a lot of
23 it just gets lost.
24 Q When you talk about the low permeabilities at
25 the site, what bodies -- what rock bodies are you

1 referring to?

2 A (Mr. Peery) I'm referring to the Chinle.

3 Q Okay.

4 A (Mr. Peery) Well, and I guess the water zone

5 at 220 feet is low permeable.

6 Q You speak of the alluvium. What is the -- how

7 far down does the alluvium go at this site?

8 A (Mr. Peery) I addressed that earlier. As I

9 recall, I said from approximately 20 to 55 feet, which is

10 actually a combination of the younger sediments, whether

11 it's the Blackwater Draw eolian sediments, Ogallala

12 sediments, but all the younger sediments sitting on top of

13 the Chinle.

14 Q So this may be more in Mr. Harper's domain,

15 but, please, if you know the answer, go right ahead. How

16 many septic leach fields are there planned to be in the

17 plant at present?

18 A (Mr. Harper) Right now we're planning on six

19 systems.

20 Q Okay. And what is the volume of water that's

21 going to go into these septic systems?

22 A (Mr. Harper) It's approximately 5,300 gallons

23 per day.

24 Q And after it's discharged, where is this going

25 to end up? Have you made any calculations?

1 A (Mr. Harper) The only thing we've looked at is
2 that the -- that amount of water going into the basins per
3 day is -- I'm sorry -- into the leach fields per day is
4 only a very small fraction of the annual rainfall that the
5 site presently sees.
6 Therefore, it's just a minuscule additional
7 amount of water, what the site sees from rainfall today,
8 and therefore, right now all the infiltration at the site
9 is essentially taken up by evapo-transpiration. Therefore
10 I would assume the same to be the case for the discharge
11 from the leach fields.
12 Q And beyond that, you've made no calculations of
13 the fate of the water from the leach fields. Is that
14 right?
15 A (Mr. Harper) Correct.
16 Q Now, with respect to the unlined basin, the
17 stormwater basin, what's the quantity of water? That's a
18 little hard to predict, but have you assigned a quantity
19 of water flowing into that basin?
20 A (Mr. Harper) We have, and that information is
21 in the environmental report and the State of New Mexico
22 groundwater discharge permit.
23 Q And have you made any calculations of the fate
24 of that water?
25 A (Mr. Harper) Yes, we have.

1 Q And where are they reflected?

2 A (Mr. Harper) We did a water balance -- annual

3 water balance for the basins that's summarized in one of

4 the RAI responses to the -- one of the NRC questions on

5 the ER.

6 Q And do you recall now where it was projected

7 that the water to that basin would go?

8 A (Mr. Harper) Yes. Our -- for the purpose of

9 the analysis for the water balance and not having the

10 detailed design of the basin available, we assumed that

11 for the water balance calculations, 50 percent infiltrated

12 and that 50 -- approximately 50 percent infiltrated and

13 approximately 50 percent evaporated. And of the amount

14 that infiltrated, it essentially would all go back up

15 through evapo-transpiration.

16 Q What depth would it reach?

17 A (Mr. Harper) We -- I --

18 Q You didn't project it?

19 A (Mr. Harper) -- did not project that.

20 Q So your conclusion was that all of it would

21 ultimately go up through plant matter and evaporation

22 and --

23 A (Mr. Harper) Correct. Yes.

24 Q Okay. Did you undertake to make measurements

25 of a projected plume associated with the unlined basin?

1 A (Mr. Harper) No, we did not.
2 Q Okay. Now, there are two basins that are
3 planned for the plant that would have a liner. Is that
4 right?
5 A (Mr. Harper) Correct.
6 Q And one of them -- what is it? It's the TEEB.
7 A (Mr. Harper) Correct.
8 Q And that's the Treated Effluent Evaporation
9 Basin. Is that right?
10 A (Mr. Harper) Very good.
11 Q Okay. I'm learning. And the other one is the
12 UBC basin. Is that right?
13 A (Mr. Harper) The UBC stormwater --
14 Q UBC stormwater basin.
15 A (Mr. Harper) Retention basin.
16 Q Okay. Now, with respect to the TEEB, have you
17 made any projections of water going out of that and into
18 the soil and subsurface?
19 A (Mr. Harper) We have these -- the design of
20 that basin is such as to contain all the water within the
21 basin through the double-lined system with an intermediate
22 leak detection and collection system.
23 Q Uh-huh. So is the answer that you've not made
24 any calculations involving water leaking from that basin?
25 A (Mr. Harper) Correct.

1 Q All right. Okay. Where is the most recent
2 design for that basin recorded? Where is it written down?
3 A (Mr. Harper) It would be in the Lockwood
4 Greene documents for the basin, and also it is summarized
5 in the groundwater discharge permit plant application that
6 LES filed with the State of New Mexico. And the
7 information in there draws upon the Lockwood Greene
8 documents.
9 Q Okay. Can you describe the liners, liner or
10 liners that are associated with the TEEB under the current
11 plan.
12 A (Mr. Harper) Under the current plan they're
13 synthetic membranes, and we've given an example is the
14 groundwater permit of either HDPE or another brand name
15 that I'd have to look in the report. But it's mentioned
16 both in the ER and in the groundwater discharge permit.
17 Q Uh-huh. And what are the other elements of the
18 containment system for the TEEB? Is there a clay liner?
19 Can you describe the various layers?
20 A (Mr. Harper) From the bottom up, there
21 would --
22 Q Yes.
23 A (Mr. Harper) -- a minimum two-foot layer of
24 clay, and the bottom liner will then sit on top of the
25 clay. And then between -- and then above that liner,

1 there is a membrane and a series of pipes to collect any
2 leakage through the upper membrane, which would rest on
3 top of that leak collection system. And there's a minimum
4 one foot of clay layer on top of the upper liner for UV
5 protection and to protect it from inadvertent punctures.
6 Q Now, the -- you spoke of pipes. What's the
7 matrix in which it is planned to in-place these pipes?
8 A (Mr. Harper) That has not been detailed as I
9 know.
10 Q Uh-huh. Is there any system planned which
11 would alert you of the fact that there was leakage of the
12 upper liner?
13 A (Mr. Harper) Yes. That's described in the
14 groundwater permit application. The leak collection
15 system will be routed to a sump, and the sump will have
16 level monitoring, which would then alert the control room.
17 Q Uh-huh. Have you undertaken any effort to
18 project the performance of this liner system for the TEEB?
19 A (Mr. Harper) We have made certain commitments
20 that the liner material, when selected, per the vendor
21 information will have a life, a projected life, you know,
22 commensurate with the projection for the facility and that
23 it will meet the minimum thickness requirements from the
24 NMED guidelines and will be engineered and designed and
25 installed in accordance with NMED guidelines.

1 Q Which guidelines are those?

2 A (Mr. Harper) They're referenced in the

3 groundwater discharge permit. They're guidelines for

4 liners for the basins.

5 Q Okay. And what is the -- you said the vendor

6 will project the life commensurate with plant life. And

7 what is that life you're talking about?

8 A (Mr. Harper) The operational period of the

9 facility is approximately 30 years.

10 Q Okay. And what year do you expect that the

11 liner will be installed?

12 A (Mr. Harper) The liners will be installed

13 prior to operation, so I would therefore -- based on the

14 current schedule, I believe that would be sometime in

15 2008.

16 Q That it would be installed in 2008 or sometime

17 before 2008?

18 A (Mr. Harper) Sometime prior to start-up.

19 Q Okay. Do you know when?

20 A (Mr. Harper) I believe the projected start-up

21 date right now for the facility is sometime in 2008.

22 Q Okay. But what's the projected date for

23 installing liners?

24 A (Mr. Harper) Well, the liners would need to be

25 installed prior to receiving liquid effluent. I don't --

1 you know, again they haven't been designed or scheduled
2 yet, so I can't tell you when -- actually when the liners
3 will be installed.
4 Q Okay. And what is the projected date for
5 closure of the facility?
6 A (Mr. Harper) Closure of the facility would be,
7 as I stated, approximately -- the facility is projected to
8 operate for approximately 30 years from initial start-up.
9 Q So does that mean the closure date is projected
10 to be 30 years after start-up? Or is it longer?
11 A (Mr. Harper) I believe it would be
12 approximately 30 years.
13 Q Okay. And that would make it what year?
14 A (Mr. Harper) Sometime around the year 2038.
15 Q Do you know how long it would take to close the
16 facility?
17 A (Mr. Harper) My recollection from the
18 information in the ER is the decommissioning period is
19 approximately scheduled to occur over nine years.
20 Q Okay.
21 A (Mr. Harper) But the decommissioning is phased
22 in where they're decommissioning some of the units while
23 they're still operating other units. So the overall
24 decommissioning phase is approximately nine years.
25 Q Do you know when the TEEB would be closed?

1 A (Mr. Harper) It would be closed when it would
2 no longer be needed.
3 Q And would that be when no part of the plant is
4 operating?
5 A (Mr. Harper) When it is no longer required for
6 either operation or to support decommissioning.
7 Q Okay. Well, do you know if that would be at
8 the beginning of the nine-year period or at the end or at
9 some other point, or don't you know?
10 A (Mr. Harper) It would be at some point during
11 the nine-year period.
12 Q Can you describe the process of closing the
13 TEEB?
14 A (Mr. Harper) The process for closing the TEEB
15 is outlined in the groundwater discharge permit
16 application.
17 Q And just briefly, what do you when you close,
18 the TEEB?
19 A (Mr. Harper) The plan for closure, for
20 decommissioning is to -- first we will sample the soil,
21 the uppermost soil on top of the liner, segregating any of
22 it that is contaminated, and dispose of it properly.
23 MR. CURTISS: May I consult with the witness?
24 (Witness and attorney conferring.)
25 THE WITNESS: (Mr. Harper) I would like to

1 clarify a previous statement. The nine-year period for
2 decommissioning --
3 BY MR. LOVEJOY:
4 Q Yes. Go ahead.
5 A (Mr. Harper) -- falls within the 30-year
6 period of -- that I gave for the operation of the plant.
7 Q Are you saying that the closure process is
8 planned to commence 21 years after operations begin?
9 A (Mr. Harper) No. I said the closure process
10 for the TEEB would commence when it is no longer needed to
11 support decommissioning.
12 Q Okay. Well, can you put a number on it as you
13 understand the plan?
14 A (Mr. Harper) I have not reviewed the
15 decommissioning schedule in detail to provide that --
16 MR. CURTISS: I think, Lindsay, here, just to
17 clarify for the witness's benefit and for yours, the
18 question that you're raising -- and I don't have an
19 objection, but just to clarify for the record -- is
20 whether the liners will last during the period that
21 they're going to be used, and I think the witness has
22 testified that the liners, in accordance with the
23 discussions that have taken place will last the 30-year
24 period and that the decommissioning of the plant will
25 occur within that 30-year period.

1 If there's some additional question relative to
2 the liners here, which is the subject of this contention,
3 and whether they will, in fact, last the period of concern
4 that you're articulating here, I think he's in a position
5 to answer that, but he's not a witness that's qualified to
6 answer questions about the details of decommissioning the
7 plant, what's going to occur when.
8 MR. LOVEJOY: Well, I don't need the details of
9 decommissioning, but the schedule is important if you're
10 talking about projecting the life of some liners, so
11 that's what I want to go to.
12 BY MR. LOVEJOY:
13 Q You don't know whether the decommissioning
14 phase is going to be -- whether decommission -- well,
15 strike that. Let me say this.
16 Is decommissioning going to be completed by the
17 end of the 30-year period, as you understand it?
18 A (Mr. Harper) I believe LES is applying for a
19 30-year license, which is from -- covers the period from
20 when nuclear material arrives on site until they finish
21 decommissioning.
22 Q Okay. You were outlining in a general form
23 what the process is to close the TEEB.
24 A (Mr. Harper) Right.
25 Q Would you complete your testimony on that?

1 A (Mr. Harper) I think I completed the sampling,
2 disposal of the one-foot clay layer above the upper liner.
3 Q Uh-huh.
4 A (Mr. Harper) The primary or uppermost liner
5 would then be sampled for potential contamination and
6 disposed of accordingly as low-level waste or, if
7 releasable, it would be disposed of as -- in an ordinary
8 landfill.
9 We will then proceed to sample the leak
10 detection components and likewise dispose of them
11 accordingly. In similar fashion, sample and dispose of
12 the lower liner as applicable. And then we've committed
13 to test the clay layer under the bottom liner.
14 Q In closing the TEEB, what would be done with
15 any liquid contained in it?
16 A (Mr. Harper) It would all be evaporated prior
17 to.
18 Q Okay. Have you investigated the availability
19 of material with a projected life commensurate with the
20 life of the plant?
21 A (Mr. Harper) I have not.
22 Q Well, has anyone undertaking the design effort
23 for LES investigated that?
24 A (Mr. Harper) Lockwood Greene has done the
25 design of record for the TEEB.

1 Q Okay. Do you know whether they've investigated
2 the availability of material with a design life
3 commensurate with the life of the plant?
4 A (Mr. Harper) My understanding is they have
5 performed an assessment and discussed with certain
6 vendors, and the design reflects being able to locate
7 material that will last the design life of the facility.
8 Q What have you heard about availability of
9 material commensurate with the projected life --
10 commensurate with the life of the plant?
11 A (Mr. Harper) We have not picked up -- since
12 there was no material, you know, the actual liner has not
13 been specified, so I don't know anything more about it
14 than what I have just stated.
15 Q Well, has anyone from Lockwood Greene come to
16 you and said, Well, we've located four or five people that
17 can supply with the liner we --
18 A (Mr. Harper) You mean, actually to the point
19 of a vendor?
20 Q Yes.
21 A (Mr. Harper) I have not had those discussions
22 with Lockwood Greene.
23 Q Do you know if anyone has attempted to project
24 the probability of leak in either the upper or the lower
25 liner of the TEEB?

1 A (Mr. Harper) No. I'm not aware of that.
2 Q Okay. The other lined basin in the current
3 plant is the UBC storage --
4 A (Mr. Harper) Storage pad stormwater.
5 Q Stormwater storage basin.
6 A (Mr. Harper) Retention basin.
7 Q Okay. And the plan is for that to have a
8 single liner. Is that correct?
9 A (Mr. Harper) Correct.
10 Q And where is the latest plan for that basin and
11 its liner laid out?
12 A (Mr. Harper) In Lockwood Greene documents.
13 Q And do you know whether those documents were
14 produced to us in this litigation?
15 A (Mr. Harper) I cannot remember without seeing
16 them. I'd have to review the list again.
17 Q Okay. Is the plan as contained in those
18 documents also in the groundwater discharge permit
19 application?
20 A (Mr. Harper) Features of it are.
21 Q What features? What part's in that application
22 and what part's not?
23 A (Mr. Harper) Well, the Lockwood -- we have
24 provided a -- you know, a synopsis of the design in the
25 groundwater permit, but it's not to the same level

1 potentially that's in the Lockwood Greene documents.

2 Q Okay. With respect to the UBC basin, has any

3 effort been undertaken to estimate where water would go or

4 water and contaminants therein, if there were a leak in

5 that basin?

6 A (Mr. Harper) No.

7 Q Can you describe from your memory what the

8 current plan is with respect to the liner of that basin?

9 A (Mr. Harper) It's a single-lined basin, and

10 the liner would be placed on suitable material, and then

11 similar to the TEEB, would have a soil cover for UV

12 protection.

13 Q When you say, suitable material, can you

14 elaborate?

15 A (Mr. Harper) The information in the

16 groundwater discharge permit reflects a clay-like material

17 obtainable on site or nearby.

18 Q And with respect to the liner of that basin,

19 what is the expected life of that liner?

20 A (Mr. Harper) It would be similar to my

21 previous testimony for the TEEB. It will be selected to

22 last the operational life of the UBC.

23 Q What's the operational life of the UBC basin?

24 A (Mr. Harper) Well, similar to the TEEB, it

25 will need to be initial operation sometime prior to start-

1 up, and I have -- and it would need to function throughout
2 the operational life of the plant.
3 Q Do you know anything about any warranties that
4 manufacturers of liner material might offer for these
5 basins?
6 A (Mr. Harper) There's information. I believe
7 it's either in the groundwater discharge permit or the
8 environmental report, but it attests to the fact that the
9 liner would be installed in accordance with all the
10 manufacturer's recommendations so as not to void any
11 manufacturer warranties.
12 Q Okay. But do you know what kind of warranties
13 such manufacturers offer?
14 A (Mr. Harper) No, I do not.
15 Q Has any effort been made to estimate the
16 qualities of the water present in either of these basins,
17 the TEEB or the UBC basin?
18 A (Mr. Harper) Yes, there has.
19 Q Okay. Can you describe what that work has
20 involved?
21 A (Mr. Harper) That information is provided in
22 both the ER and in the groundwater discharge permit plan
23 application.
24 Q And were you involved in that effort?
25 A (Mr. Harper) To some extent.

1 Q Beyond what's reported in those two
2 applications, has there been any effort to estimate the
3 quality of that water?
4 A (Mr. Harper) Not to my knowledge.
5 Q Okay. You said that you were also here to
6 testify about the constituents in UF_6 feed material. What
7 facts or opinions are you here to give us about that?
8 A (Mr. Harper) The UF_6 feed material for the
9 plant will contain only natural UF_6 and any daughter
10 products of uranium.
11 Q Now, how do you know that?
12 A (Mr. Harper) Based on the -- I've been working
13 on the project for several years now, and that's just
14 information that I have picked up throughout my
15 involvement with the project.
16 Q Okay. Where is the feed material going to
17 arrive from?
18 A (Mr. Harper) The feed material arrive --
19 that's described in the environmental report.
20 Q Do you remember where, what plants it's coming
21 from?
22 A (Mr. Harper) Off the top of my head, no.
23 Q Okay. Well, how do you know that it's only
24 going to contain natural UF_6? Do you remember some
25 reports about the constituents in the feed, or are there

1 some documents? What's the basis for your statement?
2 A (Mr. Harper) It's based on information that I
3 believe is documented in the environmental report.
4 Q Okay. And beyond that you don't recall?
5 A (Mr. Harper) Not off the top of my head.
6 Q All right.
7 MR. LOVEJOY: Okay. We can take a short break
8 now if you'd like.
9 MR. CURTISS: That would be fine.
10 (Whereupon, a short recess was taken.)
11 THE WITNESS: (Mr. Harper) I would like to
12 supplement my last -- one of my earlier responses.
13 BY MR. LOVEJOY:
14 Q Yes.
15 A (Mr. Harper) In regards to the UF_6 feed, the
16 UF_6 as described in the license application, the site will
17 not accept any feed material that is not ASTM certified as
18 natural uranium, natural uranium hexafluoride.
19 Q Okay. Thanks. How does feed material achieve
20 an ASTM certification?
21 A (Mr. Harper) That is outside my area of
22 expertise.
23 Q Has any estimation been made of the
24 contaminants that would be present or could be present in
25 the unlined stormwater basin or in the sewage leach

1 fields?

2 A (Mr. Harper) In the ER and, I believe, in the

3 groundwater discharge permit, we make note that the in-

4 flow to the unlined stormwater basin would be typical of

5 an industrial site, would receive run-off from roofs,

6 paved areas, and areas in the immediate vicinity around

7 the buildings, and that it would contain -- potentially

8 contain some oil and grease that one would typically see

9 from parking lot areas. There are no process activities

10 that occur in the drainage area to that basin. There's no

11 chemical process activity in that area.

12 Q And --

13 A (Mr. Harper) Other than inside the buildings,

14 so --

15 Q Are you saying that the areas inside the

16 buildings would not be drained to the basis?

17 A (Mr. Harper) Correct.

18 Q Okay.

19 A (Mr. Harper) Only the roofs.

20 Q Now, with respect to the septic systems, what

21 contaminants are projected?

22 A (Mr. Harper) The design calls for only

23 domestic sewage, domestic waste going to the septic

24 system, essentially toilets.

25 Q Okay.

1 A (Mr. Harper) And we have made a statement in
2 the ER that it would be just typical of that type of
3 normal sanitary waste.
4 Q Would there be any showers drained to the
5 septic systems?
6 A (Mr. Harper) Showers and hand-wash all goes to
7 the Treated Effluent Evaporative Basin.
8 Q In the plant, are there planned to be specific
9 decontamination rooms in case of inadvertent contamination
10 of somebody?
11 A (Mr. Harper) I have not reviewed that portion
12 of the application recently. I can't recall. I would
13 assume so, but I can't recall, other than to make note
14 again that only sanitary wastes are going to the septic
15 system.
16 Q Okay. Let me ask -- and this may be for you,
17 Mr. Peery. Have any tests been done on the hydraulic
18 properties of rock bodies above the Chinle?
19 A (Mr. Peery) No, they have not.
20 Q And there have been some tests of hydraulic
21 properties of the Chinle. Is that correct?
22 A (Mr. Peery) Yes.
23 Q And how many holes have been tested?
24 A (Mr. Peery) Oh, the hydraulic properties of
25 the Chinle? That data comes from the nearby WCS site, and

1 I don't know exactly how many holes have been drilled over
2 there, but I think it's over 200.
3 Q So on the LES site, there've been no tests of
4 hydraulic properties of the Chinle?
5 A (Mr. Peery) Not of the Chinle above the 220-
6 foot aquifer zone. Now, that siltstone at 220, 230 foot,
7 has had a test on Monitor Well 2 for hydraulic properties.
8 Q Okay. What tests were done? Do you remember?
9 A (Mr. Peery) On the LES site?
10 Q Yes.
11 A (Mr. Peery) It was a rising-head slug test, an
12 MW-2.
13 Q Just that one test?
14 A (Mr. Peery) Yes.
15 Q Can you describe that test?
16 A (Mr. Peery) A rising-head slug test
17 essentially is where a volume of water or an object placed
18 in the water is displaced from the water column, which
19 causes the water column in the well to drop down, and then
20 you monitor the subsequent rise of the water level until
21 it gets back to a higher point, essentially where you
22 started the test at.
23 Q You measure the time of it. Is that correct?
24 A (Mr. Peery) Yes. The change in elevation of
25 the water or depths of water versus time.

1 Q Do you have any understanding yourself of where
2 the water in MW-2 came from?
3 A (Mr. Peery) Yes. It comes from the siltstone
4 at the 200 to 230-ish nomaly zone.
5 Q And where did it come from to get into the
6 siltstone?
7 A (Mr. Peery) Oh, it -- you're -- I'm sorry.
8 Where did it come from? Where did that aquifer water
9 develop?
10 Q Yes.
11 A (Mr. Peery) Recharge water over time, and the
12 nearest recharge area is many tens of miles east -- west
13 of this location.
14 Q Where is that recharge area?
15 A (Mr. Peery) It's towards the -- I can't tell
16 you specifically, but it's towards the boundary of Eddy
17 and Lea County.
18 Q How do you know that that's a recharge area?
19 A (Mr. Peery) The -- with very low
20 permeabilities overlying that zone, recharge is not from
21 water falling directly, either -- you know, water directly
22 overlying that aquifer, so the recharge areas have to be
23 where that aquifer is closer to the ground surface.
24 Q All right. And you've identified an area. Are
25 you saying that you're aware that the -- this aquifer is

1 closer to the ground surface at a point near the Eddy
2 County boundary?
3 A (Mr. Peery) I would have to verify the depth
4 to the aquifer in that area. And, in fact, some of the
5 water in that aquifer is probably quite ancient water that
6 has not recharged in, as I said, a very, very long time.
7 Q Uh-huh. Okay. Did you see a report of a
8 pesticide being detected in MW-2?
9 A (Mr. Peery) Yes, I did.
10 Q And did you reach any conclusion about that?
11 A (Mr. Peery) Yes, I did.
12 Q What's your conclusion?
13 A (Mr. Peery) My conclusion is that the
14 contamination identified in that sample was probably a
15 result of something introduced either during drilling or
16 possibly a laboratory error, and that is based on
17 subsequent samples not having any contamination in them.
18 Q Well, do you know anything about the history of
19 the sample that contained a pesticide that leads you to
20 think it became inadvertently contaminated, either in the
21 lab or at this site?
22 A (Mr. Peery) Could you restate that question,
23 please?
24 Q Well, do you know anything about how that
25 sample was taken, the first one -- was it the first one in

1 MW-2 that showed --

2 A (Mr. Peery) Yes, it was.

3 Q -- pesticide? Do you know anything about how

4 that sample was taken that would lead you to think it was

5 contaminated inadvertently by a pesticide?

6 A (Mr. Peery) No. I don't know how -- exactly

7 how the sample was collected.

8 Q But you've rejected that as an accurate sample.

9 A (Mr. Peery) Yes.

10 Q And you've rejected it because two later

11 samples showed no pesticide.

12 A (Mr. Peery) Correct.

13 Q And there's no other basis for your rejection.

14 A (Mr. Peery) The other basis for the rejection

15 would be the potential source for a pesticide to be in

16 that lower aquifer that isn't being recharged from

17 anywhere in the immediate vicinity. There's no mechanism

18 to get a pesticide into the aquifer there.

19 Q So you rejected the possibility that there was

20 a mechanism to get the pesticide into the aquifer.

21 A (Mr. Peery) After the subsequent samples came

22 back clean.

23 Q I believe there's a statement in the

24 environmental report -- we can find it if we need to --

25 that the water in the Santa Rosa Aquifer is not potable.

1 Is that -- are you aware of that?

2 A (Mr. Peery) Yes, I am.

3 Q Do you agree with that?

4 A (Mr. Peery) Yes, I do. Yes.

5 Q Can you explain why that's so in your mind?

6 A (Mr. Peery) The total dissolved-solids

7 concentration of water produced from the Santa Rosa

8 Aquifer is above the drinking water standard.

9 Q And what standard is that?

10 A (Mr. Peery) The EPA drinking water standard.

11 Q And what's -- can you quantify it?

12 A (Mr. Peery) It's 500 milligrams per liter with

13 a cap of 1,000. It's an aesthetic standard.

14 Q A cap of 1,000?

15 A (Mr. Peery) Yes. It's 500 to 1,000.

16 Q Okay. And what is the depth of the water in

17 the Santa Rosa Aquifer underneath the LES site?

18 A (Mr. Peery) It would be approximately 1,100

19 feet.

20 Q Do you know the speed at which water is

21 traveling in that aquifer?

22 A (Mr. Peery) No.

23 Q Do you know where that water is going to emerge

24 on the surface, if anywhere?

25 A (Mr. Peery) No, I don't.

1 Q Do you know if that aquifer is pumped anywhere
2 downstream from the LES site?
3 A (Mr. Peery) I believe that -- downstream?
4 Q Down gradient.
5 A (Mr. Peery) Yes. I don't know of wells
6 specifically completed in there. There may be some
7 domestic or windmill wells, but I don't know of any that
8 are specifically completed in there, that I can recall.
9 Q Do you know if that aquifer is used for stock
10 watering, the down gradient?
11 A (Mr. Peery) It likely is. If wells are,
12 indeed, completed in it, it would likely be for stock
13 watering, because of the low yield of the well, of the
14 aquifer.
15 MR. LOVEJOY: Let's pass out one for each
16 lawyer and one for the witnesses. I guess the panel only
17 gets one, because there has to be one exhibit.
18 We should mark this Exhibit 3. We should mark
19 the official exhibit. I'm sorry. There's a process we
20 need to follow.
21 (The document referred to was
22 marked for identification as
23 Exhibit NIRS-HP 3.)
24 BY MR. LOVEJOY:
25 Q Would you please take a look at Exhibit 3.

1 MR. LOVEJOY: We can give each witness a copy,
2 but we really need to have one official exhibit.
3 BY MR. LOVEJOY:
4 Q Has either one of you seen this document
5 before?
6 A (Mr. Harper) I have.
7 Q You have? Mr. Peery, have you?
8 A (Mr. Peery) I have not reviewed this document.
9 Q Okay. Mr. Harper, did you see this at or about
10 the date it has, which is August 5 of '03?
11 A (Mr. Harper) Yes, I did.
12 Q And what was the purpose of this document?
13 A (Mr. Harper) I haven't looked at it in a
14 while, so --
15 Q Okay.
16 A (Mr. Harper) -- if you'll give me a minute
17 here. (Perusing document.) I think it's clearly stated
18 in the purpose of the document on page 1.
19 Q Okay. What language are you referring to?
20 A (Mr. Harper) "The objective of the study is to
21 evaluate and present potential options for treatment of
22 the low-level waste generated through the normal
23 operations of the NEF to remove uranium."
24 Q Okay. There's a reference right after that,
25 under Purpose, to new MCL requirements for uranium in

1 drinking water under EPA standards. Do you see that?
2 A (Mr. Harper) Yes.
3 Q Do you know whether the NEF as planned would
4 comply with those standards now, as now planned?
5 A (Mr. Harper) I'd have to go back and review
6 the report. I haven't read the report in over a year.
7 Q Uh-huh. The page that has the stamped number
8 LES-905 has a signature on it. Can you read that?
9 A (Mr. Harper) Yes, I can.
10 Q Whose signature is that?
11 A (Mr. Harper) Based on the initials and the
12 signature, I believe it is John Shaw.
13 Q And does he work for Lockwood Greene?
14 A (Mr. Harper) Yes, he does.
15 Q Where are they based, Lockwood Greene?
16 A (Mr. Harper) They're based out of Spartanburg,
17 South Carolina.
18 Q Was the work done, that Lockwood Greene did for
19 LES in connection with the NEF, to your knowledge, done at
20 the Spartanburg location?
21 A (Mr. Harper) That was their principal office
22 for this job. Yes.
23 Q What was Mr. Shaw's -- what is his expertise?
24 Do you know? What is his training?
25 A (Mr. Harper) I do not know, other than the

1 fact I know he's a trained engineer.

2 Q Okay. Over on page LES-909, under the caption,

3 Unlined Basin, the second paragraph has certain language

4 in it. I'll read it to you.

5 It says, "There are two major factors

6 considered for this decision" -- referring to the unlined

7 basin. "First, for an unlined basin, the uranium will

8 permeate into the soil. At the end of the life of the

9 plant, the contaminated soil will have to be disposed of.

10 The depth to which the uranium will permeate into the soil

11 is difficult, if not impossible, to calculate at this

12 time."

13 Do you agree with that statement?

14 A (Mr. Harper) At the time this report was

15 written, I don't believe there was sufficient design

16 detail available.

17 Q I see. So at the time it was true.

18 A (Mr. Harper) Yes. I believe it was a true

19 statement at the time.

20 Q Okay. And what work was done since this report

21 was prepared on the question addressed there?

22 A (Mr. Harper) Explicitly on estimating the

23 depth of --

24 Q The depth to which the uranium will penetrate

25 into the soil.

1 A (Mr. Harper) I'm not aware of any additional
2 work that was done in this area.
3 Q Okay.
4 MR. LOVEJOY: This will be Exhibit 4. Here's
5 another copy.
6 (The document referred to was
7 marked for identification as
8 Exhibit NIRS-HP 4.)
9 BY MR. LOVEJOY:
10 Q Would you, both witnesses, please take a look
11 at Exhibit 4 and state whether you've seen this one
12 before, either of you.
13 A (Mr. Peery) I don't recall reviewing that
14 report.
15 Q Okay. Mr. Harper, have you seen this?
16 A (Mr. Harper) I have most likely seen this
17 report.
18 Q Okay. Can you tell from any of the marks on
19 this whether it came your way at or about the date it was
20 produced?
21 A (Mr. Harper) Well, I'm not listed on the
22 distribution list there, but it did come to -- it was
23 copied to Framatome, and it's quite likely that I did
24 review this. Thus, they sent it as a --
25 Q Okay. Over on page 5, under, Lined Basin,

1 there's some text I want to ask you about, the first
2 paragraph there. You can --
3 A (Mr. Harper) Page 5?
4 Q Page 5. It's LES-928. Under Lined Basin, it
5 says, "The basin should be double-lined. The liner could
6 consist of a layer of clay and a HDPE" --
7 A (Mr. Harper) Could you stop? Where are yo
8 now?
9 Q Under 2.3.2.3 --
10 A (Mr. Harper) Okay.
11 Q -- Lined Basin.
12 A (Mr. Harper) Yes.
13 Q "The basin should be double-lined. The liner
14 could consist of a layer of clay and a HDPE liner on top
15 or two layers of HDPE. Basin design will be done after
16 all geological information is obtained. The liner type
17 and design may be contingent on whether or not the State
18 or the NRC may require leak monitoring or just groundwater
19 monitoring."
20 As the terms are used here, do you understand
21 what's meant by "leak monitoring" and "groundwater
22 monitoring"?
23 A (Mr. Harper) Yes, I do.
24 Q What is leak monitoring, and what's groundwater
25 monitoring, as used in this document?

1 A (Mr. Harper) I would interpret leak monitor to
2 apply to a system similar to what we have now in the
3 design of the TEEB, which is a -- you know, the leak-
4 detection system, which would be designed to monitor a
5 leak through the liner. Groundwater monitoring I would
6 interpret to mean putting in some groundwater monitoring
7 wells in the vicinity of the basin and monitoring the
8 groundwater.
9 Q At some point, did you learn that you were
10 going to have leak monitoring rather than just groundwater
11 monitoring in the system, in the plant?
12 A (Mr. Harper) The -- well, the final design or
13 the design of record for the TEEB does have a leak
14 detection system, and as outlined in the ER in the
15 groundwater permit application, we have designed a
16 groundwater monitoring program.
17 Q So you're going to have both.
18 A (Mr. Harper) We're going to have both.
19 Q Okay. Did you hear at some point whether the
20 State or the NRC required leak monitoring?
21 A (Mr. Harper) We based on our decisions on
22 providing leak detection in groundwater monitoring as a
23 result of our overall design and a look at all the
24 regulations and requirements. At no point am I aware of
25 either the State or the NRC directing that we had to have

1 either of those.

2 Q Okay.

3 A (Mr. Harper) Other than it is -- you know, it

4 is called out for and discussed, especially groundwater

5 monitoring, in the groundwater discharge permit plan.

6 Q Okay.

7 MR. LOVEJOY: Let's mark this, please.

8 (The document referred to was

9 marked for identification as

10 Exhibit NIRS-HP 5.)

11 BY MR. LOVEJOY:

12 Q Let me ask each of you to look at -- I'm

13 captioning my exhibits HP, with your initials, Number 5.

14 A (Mr. Harper) Okay.

15 Q Look at Exhibit 5, please, and identify it if

16 you can.

17 A (Mr. Harper) It is the draft report that was

18 prepared by contractor to -- the MACTEC contractor to

19 Lockwood Greene on the preliminary subsurface geotechnical

20 exploration.

21 Q Was there a final version of this report

22 prepared?

23 A (Mr. Harper) Yes, I believe there was.

24 Q Mr. Peery, have you seen this report?

25 A (Mr. Peery) Yes, I have.

1 Q Okay. Did you see a final version also?
2 A (Mr. Peery) I don't recall.
3 Q Okay. Over on page 5 of the report -- Mr.
4 Peery, maybe I should ask you this -- there's a paragraph
5 starting, "Based on the information." Why don't you read
6 that.
7 A (Mr. Peery) "Based on the information from
8 geotechnical" --
9 Q Well, you can just read it to yourself. It's
10 in the record.
11 A (Mr. Peery) (Perusing document.) Okay.
12 Q Did you review this document as part of your
13 review of the geological investigations made for the LES
14 site?
15 A (Mr. Peery) Yes, I did.
16 Q Okay. There's a reference here to an
17 investigation done by Weaver Boos & Gordon. Did you
18 examine that, that report?
19 A (Mr. Peery) I'd have to see the title of that
20 report. I don't remember exactly that reference offhand
21 without seeing the title of the report.
22 Q Do you know anything about that investigation
23 referred to, other than seeing this reference?
24 A (Mr. Peery) Well, again, I'd really need to
25 see what the title of that report was.

1 Q Okay. Then the paragraph also refers to
2 piezometers installed for a project in Andrews County,
3 Texas, and there's a reference to Jack H. Holt, Ph.D. &
4 Associates. Did you review any materials about that
5 investigation?
6 A (Mr. Peery) Okay. Let me clarify the Weaver
7 Boos report first. It's in the references here, and I
8 have not reviewed that report. (Perusing document.) I
9 would have to see the Holt report. It's possible that I
10 saw that, but I don't recall.
11 Q In hydrology, what is the function of
12 piezometers?
13 A (Mr. Peery) Piezometers specifically are to
14 monitor water levels.
15 Q Did you -- apart from this reference, were you
16 aware that piezometers had indicated a depth to
17 groundwater of about 150 to 188 feet for a project in
18 Andrews County?
19 A (Mr. Peery) Yes. I am aware of that, but I
20 think I should clarify that their -- the depth to water is
21 actually the potentiometric surface elevation, so it's
22 the -- if a well is completed in a confined aquifer, such
23 as see at the 220-foot zone at the LES site and at the WCS
24 site for that matter, the water in the aquifer actually
25 rises about the top of the aquifer, because the overlying

1 Chinle has such a low permeability that it holds the water
2 into this little zone of aquifer, and so when a hole goes
3 into it, the water level can then rise up to what is
4 called the potentiometric surface elevation.
5 These depth to waters of 150 to 188 feet
6 correspond well with the potentiometric surface elevation
7 or the depth to the water, if you will, in these confined
8 aquifer wells.
9 Q How do you know that the water under the LES
10 site was in a confined aquifer?
11 A (Mr. Peery) The sediments above the aquifer
12 were dry, and the water level in MW-2 started off quite
13 low in the aquifer and continued to rise up to a depth of
14 about 120 feet below ground surface.
15 Q Okay. Now, the MACTEC contractor did some
16 drilling on the LES site, did they not?
17 A (Mr. Peery) Yes, they did.
18 Q However, on page 8, under Groundwater
19 Conditions, the first paragraph says, "Groundwater was not
20 observed in the test borings at the time of drilling.
21 Also, it was reported that groundwater was not encountered
22 in borings drilled at the site by others for water well
23 development to depths of 220 feet."
24 Do you know anything about those borings
25 drilled for water well development? Did you hear anything

1 about that in your investigations?

2 A (Mr. Peery) No. Other than this reference, I

3 haven't heard anything about that.

4 Q Did you make any inquiry about those wells?

5 A (Mr. Peery) I'm assuming that this isn't the

6 monitoring wells. No, I did not.

7 Q Then it says, "For safety reasons, the borings

8 drilled as part of MACTEC's scope of work were backfilled

9 promptly after drilling. Consequently, long-term

10 measurements for the presence or absence of groundwater

11 were not obtained." Did you express any opinion about the

12 fact that those MACTEC wells were backfilled promptly

13 after drilling?

14 A (Mr. Peery) Any opinion related to what?

15 Safety reasons?

16 Q No, not safety, but the opinion addressed to

17 the data which might have been obtained if they had not

18 been backfilled.

19 A (Mr. Peery) I did, specifically related to the

20 moist sediments in, I believe it is, B-2 of MACTEC's

21 drilling, and as my earlier testimony reflects, the

22 occurrence of moist samples doesn't indicate anything in

23 terms of additional data to be gained.

24 Q Well, you didn't tell anybody, It's too bad

25 they filled them right up again, because we might have had

1 some groundwater data?

2 A (Mr. Peery) No, I did not say that.

3 Q Okay. What are the safety reasons that support

4 backfilling these holes?

5 A (Mr. Peery) I can speculate why they did it.

6 I know why I would do it on a site. I can only speculate

7 why --

8 Q Why would you do it?

9 A (Mr. Peery) I would do it to keep people from

10 falling in the hole. You don't want people to trip or

11 animals to fall inside these kind of things.

12 Q Over on the page stamped LES-750, there is a

13 plan view of the site. Can you identify that?

14 A (Mr. Peery) I'm sorry. What page?

15 Q LES-750. It says, Figure 2: Boring location

16 plan.

17 A (Mr. Peery) Okay. I see that figure.

18 Q Okay. Are these -- are the -- do the circles

19 with, let's say, black and white pie sections marked on

20 them, do they indicate the wells drilled by MACTEC or

21 under their supervision?

22 A (Mr. Peery) My understanding, based on this

23 boring and what I've read, is, yes, that's correct.

24 They're actually borings, not wells.

25 Q Okay. And are you making a distinction? What

1 would be a well but not a boring?

2 A (Mr. Peery) Casing, actual physical casing of

3 the well.

4 Q Oh, okay. The completed well.

5 A (Mr. Peery) Yes.

6 Q And where was moisture detected as among these

7 holes?

8 A (Mr. Peery) I believe it's B-2.

9 Q Okay.

10 MR. LOVEJOY: Let's move on. That's November

11 19. This would be 6.

12 (The document referred to was

13 marked for identification as

14 Exhibit NIRS-HP 6.)

15 BY MR. LOVEJOY:

16 Q Would both witnesses please look at this,

17 what's been marked Exhibit 6, and state whether you've

18 seen it before.

19 A (Mr. Peery) I've seen this before.

20 A (Mr. Harper) I have also seen it before.

21 Q Okay. Is this a report prepared in connection

22 with the hydrogeologic investigation of the LES site?

23 A (Mr. Peery) Yes, it is.

24 Q I'll state for the record that this has in the

25 upper right corner an ML number which indicates how it was

1 retrieved from NRC's computer system. I put that there.
2 Was this report prepared as part of the basis
3 for -- no. Strike that. I've asked that.
4 In preparation of this report, did the Cook-
5 Joyce firm conduct some drilling on the LES site?
6 A (Mr. Peery) Yes, they did.
7 Q And what -- do you recall what boreholes were
8 made?
9 A (Mr. Peery) They drilled nine boreholes and
10 installed three monitoring wells.
11 Q These were in addition -- the three wells were
12 in addition to the boreholes?
13 A (Mr. Peery) Yes.
14 Q And did they locate groundwater in the wells
15 they drilled?
16 A (Mr. Peery) They were -- reported groundwater
17 in Monitor Well 2.
18 Q And at what depths did they find groundwater?
19 A (Mr. Peery) I'd have to look specifically at
20 what they said, but it's in the aquifer, currently
21 referred to as the one at about 220, 230 foot down the
22 siltstone.
23 Q At the bottom of page 3 of this report, the
24 statement appears, "Groundwater has not been identified in
25 the 125-foot silty sandstone zone. Groundwater in the

1 180-foot zone is present at some locations but not
2 continuously across the WCS property." And it says,
3 "Groundwater is present in a 230-foot across the entire
4 portion of the WCS property that's been investigated."
5 Does that refresh your recollection as to where
6 they found groundwater, the Cook-Joyce firm?
7 A (Mr. Peery) Yes, it does.
8 Q Okay. Where did they -- where to your
9 recollection now did they find groundwater?
10 A (Mr. Peery) According to this, the 180-foot
11 zone, it says it's present in some locations. Where I
12 recalled they actually found water is in Monitor Well 2 at
13 that 230-foot zone.
14 Q Okay. Do you know what drilling techniques
15 were used by Cook-Joyce, what methods?
16 A (Mr. Peery) As I recall, the B-1 through -9
17 borings were hollow-stem auger, and the monitoring wells
18 were direct air rotary.
19 Q Did they use no fluids at all in their air
20 rotary drilling?
21 A (Mr. Peery) I do not recall the mention of
22 using fluids when they drilled.
23 Q Over on page 5, they talk about monitor well
24 drilling and installation program. It says, "The three
25 monitor wells were designed based on the results of the

1 geophysical logs. The design consisted of the placement
2 of the screen interval across the 230-foot zone that is
3 approximately 15 feet in thickness."
4 Do you know why monitoring screens were not set
5 at any shallower zones?
6 A (Mr. Peery) Based on my understanding of this
7 report, there wasn't water present above this zone as
8 determined by drilling these three monitoring wells in the
9 geophysical logs.
10 Q Over on page 8 under, Data Analysis -- well, in
11 connection with this, do you know what well development
12 efforts were conducted with respect to the monitoring
13 wells?
14 A (Mr. Peery) I believe it's spelled out here
15 fairly clearly, but to the best of my memory, they tried
16 to develop the wells and were having a difficult time
17 getting some water in, and they put some water in the
18 wells to try to induce flow, so they could sort of surge
19 the formation with some water, try to develop the
20 formation, and then recovered that water.
21 Q Now, are you talking about MW-1, MW-2 -- and
22 was it in MW-3?
23 A (Mr. Peery) Yes. I think it's spelled out in
24 here, but that's generally what I recall.
25 Q Where is that spelled out? Can you find it? I

1 can tell you that on Table 2, there's reference to
2 development in the footnote.
3 A (Mr. Peery) (Perusing document.) No. I'm not
4 finding that. I don't see a reference in this reference
5 to the development of the wells.
6 Q Okay. What efforts in the way of well
7 development would industry practice have called for at
8 this site?
9 A (Mr. Peery) There would -- industry practice
10 would normally allow several things to occur. I think the
11 first thing that would generally occur would be to attempt
12 to bail and swab the screen section or the bailing could
13 actually do some swabbing of the screen section to try to
14 induce flow from the formation into the well, try to
15 repair the formation damage that occurs during drilling.
16 If that's unsuccessful, it's not uncommon for
17 people to attempt to introduce water into the well, using
18 various methods, sometimes pouring it in the well and then
19 swabbing it, as I previously described, or using a jetting
20 technique to try to repair the formation damage, and
21 subsequently bailing that water from the well.
22 Q What formation damage are you referring to?
23 A (Mr. Peery) Formation damage occurs when a
24 hole is drilled into the ground by any method.
25 Q What kind of damage?

1 A (Mr. Peery) It tends to smear the side walls
2 of the formation, and development is undertaken to remove
3 that material, the fine-grain sediments that are generated
4 during drilling, so that water can enter the well.
5 Q On page 8, there's a reference in the fourth
6 paragraph to recovery rates of groundwater in Monitor Well
7 MW-2. Is that the reference to the testing that you spoke
8 of several minutes ago?
9 A (Mr. Peery) Yes, it is.
10 Q What kind of a test do you call that, just for
11 shorthand?
12 A (Mr. Peery) Slug test.
13 Q Slug test? Okay.
14 A (Mr. Peery) And they give a reference here for
15 the type of --
16 Q Oh, yes. Sorry. And in Table 2, would you
17 look at that, please.
18 A (Mr. Peery) Yes. I'm at Table 2.
19 Q Do you see the references to water levels,
20 groundwater level data with respect to Monitor Well MW-2?
21 A (Mr. Peery) Yes.
22 Q And those dates indicate the measurements were
23 made. Is that right?
24 A (Mr. Peery) Yes. The dates are the
25 corresponding -- for the corresponding water level.

1 Q Does this show the gradually-increasing water
2 level in MW-2 that you spoke about before?
3 A (Mr. Peery) Yes.
4 Q And what do you infer from this?
5 A (Mr. Peery) What I infer from this is that the
6 well was completed in a confined aquifer.
7 Q Now --
8 A (Mr. Peery) As evidenced by the fact that the
9 water level is roughly 100 feet above the top of the
10 screen.
11 Q Now, what do the indications in Monitor Well
12 MW-1 report, the DTW TOC? Is that depth to water?
13 A (Mr. Peery) Yes.
14 Q And what is TOC?
15 A (Mr. Peery) Top of casing.
16 Q Okay. So that's the difference from the top of
17 the casing to the depth of the water?
18 A (Mr. Peery) Yes.
19 Q And what do those numbers mean here under MW-1?
20 A (Mr. Peery) It reports that the well is dry
21 for quite a number of measurements, September 22 through
22 the October 15 measurements. There's some water measured
23 for several of the following measurements to November 10,
24 and then it appears they have N/As at the last couple of
25 measurements.

1 Q What does N/A mean? Does it mean no test was
2 taken?
3 A (Mr. Peery) It doesn't reference it at the
4 bottom of the table.
5 Q Okay. And what's the significance of a report
6 of water present in MW-1 at 212, 215 feet in October of
7 '03?
8 A (Mr. Peery) That's just the fact that they
9 measured some water in there, and I don't recall if this
10 was after their development technique or attempts, or if
11 they put some water in the borehole and there was some
12 residual water left or not.
13 Q Okay. And do you know the significance of the
14 water levels reported for MW-3 in October 16 through
15 November 19?
16 A (Mr. Peery) Yes. And upon a little further
17 evaluation of this table, it's -- the last footnote on
18 this table says, "Monitor Wells MW-1 and -3 were surged
19 five times using 12 to 13 gallons of DI" -- which I assume
20 would be deionized -- "water from 10/16 to 10/20."
21 So the corresponding depth-to-water
22 measurements prior to -- I should say, the water level
23 measurements prior to 10/16 were dry, and then there's
24 some reports of water in these holes after they added
25 water to them and attempt to develop them, so the

1 conclusion I would draw is that this water is most likely
2 deionized water that they couldn't retrieve after their
3 development attempts.
4 Q What does the word "surged" mean here?
5 A (Mr. Peery) Surged normally means a bailer or
6 other device placed in the well, and it moved up and down
7 through the screen section to try to force water through
8 the gravel pack and formation to repair formation damage,
9 just mechanical action.
10 MR. LOVEJOY: Let's mark this.
11 (The document referred to was
12 marked for identification as
13 Exhibit NIRS-HP 7.)
14 BY MR. LOVEJOY:
15 Q Would you both, please, look at Exhibit 7 and
16 tell me whether you've seen that before.
17 A (Mr. Harper) I have.
18 Q Okay. This is addressed to you, isn't it, Mr.
19 Harper?
20 A (Mr. Harper) Correct.
21 Q Okay. And this is dated in March of this year.
22 Is that about when you received it?
23 A (Mr. Harper) Yes. That's correct.
24 Q Okay. Would you look at the second page where
25 there's a diagram of, to my understanding, a basin liner.

1 A (Mr. Harper) Yes.

2 Q Does that diagram show the present plan that

3 LES intends to use for a basin liner of the TEEB?

4 A (Mr. Harper) No, it does not.

5 Q Okay. How does the present plan vary from what

6 we see here?

7 A (Mr. Harper) The present plan is described in

8 the ER and in the groundwater discharge permit.

9 Q And how does that vary from this?

10 A (Mr. Harper) The text description on the top

11 half of the page is pretty much in accordance with the

12 design as specified in the license application, the

13 groundwater discharge permit. The figure is a

14 representation that Lockwood Greene put together, and this

15 was developed as part of the preparation of the -- of

16 information that was developed during the preparation of

17 the groundwater discharge permit. But this figure is not

18 an actual representation of the design.

19 Q Well, how does it vary from the design?

20 A (Mr. Harper) Well, the basin has not been

21 designed completely to the level of detail that this

22 little schematic is attempting to represent, so this is

23 not -- I would not consider this design to be -- it was

24 not prepared as part of the true design package for the

25 TEEB. It more or less was prepared as an informational

1 package.

2 Q Okay. So are you saying that LES is not

3 committed to follow this design?

4 A (Mr. Harper) We're committed to follow the

5 design that's in the groundwater discharge permit

6 application.

7 Q Okay.

8 A (Mr. Harper) And in the license application.

9 MR. LOVEJOY: This is 8.

10 (The document referred to was

11 marked for identification as

12 Exhibit NIRS-HP 8.)

13 BY MR. LOVEJOY:

14 Q Mr. Harper, would you look at Number 8 and tell

15 us if you've seen this before.

16 A (Mr. Harper) Yes, I have.

17 Q Is this something you received around March 1

18 of this year?

19 A (Mr. Harper) Yes, it is.

20 Q And looking at the second page, can you say

21 whether the diagram represents the liner plan that LES is

22 going to follow with respect to the UBC basin?

23 A (Mr. Harper) It does with respect to the

24 description of the -- from the bottom up, the compacted

25 clay layer, two-foot thick.

1 Q Uh-huh.

2 A (Mr. Harper) It also does with regards to the
3 one-foot thick protective layer on top of the geosynthetic
4 liner. But the details provided for the geosynthetic
5 liner are beyond those that are presently specified in the
6 design of the basin.

7 Q Okay.

8 A (Mr. Harper) Again, this was prepared as --
9 during the -- this was prepared during the preparation of
10 the groundwater discharge permit, but is not an official
11 design document.

12 Q Did you consider including this in the
13 groundwater discharge permit application?

14 A (Mr. Harper) These were developed while we
15 were working with Lockwood Greene to develop the
16 information required for the groundwater discharge permit
17 application. This was -- it evolved during the
18 development of the permit application.

19 Q Okay. Well, did you discuss with others
20 working on that application whether this should be
21 included in that application?

22 A (Mr. Harper) Not whether this should
23 specifically be included.

24 Q Well, did you -- sorry. Go ahead.

25 A (Mr. Harper) We have included -- what we

1 included in the groundwater discharge permit adequately
2 reflects the current design for the system.
3 Q Well, do you remember discussing with others
4 involved in preparing that application whether you should
5 include more detail, such as is shown in this diagram in
6 the application?
7 A (Mr. Harper) In the groundwater permit
8 application?
9 Q Yes.
10 A (Mr. Harper) We were -- I did review other
11 permit applications, and we feel that what we've provided
12 in the application is adequate.
13 Q But the question was: Do you remember
14 discussing with others working on that whether you should
15 put in more detail, such as is shown in this diagram?
16 A (Mr. Harper) No. We believed that the text
17 description adequately defines the proposed system. I'm
18 referring to the text description from the permit
19 application.
20 MR. LOVEJOY: Can we mark this one? 172. I
21 guess this is Number 9.
22 (The document referred to was
23 marked for identification as
24 Exhibit NIRS-HP 9.)
25 BY MR. LOVEJOY:

1 Q Mr. Harper, I'll ask you to look at Number 9
2 and state whether you saw this around March 1 of this
3 year.
4 A (Mr. Harper) (Perusing document.) Yes, I
5 believe I did.
6 Q This is from someone named Carroll Walker to
7 you, and the text says, "How close is this to what you
8 need?" Do you remember requesting something from Carroll
9 Walker to which this is a response?
10 A (Mr. Harper) We went down and met with the
11 Lockwood Greene staff during the early preparation phase
12 for the groundwater discharge permit, and these emails
13 were in response to some preliminary information that
14 Lockwood Greene was putting together to support the permit
15 development.
16 Q Okay.
17 A (Mr. Harper) And I would also like to point
18 out this email was a earlier version of the two exhibits
19 ago.
20 Q This was an earlier version of what?
21 A (Mr. Harper) Of the exhibit that starts on
22 page LES-168.
23 Q That's Exhibit 7?
24 A (Mr. Harper) Yes. You'll notice there the
25 first line of that email says, "Treated Effluent Basin

1 (REVISED)."

2 Q Okay. Well, do you remember how you responded

3 to Exhibit 9 and the question, "How close is this to what

4 you need?"?

5 A (Mr. Harper) It was likely there was -- we had

6 a former discussion. I can't remember the exact details.

7 I'd have to go back and do a line-by-line comparison and

8 see what if any changes there are between the two emails.

9 But since they look quite similar and there's the

10 "Revised" note on Exhibit 7, I'm assuming it was a follow-

11 up email, and given the timing of the emails also.

12 Q Does Exhibit 9 show a -- what I would call a

13 two-layer liner system for a basin? Is there's a

14 reference to 60 mil HDPE liner, and then a 60 mil HDPE

15 liner, secondary liner.

16 A (Mr. Harper) Correct. It is a representation

17 of a -- of what a double-lined system could look like.

18 Q Okay. And do you remember discussing with the

19 Lockwood Greene people the possibility of having a double

20 liner for the UBC storage pads, stormwater retention

21 basin?

22 A (Mr. Harper) No. At no time did we -- in

23 fact, I do note the difference on Exhibit -- Exhibit 9

24 says, "Treated Effluent Evaporative Basin and UBC Storage

25 Pad Stormwater Retention Basin." You'll then notice on

1 Exhibit 7 that the "UBC Storage Pad Stormwater Retention
2 Basin" has been deleted in the revised version.
3 Q Uh-huh. I see that. And the question is: Did
4 you discuss with them having a double-lined system for the
5 UBC storage pad stormwater retention basin as shown in
6 Number 9?
7 A (Mr. Harper) I believe that upon review of the
8 Exhibit 9, it's likely I had a discussion with Lockwood
9 Greene, pointing out the mistake in Exhibit 9, that said
10 that this applied to the UBC storage pad stormwater
11 retention basin.
12 Q Had they misunderstood your instructions?
13 A (Mr. Harper) I'm not sure.
14 Q Was there a contractor working for LES or maybe
15 for Framatome named GL Environmental, Inc., that worked on
16 the LES project?
17 A (Mr. Harper) Yes, there is.
18 Q And where are they based?
19 A (Mr. Harper) They're based out of, I believe
20 it is, Rio Rancho, New Mexico.
21 Q And what were their functions in connection
22 with the LES project for New Mexico?
23 A (Mr. Harper) It provided some various
24 environmental-related services. Some examples would be
25 endangered species surveys, archaeological evaluations of

1 the site.

2 Q Who were the individuals at GL Environmental

3 that did work on this project?

4 A (Mr. Harper) Any aspect of the project?

5 Q Yes.

6 A (Mr. Harper) Denise Gallegos, Tim Leftwich.

7 Q Anybody else?

8 A (Mr. Harper) That is all.

9 Q And what is the professional training of Denise

10 Gallegos?

11 A (Mr. Harper) I have not reviewed her resume.

12 Q Okay. And what is the professional training of

13 Tim Leftwich?

14 A (Mr. Harper) I have not reviewed his resume.

15 Q Okay. GL Environmental did work in connection

16 with the groundwater discharge permit, did they not?

17 A (Mr. Harper) They did -- they performed a

18 review o the draft permit application that we put

19 together.

20 Q And did you receive the results of that review?

21 A (Mr. Harper) Yes, we did.

22 Q Did you yourself in your job review the review

23 and decide what action to take?

24 A (Mr. Harper) Yes, I did.

25 Q Okay.

1 MR. LOVEJOY: Let's mark this. This would be
2 10.
3 (The document referred to was
4 marked for identification as
5 Exhibit NIRS-HP 10.)
6 BY MR. LOVEJOY:
7 Q Do you have Number 10, Mr. Harper?
8 A (Mr. Harper) Yes, I do.
9 Q Can you tell us whether you've seen this one
10 before.
11 A (Mr. Harper) Yes, I have.
12 Q Did you see this around April 6 of this year?
13 A (Mr. Harper) Yes, I did.
14 Q Yes. Do you remember receiving this and
15 reviewing the contents?
16 A (Mr. Harper) Yes, I did.
17 Q Did you respond to this?
18 A (Mr. Harper) I do not believe I responded to
19 it, other than to review the comments.
20 Q Do you remember what action you took based on
21 these comments?
22 A (Mr. Harper) Without going back and reading
23 right here, I would -- I believe in some cases, we
24 incorporated those comments and suggestions into the
25 permit.

1 Q Do you remember what instances those were?
2 A (Mr. Harper) Not specifically without -- I'd
3 have to do a comparison between --
4 Q Okay. Would you read the text on the page that
5 has LES-122 on it. Just read to yourself the entry under,
6 Groundwater Conditions.
7 A (Mr. Harper) (Perusing document.) Yes.
8 Q It says, "Copies of drill logs should be
9 provided and referenced. Under 'Groundwater Conditions,'
10 will information on the fault under NEF be provided?" Do
11 you know what fault is referred to?
12 A (Mr. Harper) Yes, I do. But it is not
13 properly characterized in the comment here.
14 Q Okay. What fault is referred to?
15 A (Mr. Harper) Given the timing here, I believe
16 it was back just before this email was sent to me, there
17 was a fault identified on the WCS property
18 Q And how did you learn about that fault?
19 A (Mr. Harper) It was either conveyed to me by
20 WCS and/or Cook-Joyce. I'm not sure who without going
21 back and --
22 Q So you got information orally?
23 A (Mr. Harper) It was probably orally. Yes.
24 Q Was there anything in writing about it?
25 A (Mr. Harper) No. Other than I did receive

1 some photographs also.

2 Q What were the photographs of?

3 A (Mr. Harper) I forget the exact year, but a

4 number of years ago, during excavation at the WCS

5 property, there was a fault in some very -- I believe in a

6 Triassic formation was noted during excavation for one of

7 their burial pits.

8 Q And what were you told about the fault when you

9 first learned about it?

10 A (Mr. Harper) I was told that WCS was

11 undertaking an evaluation of the fault.

12 Q And that was in 2004 you were told that?

13 A (Mr. Harper) That's correct.

14 Q Did you ever hear of any of the outcome of that

15 evaluation?

16 A (Mr. Harper) Yes. Back in the end of May,

17 LES, which I was a part of the team, accompanied the NRC

18 to the site to visit the fault or to inspect the fault, I

19 should say. And then we have subsequently received and

20 provided a report to the NRC on the characterization of

21 the fault.

22 Q Did you learn anything about the results of the

23 WCS evaluation of the fault?

24 A (Mr. Harper) I have reviewed their report that

25 was submitted to the State of Texas.

1 Q Who did that report?

2 A (Mr. Harper) Cook-Joyce and a company by the

3 name of Enterra.

4 Q Do you have a copy of that report?

5 A (Mr. Harper) Yes, I do.

6 MR. LOVEJOY: We're going to be requesting a

7 copy of that report.

8 MR. CURTISS: Okay. We'll see if we've

9 provided it already, but --

10 THE WITNESS: (Mr. Harper) It was submitted to

11 the NRC.

12 MR. LOVEJOY: Is this in the ADAMS system?

13 MR. KRICH: Should be. I haven't checked the

14 last couple days, but I believe it is.

15 MR. LOVEJOY: Was it submitted recently?

16 MR. KRICH: Yes. In the last two weeks. In

17 August actually.

18 THE WITNESS: (Mr. Harper) Correct. Yes.

19 With the last round of our --

20 MR. KRICH: It was submitted at the end of

21 August.

22 BY MR. LOVEJOY:

23 Q So you and some others visited the site of the

24 fault in May of this year.

25 A (Mr. Harper) That's correct.

1 Q And who was there at that time?

2 A (Mr. Harper) There was one person from the NRC

3 Washington office.

4 Q Who was that?

5 A (Mr. Harper) Herman Graves.

6 Q Herman --

7 A (Mr. Harper) Graves.

8 Q Herman Graves. Who else was on this visit?

9 A (Mr. Harper) There was three contractors to

10 the NRC.

11 Q And who were they?

12 A (Mr. Harper) I couldn't accurately give you

13 their names right now, but I --

14 Q Okay. Do you have it written down somewhere?

15 A (Mr. Harper) Yes, I do.

16 Q And where did you go? You went to the site of

17 the fault?

18 A (Mr. Harper) We went to the site of the fault.

19 That's correct.

20 Q Were there people there from WCS to show you

21 the site?

22 A (Mr. Harper) We were showed the excavation by

23 staff from Cook-Joyce and from Enterra.

24 Q Do you remember any of those folks' names?

25 A (Mr. Harper) Yes. From Cook-Joyce it would

1 have been Doug Granger.

2 Q Doug Ranger?

3 A (Mr. Harper) Granger, G. I believe Steve Cook

4 was there.

5 Q He's the Cook in Cook-Joyce?

6 A (Mr. Harper) He's the Cook in Cook-Joyce. And

7 a gentleman by the name of Gerry Grizak, Gerry with a G,

8 Grizak with a G.

9 Q Who's he with? Cook-Joyce?

10 A (Mr. Harper) He's with Enterra.

11 Q Enterra?

12 A (Mr. Harper) Yes. And Dan Green, who is a

13 contractor to LES.

14 Q Okay. So what did you see when you looked at

15 the site of the fault?

16 A (Mr. Harper) We first observed the excavation

17 from the top side, which pointed out the fault in the

18 mapping activities that were going on in the excavation,

19 and then we drove down into the excavation. It's quite

20 deep. It's quite a large excavation. They had opened up

21 a large face of the redbeds, the Chinle redbeds, and they

22 were doing detailed mapping of the fault.

23 Q How deep was this excavation?

24 A (Mr. Harper) I'll estimate it 70 feet, if not

25 deeper. It was fairly deep. The actual -- there's more

1 information in the report that was submitted to the NRC.
2 Q Okay. Was the report that was submitted to the
3 NRC, was this the report by Cook-Joyce and Enterra?
4 A (Mr. Harper) Yes, it was. We submitted the
5 section of the report -- this was a report that was
6 generated for WCS as part of one of their license
7 applications. We submitted just the portion on the fault
8 investigation to the NRC, because that was the issue that
9 we were responding to.
10 Q What prompted this submission?
11 A (Mr. Harper) A request from the NRC.
12 Q What had they requested?
13 A (Mr. Harper) They requested that we would
14 provide them with a copy of the report when it was
15 completed.
16 Q How did they know there was a report?
17 A (Mr. Harper) They accompanied us on the May
18 site inspection.
19 Q Okay. Well, how did they find out that there
20 was a fault to inspect?
21 A (Mr. Harper) That I do not know.
22 Q Okay. Do you remember what conclusions were
23 reached in the report?
24 A (Mr. Harper) The main focus of the report was
25 to determine the age of the fault and whether or not it

1 was considered active or capable, and the report concludes
2 that the fault was -- I believe it was Triassic-aged or
3 earlier. It's on the order of hundreds of millions of
4 years old.
5 Q Was there a determination whether it was --
6 strike that.
7 The age of the fault was Triassic. Are you
8 distinguishing between the age of the fault and the age of
9 the strata?
10 A (Mr. Harper) The purpose of the investigation
11 was to determine the age of the fault displacement.
12 Q And what was the age of the strata?
13 A (Mr. Harper) I'd have to go back and read the
14 report. It was at least that old, since the fault was in
15 it. But I don't -- again, I used -- it's Triassic or
16 Jurassic. It was pre-Quaternary, I believe.
17 Q Was there any discussion in the report about
18 the -- whether the fault was active or capable, as you use
19 it?
20 A (Mr. Harper) I believe a summary that -- I
21 believe it is -- it concluded that the fault was very old.
22 That was gist.
23 MR. CURTISS: Lindsay, let me raise a question
24 here in terms of a form of an objection.
25 MR. LOVEJOY: Yes.

1 MR. CURTISS: If you're endeavoring to tie this
2 back in some way to the groundwater question that you're
3 raising, these are the witnesses that can address that.
4 If you're, as you appear to be, pursuing of line of
5 inquiry that goes to a seismic issue -- and my
6 understanding is that the individuals who accompanied --
7 who visited this fault were seismic experts and looked at
8 it for that reason -- I think we would interpose an
9 objection.
10 At this point, you're entitled to pursue this
11 line of questioning, but if and to the extent that the
12 questions here can be linked to the groundwater issue
13 that's properly within the scope of this contention, this
14 is the panel that can address it.
15 MR. LOVEJOY: Good.
16 MR. CURTISS: But if you're seeking to address
17 issues related to seismic -- and it appears that that's
18 the direction that the question is going -- I would submit
19 (a) this is not the panel, and (b) your contention doesn't
20 encompass that. So we would hope that if you could link
21 it back to the groundwater question, feel free to do that.
22 In the alternative, we would object to a seismic inquiry,
23 because that's not an issue that's before the board.
24 MR. LOVEJOY: Well, it may touch on both
25 issues. That's the thing, so I'm going to be asking these

1 folks about the hydrologic aspects of this, and I think
2 that's --
3 MR. CURTISS: That's a fair question, and to
4 the extent that it's related to that, I think that's an
5 appropriate question. But to the extent that it's not, I
6 think we would object and just for the record note that.
7 MR. LOVEJOY: Okay.
8 BY MR. LOVEJOY:
9 Q You say the reported concluded that the fault
10 was very old. Did the report conclude whether the fault
11 was possibly still active or not, or did --
12 A (Mr. Harper) I can't remember. I'd have to
13 look at the report again.
14 Q Okay.
15 A (Mr. Harper) It was more focused on the age.
16 Q Okay. Mr. Peery, have you received any
17 information about this fault in connection with your work?
18 A (Mr. Peery) No, I have not.
19 Q Has any effort been undertaken to examine the
20 question of this fault from the standpoint of flow paths
21 for water?
22 A (Mr. Harper) Not to my knowledge.
23 Q Is there any reason why that was not examined?
24 A (Mr. Harper) The focus of the investigation
25 was seismic-related.

1 Q Was there any reason it was considered
2 inappropriate to investigate this from a hydrologic
3 standpoint?
4 A (Mr. Harper) I'm only aware of the evaluation
5 that was done in regards to the -- whether it was a
6 capable fault or not. I'm not aware of any other studies
7 they did while the excavation was open.
8 Q Is this fault mentioned in any version of the
9 environmental report?
10 A (Mr. Harper) The report was issued in, I
11 believe it was, sometime -- August, late August of '04, so
12 it has not been -- it is not mentioned in the ER, but it
13 has been -- it is part of the license application in that
14 we have submitted formal RAIs to the NRC.
15 MR. CURTISS: Let's take a break here, Lindsay,
16 and you're still going to pursue this, or if you're at the
17 conclusions of your questions and are prepared to move on,
18 that's fine. If not, we'll take a break, and we'll
19 discuss whether we have the right people here, and whether
20 this is relevant to the issues that we think you've raised
21 here.
22 So we'll take a brief break --
23 MR. LOVEJOY: Do you want to take a break?
24 MR. CURTISS: Yes. Five minutes.
25 MR. LOVEJOY: Okay.

1 (Whereupon, a short recess was taken.)

2 MR. CURTISS: I think we can discuss an

3 approach to go forward here, and propose an approach.

4 This panel that we have here is able to answer any

5 questions that you have -- and we'll stay as long as you

6 wish -- on the groundwater contamination issues that are

7 the subject of the deposition this morning.

8 If you are able to articulate for us the nexus

9 that you see between the seismic issue that you've been

10 discussing in the past 45 minutes or so and that was the

11 subject of an early objection from me, on the ground that,

12 at least at that point, I didn't see the nexus -- but also

13 allowing the possibility that you might, in your

14 questioning, get to that point of establishing nexus.

15 I think we're to the point now where we get to

16 see what you view the nexus to be between the seismic

17 issue and the groundwater contamination contention that

18 these folks are the experts on.

19 If at some point you think you -- and we're I

20 think perfectly willing to listen to how you might

21 articulate that nexus and get into the questions of these

22 experts, who are experts on the groundwater issue as to

23 the relationship between the seismic inquiry that you've

24 undertaken and the groundwater issue that they're experts

25 on.

1 In the absence of that, I think we're going to
2 have to say if you think you're entitled to pursue the
3 seismic issue at some point, feel free to seek to bring it
4 before the Board in the manners that are permitted, and if
5 it's -- you're successful on that, we'll get the right
6 panel here on that, but this is not the panel to go into
7 the detailed questioning of the seismic issue.
8 If you have a view about that and questions
9 that relate to the groundwater that will be the nexus that
10 we get to see in the line of questioning that you pursued,
11 please outline that for us, and you can start questioning
12 about this.
13 But in the absence of that, I propose to move
14 on to your next line of inquiry, as these are not the
15 folks to talk about seismic absent a connection to the
16 groundwater issue.
17 BY MR. LOVEJOY:
18 Q Mr. Peery, as a hydrologist, would you consider
19 a fault line to be at least potentially a fast-flow path?
20 A (Mr. Peery) Potentially. Faults can be --
21 faults can create fracturing, but faults can also create
22 gouge within the fault itself, making it a low-permeable
23 barrier as well.
24 Q So if you were investigating the hydrology of a
25 particular site, would you wish to know whether there was

1 a fault present beneath or near the site?

2 A (Mr. Peery) Yes.

3 Q You would. Okay. When did you complete you

4 investigations of the LES site?

5 A (Mr. Peery) I didn't actually perform

6 investigations as such. I performed a review of the

7 investigations at the site.

8 Q And when was that, did you finish that?

9 A (Mr. Peery) Oh, earlier this week.

10 Q And you've not seen the report that was

11 submitted to NRC concerning this fault.

12 A (Mr. Peery) I have not.

13 Q Would you like to see that?

14 A (Mr. Peery) Yes, I would.

15 Q Why is that?

16 A (Mr. Peery) I want to see what extra

17 information was discovered relating to the fault. It's

18 interesting in that there was a fault discovered at the

19 site, and the data collected at the WCS facility clearly

20 shows low permeability throughout the Chinle formation, so

21 I'm interested to see what happens with the fault.

22 Q Are you going to pursue that investigation?

23 A (Mr. Peery) Yes.

24 Q Okay.

25 MR. LOVEJOY: Let's mark this one. Is this 11

1 now?

2 THE REPORTER: Yes.

3 (The document referred to was

4 marked for identification as

5 Exhibit NIRS-HP 11.)

6 BY MR. LOVEJOY:

7 Q Would you both please look at Number 11 and

8 state whether you can identify this as something you've

9 seen before.

10 A (Mr. Peery) Yes. I've seen this.

11 A (Mr. Harper) And I have seen this before.

12 Q Okay. What -- are wells indicated on the

13 diagram that's page 2? I see it's got some groundwater

14 monitoring well locations.

15 A (Mr. Harper) This is a figure that was

16 prepared in response to the RAIs that we received from the

17 NRC where we were providing the latest information on the

18 locations for the groundwater monitoring wells for the

19 site.

20 Q Does this describe wells that exist now?

21 A (Mr. Harper) No.

22 Q Are these wells planned to be --

23 A (Mr. Harper) These are planned.

24 Q Okay. So the references here to MW-1, MW-2,

25 and MW-3, do they bear any relation to the MW-1, MW-2, and

1 MW-3 that were drilled and reported on by Cook-Joyce?
2 A (Mr. Harper) No. No, they do not.
3 Q Okay.
4 MR. LOVEJOY: This is 12.
5 (The document referred to was
6 marked for identification as
7 Exhibit NIRS-HP 12.)
8 BY MR. LOVEJOY:
9 Q Would you look at Number 12 and each of you
10 please state whether you've seen this before.
11 A (Mr. Peery) I've seen this before.
12 A (Mr. Harper) And I have seen this before also.
13 Q And, Mr. Harper, can you tell why this was
14 created? Do you know?
15 A (Mr. Harper) It appears that this figure was
16 created to -- for inclusion in the groundwater discharge
17 permit application, although I can't tell by looking at
18 the document here if it is the final version of the
19 figure.
20 Q Okay. There's a legend which refers to number
21 1, soil sample; number 2, vegetation sample; and number 3,
22 water sample/sediment sample.
23 A (Mr. Harper) Yes.
24 Q Are these identified to identify proposed
25 sampling locations for use under the discharge permit?

1 A (Mr. Harper) Yes, they are.

2 Q Do you know the frequency of the samples that

3 was proposed?

4 A (Mr. Harper) I'd have to check the permit.

5 Q Okay.

6 A (Mr. Harper) They may vary for different

7 media.

8 MR. LOVEJOY: This will be 13.

9 (The document referred to was

10 marked for identification as

11 Exhibit NIRS-HP 13.)

12 BY MR. LOVEJOY:

13 Q Mr. Harper, Mr. Peery, could you identify

14 Exhibit 13?

15 A (Mr. Peery) Exhibit 13 is LES Boring and

16 Monitor Well Survey Data table.

17 Q Okay. Mr. Harper, do you recognize this as

18 something you've seen?

19 A (Mr. Harper) I'm not sure if I have seen this

20 information in this particular form right here, but I'm

21 familiar with the information.

22 Q What wells does this refer to?

23 A (Mr. Harper) The BH-1 through the BH-9 would

24 be the nine shallow groundwater borings.

25 Q And the MW-1, -2 and -3, are those the wells

1 that were drilled --

2 A (Mr. Harper) The three --

3 Q -- under Cook-Joyce's supervision?

4 A (Mr. Harper) Right. The three deep wells.

5 Q Okay. Good.

6 MR. LOVEJOY: This is 14.

7 (The document referred to was

8 marked for identification as

9 Exhibit NIRS-HP 14.)

10 BY MR. LOVEJOY:

11 Q Would you each please say if you've seen this

12 document before.

13 A (Mr. Peery) I have not reviewed this document.

14 Q Mr. Harper, do you --

15 A (Mr. Harper) I have seen this document.

16 Q Okay. Do you know what the date of this

17 document is approximately?

18 A (Mr. Harper) This document was prepared --

19 originally prepared in support of the Rev. 0 license

20 application.

21 Q And that was submitted in December of '03. Is

22 that right?

23 A (Mr. Harper) Correct.

24 Q Was it shortly before that date?

25 A (Mr. Harper) The calculation was originally

1 performed sometime before that date.

2 Q Okay. Over on page 4 of 40 in the lower right

3 corner --

4 A (Mr. Harper) I'd like to make one --

5 Q Please. Go ahead.

6 A (Mr. Harper) Supplement my previous response.

7 Even though the calculation was prepared prior to the

8 application submittal, it was not formalized until

9 recently.

10 Q What was the formalizing process you're talking

11 about?

12 A (Mr. Harper) It was essentially just to get

13 the cover sheets on and it all signed and dated.

14 Q Has that been submitted to NRC now?

15 A (Mr. Harper) This calculation?

16 Q Yes.

17 A (Mr. Harper) No, it has not.

18 Q Over on page 4 of 40, under the caption,

19 Radioactivity Estimate, why don't you read the first

20 paragraph there.

21 A (Mr. Harper) (Perusing document.)

22 Q It says -- well, under the major caption,

23 Inputs and Assumptions, it says, "The radioactivity

24 present on the surface of cylinders is the maximum

25 allowable for standard offsite transport per 49 CFR 173."

1 And it goes on.

2 Did you give instructions to someone preparing

3 an estimate of contamination that --

4 A (Mr. Harper) Where did you just read that

5 statement?

6 Q It's under, Radioactivity Estimate.

7 A (Mr. Harper) Okay.

8 Q Did you give instructions to use the maximum

9 allowable, as it's stated here, in estimating

10 radioactivity that would be present on the cylinders in

11 storage?

12 A (Mr. Harper) No, I did not.

13 Q Well, do you know who did? Do you know why

14 that rule is chosen?

15 A (Mr. Harper) It was an assumption that was --

16 a conservative assumption that was proposed by the author

17 in conjunction with discussions with other staff of

18 Framatome.

19 Q The author is Mr. Bellini?

20 A (Mr. Harper) Mr. Bellini. Correct.

21 Q Okay. Do you know whether calculations were

22 done assuming a greater amount of radioactivity than that

23 allowable for transportation?

24 A (Mr. Harper) I am not aware of it.

25 Q Okay.

1 MR. LOVEJOY: Let's mark this.

2 (The document referred to was

3 marked for identification as

4 Exhibit NIRS-HP 15.)

5 BY MR. LOVEJOY:

6 Q Have you seen Number 15, Mr. Harper, and you

7 too, Mr. Peery, if you might have seen this?

8 A (Mr. Peery) I have not reviewed this document.

9 A (Mr. Harper) I have seen it before.

10 Q Do you know what the date of this document is?

11 A (Mr. Harper) This calculation was originally

12 prepared in support of our submitting the responses to the

13 round NRC RAIs. I believe it was originally prepared back

14 in the July time frame.

15 Q July of '04?

16 A (Mr. Harper) July of '04.

17 Q And this is marked, Draft. Do you know if this

18 was ever completed?

19 A (Mr. Harper) The calculation, I believe, has

20 been signed or is awaiting final sign-off right now.

21 Q Well, has this or a version of this document

22 been submitted to NRC in response to an RAI?

23 A (Mr. Harper) A summary of it was supplied as

24 part of the RAI.

25 Q When was that?

1 A (Mr. Harper) I'd like to also add. These
2 types of calculations are not routinely submitted to the
3 NRC.
4 Q When was the summary submitted?
5 A (Mr. Harper) July of '04 time frame.
6 Q Okay. That's all I have on that one. Now, I
7 copied part of the latest environmental report. Draft 2.
8 Some of the pages are marked December '03, rather than
9 bring the whole thing.
10 A (Mr. Harper)
11 MR. LOVEJOY: This would be 16?
12 (The document referred to was
13 marked for identification as
14 Exhibit NIRS-HP-16.)
15 BY MR. LOVEJOY:
16 Q I just have a couple of questions about this.
17 Certainly, Mr. Harper, you've reviewed the environmental
18 report in various versions as it's been submitted. Is
19 that right?
20 A (Mr. Harper) Correct.
21 Q Now, Mr. Peery, have you?
22 A (Mr. Peery) I've reviewed sections related to
23 the site hydrogeology.
24 Q Did you review Section 3.4?
25 A (Mr. Peery) Yes.

1 Q Did you comment on it, or did you --

2 A (Mr. Peery) I haven't provided any comments to

3 anyone.

4 Q Okay. Over on page 3.4-5, there's a paragraph

5 a little over halfway down. It says, "The first presence

6 of saturated porous media," and it goes on. Why don't you

7 take a look at that one, Mr. Peery. I'm going to ask you

8 just a couple of questions.

9 A (Mr. Peery) (Perusing document.)

10 Q Okay. There's a reference to intersecting of

11 saturated porous media 200 to 300 below land surface. Do

12 you know what intersections that refers to?

13 A (Mr. Peery) As I recall, that's the zone I

14 previously described as the 220- to 230-foot zone.

15 Q That was encountered in MW-2 also?

16 A (Mr. Peery) Yes.

17 Q Okay. Then there's a reference to a zone -- it

18 says, "Similarly. there is a 30.5-meter, 100-foot, thick

19 water-bearing layer at about 183 meters, 600 feet, below

20 ground surface," and a reference, I take it, to Cook-

21 Joyce.

22 Do you know what data supports that statement?

23 A (Mr. Peery) I don't recall that offhand. I

24 don't recall offhand.

25 Q Okay. And then in the next paragraph, it says,

1 "The first occurrence of a well-defined aquifer is
2 approximately 244 meters, 800 feet below land surface."
3 Do you know what supports that statement?
4 A (Mr. Harper) Could I speak to that statement?
5 Q Of course.
6 A (Mr. Harper) In the Revision 2 to the ER, we
7 revised the discussion on the Santa Rosa formation, and
8 this particular passage that describes it here was either
9 missed during the revision or somehow got -- did not get
10 typed and incorporated.
11 Q Well, is the statement now incorrect in your
12 view?
13 A (Mr. Harper) Based on the February 2004
14 information from the Cook-Joyce report, we have revised
15 that statement, and it is revised in other sections here.
16 I'm just trying to put my -- (Perusing document.)
17 Q Do you want to find places where it's stated as
18 revised?
19 A (Mr. Harper) (Perusing document.) On page
20 3.4-13 --
21 Q Would you point to what you're talking about?
22 A (Mr. Harper) The third paragraph from the
23 top --
24 Q Yes.
25 A (Mr. Harper) -- starts off, "The first

1 occurrence."

2 Q Yes.

3 A (Mr. Harper) So that prior passage on the

4 prior page should read similar to that passage, and that

5 change is in progress for the next revision of the ER.

6 Q So are you saying that the Santa Rosa should be

7 identified as occurring 340 meters or 1,115 feet below

8 land surface, rather than 244 meters or 800 feet?

9 A (Mr. Harper) Correct.

10 Q Do you know how to figure 800 feet or 244

11 meters got into the text originally?

12 A (Mr. Harper) I believe it's based on some

13 early information that we obtained during the original

14 development of the ER.

15 Q What information was that?

16 A (Mr. Harper) I believe it was information that

17 was informally provided or, let's say, verbally provided,

18 based on discussions with WCS personnel.

19 Q So you were told by WCS personnel that the

20 Santa Rosa was found at 800 feet?

21 A (Mr. Harper) I believe that is probably the

22 case.

23 Q Okay.

24 A (Mr. Harper) And I'm also not sure -- well,

25 let's say I would like to -- I'm not sure if they were

1 referring, now when I read this passage, the physical
2 location of the Santa Rosa or the piezometric surface of
3 the Santa Rosa, which may describe the difference,
4 assuming it's a confined aquifer and the piezometric
5 surface is higher than the physical location of the Santa
6 Rosa formation itself.
7 Q Okay. I have a couple of questions about the
8 text of the draft EIS.
9 MR. LOVEJOY: I didn't run a full copy of this,
10 and you can either show the witness the text, or I will
11 show him the text.
12 BY MR. LOVEJOY:
13 Q Let's first identify the map on page 3-36.
14 Now, I realize this is not an LES document, but based on
15 your knowledge of the site and the work that's been done
16 there, can you state what's depicted in Figure 3-21?
17 MR. CURTISS: Can the record reflect that the
18 witnesses are looking at page 3-36 of the draft
19 environmental impact statement published by the NRC.
20 THE WITNESS: (Mr. Harper) This is your note
21 there on the very small text, near the bottom of the
22 legend there, the source of the ER report December 2003.
23 And what we're looking at here is the borings that have
24 been -- that were performed prior to December 2003 on the
25 site. So you see the nine shallow groundwater borings,

1 the five geotechnical borings, and the location of the
2 three monitoring wells.
3 BY MR. LOVEJOY:
4 Q You called them geotechnical borings. Under
5 whose supervision were they made?
6 A (Mr. Harper) Those are MACTEC borings.
7 Q Those are the earlier ones --
8 A (Mr. Harper) Correct.
9 Q -- and then the Cook-Joyce.
10 A (Mr. Harper) Yes. The sole purpose of those
11 borings was to collect geotechnical information.
12 Q Okay. Would you look at page 4-13 of the DEIS,
13 please. There is a discussion of a site stormwater
14 detention basin, and the second paragraph has some text
15 that I'll just read and I'd like your comments on.
16 "A conservative estimate of the impact from
17 this basin assumes that the local groundwater velocity at
18 the plume coming from the site stormwater detention basin
19 could be 252 meters at .16 mile per year. The cross-
20 section perpendicular to the flow direction of this plume
21 would be 2,850 square meters, 30,700 square feet. The
22 depth of the plume would be about 2.85 meters, 9.3 feet,
23 for a nominal plume width of 1,000 meters, 3,280 feet."
24 Do you know of the calculations which gave rise
25 to these figures?

1 A (Mr. Harper) I do not.

2 A (Mr. Peery) I do not.

3 Q Okay. Over on the next page, 4-14, in the

4 first paragraph on that page, there's a discussion of

5 septic tanks and leach field. At the end of that first

6 paragraph, it says, "The local groundwater velocity of the

7 plumes coming from the septic system would then be about

8 252 meters, .16 mile, per year. The total cross-section

9 perpendicular to the flow direction of the septic system

10 plumes would be 116 square meters, 1,250 square feet. The

11 depth of the plumes was calculated to be about 1.16

12 meters, 3.8 feet, for a nominal total plume width of 100

13 meters, 328 feet."

14 Do you know the origin of those figures, either

15 one of you?

16 A (Mr. Peery) I do not.

17 A (Mr. Harper) I do not, either.

18 Q That's all I have on that.

19 MR. LOVEJOY: If we can have a minute or two

20 with my technical advisor, we may be able to end this.

21 (Whereupon, a short recess was taken.)

22 THE REPORTER: We're back on the record.

23 MR. LOVEJOY: Thank you.

24 BY MR. LOVEJOY:

25 Q Mr. Harper, we just looked at the discussion in

1 the draft EIS of plumes associated with the site
2 stormwater detention basin and the septic tanks and leach
3 fields. From reading those, can you tell whether you
4 would agree or disagree with those analyses?
5 MR. CURTISS: Could we have a page reference
6 there?
7 BY MR. LOVEJOY:
8 Q On page 4-13 and 4-14.
9 A (Mr. Harper) The first one's on 4-13?
10 Q Yes.
11 A (Mr. Harper) I guess I make two points.
12 First, I would have to see the calculation to understand
13 the basis for the assumptions made and the inputs. And,
14 number two, for the site stormwater detention basin, it's
15 not clear in this calculation if they're taking any credit
16 for evapo-transpiration, and that may be a -- if they're
17 not, that would be a very overly conservative assumption
18 in my belief.
19 Q And what's your view of the discussion of the
20 septic tanks and leach fields on 4-14?
21 A (Mr. Harper) Based on the sentence there in
22 the middle of the paragraph -- "A conservative estimate of
23 the impact from septic systems assumes all of the
24 infiltrating water was transported down gradient." So,
25 again, without seeing the calculation and also -- and

1 specifically here it says they did not take any credit for
2 evapo-transpiration. This would appear to be an
3 evaluation that assumes that all -- that the evapo-
4 transpiration is not accounted for in the analysis, so I
5 would not agree with it.
6 Q Can I ask each of you witnesses: Have you ever
7 known a liner of a basin to leak?
8 A (Mr. Peery) I don't have a lot of experience
9 with lined sites.
10 Q Okay. Mr. Harper?
11 A (Mr. Harper) During my career as an engineer,
12 I believe at some points I have read articles over heard
13 cases where liners have leaked.
14 Q Can you remember the causes that were
15 attributed to those leakages?
16 A (Mr. Harper) Since I don't have any particular
17 examples, I -- they would just be this -- I would assume
18 the usual suite of potential reasons why a liner could
19 leak.
20 Q What's the usual suite?
21 A (Mr. Harper) Improper installation, for
22 example.
23 Q Anything else?
24 A (Mr. Harper) Some type of a puncture due to
25 poor maintenance practice or burrowing animals, something

1 else, would be a potential.

2 MR. LOVEJOY: Okay. I'm done.

3 MR. CURTISS: Okay.

4 MR. LOVEJOY: We'll go off the record here.

5 (Whereupon, the taking of the instant

6 deposition was concluded.)

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

CERTIFICATE

This is to certify that the foregoing proceedings

in the matter of: The Deposition of
George A. Harper
Roger L. Peery

held on: September 17, 2004

at the location of: Santa Fe, NM

were duly recorded and accurately transcribed under my direction; further, that said proceedings are a true and accurate record of the testimony given by said witness; and that I am neither counsel for, related to, nor employed by any of the parties to this action in which this deposition was taken; and further that I am not a relative nor an employee of any of the parties nor counsel employed by the parties, and I am not financially or otherwise interested in the outcome of the action.

Carol Oppenheimer

Carol Oppenheimer

AUTHENTICATION BY SIGNATURE

I, the undersigned, do hereby certify by my signature hereunder that I have read the foregoing deposition of testimony given by me on September 17, 2004, and find said transcription to be a true and accurate record, as corrected.

George A. Harper

Sworn to and subscribed before me this 28th day of October, 2004.

Barbara Ann Lema
Notary Public

My commission expires August 20, 2010.

Barbara Ann Lema, Notary Public
Commonwealth of Massachusetts
My Commission Expires 8/20/2010

0917LOVE

NEAL R. GROSS & CO., INC.
1323 RHODE ISLAND AVENUE, NW
WASHINGTON, D.C. 20005
TELEPHONE (202) 234-4433

ERRATA ERRATA

RE THE DEPOSITION OF George A. Harper
(deponent's name)

TAKEN ON Sept. 17, 2004
(date)

IN THE MATTER OF

LES v. NIRS/PC
(party) (party)

DOCKET NO. _____.

IN _____.
(name of court)

PAGE NO.	LINE NO.	CORRECTION
10	12	"DM" should be "dam"
10	14	"DM" should be "dam"
12	10	"pump" was probably
		an "ah"
13	1	"--" should be "and"
37	13	"is" should be "in"
38	1	"membrane" refers to
		the "upper liner"
38	2	"membrane" refers to
		"liner"
63	7	"yo" should be "you"
64	21	first use of "on"
		should be ~~deleted~~ GAH 10/28/04
		deleted
64	22	"in" should be "and"
85	6	"formes" should be "phone"
87	18	"o" should be "of"

NEAL R. GROSS & CO., INC.
1323 RHODE ISLAND AVENUE, NW
WASHINGTON, D.C. 20005
TELEPHONE (202) 234-4433

PAGE NO.	LINE NO.	CORRECTION
91	3	"Enterra" should be
		"Intera"
92	23	"Enterra" should be "Intera"
93	11	"Enterra" should be "Intera"
93	17	"in" should be "and"
94	3	"Enterra" should be "Intera"
95	22	"gist" should be "it"
108	13	Insert "of" after "round"
113	20	"This is your" probably
		should be "There is a"
117	12	"over" probably should
		be "or"

AUTHENTICATION BY SIGNATURE

I, the undersigned, do hereby certify by my signature hereunder that I have read the foregoing deposition of testimony given by me on September 17, 2004, and find said transcription to be a true and accurate record, as corrected.

_____
Roger L. Peery

Sworn to and subscribed before me this _____day of _____, 20__ __.

_____
Notary Public

My commission expires _____.

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE COMMISSION

In the Matter of:	)	
	)	
	)	Docket No. 70-3103-ML
LOUISIANA ENERGY SERVICES, L.P.	)	
	)	ASLBP No. 04-826-01-ML
(National Enrichment Facility)	)	
	)	

Deposition of:

GEORGE R. (RANDY) CAMPBELL

ROD KRICH

ROGER L. PEERY

LEN STOKES

TIM WOOMER

witnesses of lawful age, taken on behalf of the Nuclear Information & Resource Service and Public Citizen, pursuant to notice, in the New Mexico Environment Department, Office of the Secretary, Conference Room, Harold Runnels Building, 1190 St. Francis Drive, Santa Fe, New Mexico, on Friday, September 17, 2004, at 2:00 p.m., before Carol Oppenheimer, Notary Public, when were present:

APPEARANCES:

On behalf of Nuclear Information & Resource Service and Public Citizen:

LINDSAY A. LOVEJOY, JR., ESQ.

618 Paseo del Peralta, Unit B

Santa Fe, New Mexico 87501

On behalf of the Louisiana Energy Services, L.P.:

JAMES R. CURTISS, ESQ.
MARTIN J. O'NEILL, ESQ.
Winston & Strawn, LLP
1400 L Street, N.W.
Washington, D.C. 20005-3502

On behalf of the Nuclear Regulatory Commission:
LISA CLARK, ESQ.
Nuclear Regulatory Commission

Also Present:
JOHN W. LAWRENCE, ESQ.
National Enrichment Facility

GEORGE RICE
Expert Witness, Groundwater Hydrologist

ALAN TOBLIN
Advanced Technologies and Laboratories
International, Inc.

ABE ZEITOUN, Ph.D.
Advanced Technologies and Laboratories
International, Inc.

I N D E X

WITNESS	EXAMINATION
George R. (Randy) Campbell	
Rod Krich	
Roger L. Peery	
Len Stokes	
Tim Woomer	
Examination By Mr. Lovejoy	4
Nuclear Information & Resource Service and Public Citizen	

EXHIBITS	PAGE	DESCRIPTION
NIRS-Panel-1	31	Krich resume
NIRS-Panel-2	31	Stokes resume
NIRS-Panel 3	31	Peery resume
NIRS-Panel 4	31	Lockwood Greene/Hobbs Meeting minutes, 10/14/03
NIRS-Panel 5	32	Lockwood Greene/Eunice Meeting minutes, 10/13/03
NIRS-Panel 6	32	MOU, Lockwood Greene/City of Hobbs, 12/30/03
NIRS-Panel 7	33	MOU, Lockwood Greene/City of Eunice, 1/21/04
NIRS-Panel 8	37	Lea County Waters Users Association Municipal Water Audit

1 P R O C E E D I N G S

2 Whereupon,

3 GEORGE R. (RANDY) CAMPBELL

4 ROD KRICH

5 ROGER L. PEERY

6 LEN STOKES

7 TIM WOOMER

8 having been first duly sworn, were called as a witnesses

9 herein, and were examined and testified as follows:

10 EXAMINATION

11 BY MR. LOVEJOY:

12 Q Would the witnesses please identify themselves,

13 starting with Mr. Peery.

14 A (Mr. Peery) Roger Peery.

15 A (Mr. Woomer) Tim Woomer.

16 A (Mr. Stokes) Len Stokes.

17 A (Mr. Campbell) Randy Campbell.

18 A (Mr. Krich) Rod Krich.

19 Q Thank you. This is kind of an unusual format.

20 I just feel I should caution everyone and myself at the

21 same time that there's a whole crowd of us here supposed

22 to be talking, and if there's more than one talking at

23 once, nothing good happens at all.

24 Anyway, with that in mind, let's see. Mr.

25 Peery, you've identified yourself in the previous

1 deposition. So we'll turn to Mr. Woomer. Can you state
2 what position you hold professionally now?
3 A (Mr. Woomer) Yes, sir. I'm the utilities
4 director for the City of Hobbs, New Mexico.
5 Q And how long have you been that?
6 A (Mr. Woomer) I've been in that capacity, it
7 will be four years in December.
8 Q And what's your educational background? Could
9 you just --
10 A (Mr. Woomer) I have a --
11 Q -- start with college?
12 A (Mr. Woomer) -- bachelor of science in mining
13 engineering from West Virginia University.
14 Q Do you have any graduate degrees?
15 A (Mr. Woomer) No.
16 Q Okay. Do you have any -- have you had any
17 instruction in matters of hydrology or geology?
18 A (Mr. Woomer) Are you asking about formal
19 classwork?
20 Q Yes.
21 A (Mr. Woomer) No, sir.
22 Q Okay. Do you regard yourself as an expert in
23 matters of hydrology?
24 A (Mr. Woomer) No, sir.
25 Q Are the matters you're going to be testifying

1 about in this proceeding, do they involve hydrology?
2 A (Mr. Woomer) I think you'd probably need to
3 get more specific. Am I going to be testifying about
4 hydrology? Is that what you mean or --
5 Q Yes.
6 A (Mr. Woomer) I don't intend to testify about
7 hydrology.
8 Q Okay. Mr. Stokes, where are you employed now?
9 A (Mr. Stokes) I'm the president of Progressive
10 Environmental Systems.
11 Q And where is that based?
12 A (Mr. Stokes) My home office is in Capitan, New
13 Mexico.
14 Q And are you going to be offering expert
15 evidence in this case?
16 A (Mr. Stokes) Yes.
17 Q On what issues?
18 A (Mr. Stokes) Water supply and water rights
19 administration if asked.
20 Q And what training do you have in the area of
21 water supply and water rights?
22 A (Mr. Stokes) I've been engaged in the -- as a
23 water supply consultant since -- for about ten years.
24 City of Las Cruces, I do all of their water supply, water
25 rights work. City of Alamogordo, I'm the project manager

1 on the permitting of their desalination plant. I'm the
2 contract director of the Lea County Water Users
3 Association, and I'm under contract with the New Mexico
4 State Interstream Commission for the Pecos River
5 Compliance Project.
6 Q Okay. Pardon me. I'm going to look through
7 this. I just received your resume. (Perusing document.)
8 You say you've acted as a water supply
9 consultant for the City of Las Cruces for about ten years.
10 What activities has that involved?
11 A (Mr. Stokes) I deal with their permitting
12 issues, water rights. I negotiate purchases of water
13 rights and contracts with the Elephant Butte Irrigation
14 District on their behalf, I do some lobbying strictly on
15 water issues for the City.
16 Q Do you regard yourself as an expert in water
17 supply and water rights?
18 A (Mr. Stokes) Yes, sir. I've been certified
19 such by the Federal Bankruptcy Court and provided
20 testimony in -- expert testimony in several New Mexico
21 State Engineering proceedings.
22 Q Okay. What proceeding involving the Bankruptcy
23 Court was that?
24 A (Mr. Stokes) That was the Crowder in Judge
25 McPhiely's -- in front of Judge McPhiely. It was the

1 Crowder, Santa Theresa case.

2 Q Okay. Now, Mr. Campbell, can you state your

3 present position?

4 A (Mr. Campbell) Yes, sir. I'm with Lockwood

5 Greene Engineers, and my current position is that of a

6 senior consultant.

7 Q And what's your area of expertise with Lockwood

8 Greene?

9 A (Mr. Campbell) I'm a mechanical engineer, and

10 my area of expertise is in process engineering and in

11 mechanical engineering.

12 Q And what issues are you going to be testifying

13 about in this proceeding?

14 A (Mr. Campbell) The derivation of water usage

15 for the NEF.

16 Q And we don't have your resume. Can you

17 describe what your educational background is --

18 A (Mr. Campbell) Yes, sir. I --

19 Q -- in the relevant areas?

20 A (Mr. Campbell) I have a bachelor's of

21 mechanical engineering technology from the University of

22 North Carolina at Charlotte. And I do not have any

23 advanced degrees.

24 Q Have you testified as an expert in the past?

25 A (Mr. Campbell) No, sir, I have not.

1 Q Mr. Krich, insofar as this deposition is
2 concerned, what areas of expertise, if any, are you going
3 to be testifying in?
4 A (Mr. Krich) Basically the same as Randy. It's
5 the demand of the water for the facility, what the
6 facility needed in terms of its usage.
7 Q And what training and experience do you have in
8 that area?
9 A (Mr. Krich) I am a mechanical engineer and a
10 nuclear engineer. I have done engineering and licensing
11 for 30 years in the nuclear field, so I've done this type
12 of work before.
13 Q Have you testified as an expert?
14 A (Mr. Krich) I have. Yes.
15 Q When has that happened?
16 A (Mr. Krich) That was in an NRC ASLB hearing
17 for the Big Rock Point spent-fuel pool expansion.
18 Q What company was that for?
19 A (Mr. Krich) That was for Consumers Power.
20 Q And what was the substance -- what was the
21 subject of your testimony there?
22 A (Mr. Krich) It was a long time ago. It had to
23 do with cranes and water, basically the supply of cooling
24 water to the spent-fuel pool.
25 Q Okay. Supply or demand?

1 A (Mr. Krich) Supply. And that's based on, of
2 course, the heat loads, so it's based on a demand.
3 Q Okay. Let's start at the left again. Mr.
4 Peery, what is the substance of the facts and opinions
5 you're going to be testifying about the Board in this
6 proceeding, apart from what we've discussed in the other
7 deposition this morning?
8 A (Mr. Peery) Well, water availability in the
9 Lea County Underground Water Basin, and I also have
10 knowledge of the administrative criteria for the Lea
11 County Underground Water Basin, which I can present as
12 well.
13 Q And what conclusions are you going to testify
14 to about water availability in the basin?
15 A (Mr. Peery) Impacts related to pumping the
16 proposed water from the Lea County basin for the LES
17 facility.
18 Q Can you state what conclusion you're going to
19 give the Board?
20 A (Mr. Peery) My conclusion will be that there
21 is a de minimis impact on water in the Ogallala Aquifer.
22 Q And how do you measure -- how do you calculate
23 the impact?
24 A (Mr. Peery) Impact can be calculated in
25 several ways. As a percentage of water withdrawn in

1 relation to the amount of water available in the Lea
2 County Underground Water Basin and the potential
3 additional declines in water levels at existing wells,
4 specifically the Hobbs and Eunice wells.
5 Q Have you calculated those figures, the declines
6 in the percentage of water withdrawn?
7 A (Mr. Peery) I haven't calculated them in a
8 fashion where I've provided them to anyone else, but I
9 have calculated them.
10 Q Can you share your calculations with us? Are
11 they on paper?
12 A (Mr. Peery) No, they're not.
13 Q All right. Can you tell them into the record?
14 A (Mr. Peery) What I did for my calculations on
15 the impacts of water levels was look at published
16 hydrogeologic information, specifically related to the
17 area of the Hobbs and Eunice well field. I looked at the
18 transmissivity of the aquifer in that area, the specific
19 yield of the sediments, and what the proposed withdraw of
20 the equivalent of 75, 80 feet a year would be actually
21 from an individual well. So I looked at a worst-case
22 scenario, not looking at what that withdrawal would be as
23 spread out over numerous wells or several well fields.
24 Q Did you do this all in your head?
25 A (Mr. Peery) No. I did it on my computer.

1 Q And is the data you generated in your computer
2 now?
3 A (Mr. Peery) No.
4 Q What happened to it?
5 A (Mr. Peery) I didn't save the data. I can
6 tell you what my assumptions were. I ran different
7 scenarios.
8 Q Okay. What were your assumptions?
9 A (Mr. Peery) My assumptions were based on State
10 Engineer's Office groundwater flow model for that area,
11 which you can find reference to in the Lea County
12 Underground Water Basin -- or Lea County Regional Water
13 Plan.
14 Q Uh-huh.
15 A (Mr. Peery) It's a 1999 report by Musarieff &
16 Chudnov. I used the transmissivity values they report for
17 the Hobbs well field area and specific yield of that area.
18 Q Do you remember those figures, the
19 transmissivity?
20 A (Mr. Peery) I looked at two different
21 scenarios, one with transmissivity of approximately 80,000
22 GPD per foot, and another with a transmissivity of
23 approximately 50,000 GPD per foot. Specific yield of 23
24 percent and the pumping rate equivalent, the continuous
25 pumping rate equivalent to 75-acre feet per year.

1 Q Where did you get the figure 80,000?

2 A (Mr. Peery) From the State Engineer's

3 published data on hydraulic conductivity for that area.

4 Q Is that in the regional water plan?

5 A (Mr. Peery) By reference, the range of

6 hydraulic conductivities are.

7 Q When you say, by reference, would you be able

8 to find it if I gave you a copy of the plan?

9 A (Mr. Peery) I could probably find where it

10 says the hydraulic conductivity range is from X to X.

11 Q Okay. I just have one kind of marked-up copy

12 here. Do you think you can find it?

13 A (Mr. Peery) I might.

14 MR. CURTISS: What's the document, Lindsay,

15 you're referring to?

16 MR. LOVEJOY: Well, it's a Lea County Regional

17 Water Plan, as run off from the web, from the State

18 Engineer's web site, and I think we gave you the html in

19 our identifying documents.

20 MR. CURTISS: Okay.

21 BY MR. LOVEJOY:

22 Q I don't know if we -- that's the only copy I

23 have. I've been --

24 A (Mr. Peery) It should be understood this is a

25 preliminary estimate. It has not been reviewed by anyone

1 else here at this table, nor anyone in my office, and it's
2 standard for us to do peer review on everything that we
3 do, and that is why I'm just not providing anything
4 written on this.
5 Q I see.
6 A (Mr. Peery) (Perusing document.) Let me read
7 a specific sentence in this Lea County Regional Water
8 Plan. It's on page 6-9. Maybe a couple of sentences.
9 "Hydraulic conductivity reported for various
10 portions of the Ogallala Aquifer in Lea County Underground
11 Water Basin has been evaluated by a number of different
12 authors, using different techniques. Values reported
13 range from 3 to 262 feet per day."
14 "With higher" -- and I'm going to just pick out
15 a select section here. "With higher hydraulic
16 conductivity near the central portion of the basin between
17 Tatum and Lovington, eastward to the Texas border and near
18 Hobbs, specific yields ranging from 10 to 28 percent."
19 Q Was that the source of the data that you used
20 in your calculations?
21 A (Mr. Peery) Yes.
22 Q The figures you gave were 80,000. Is GPD
23 gallons per day?
24 A (Mr. Peery) Gallons per day per foot.
25 Q Per foot. Yes.

1 A (Mr. Peery) But I think I'd like to discuss
2 the more conservative of 50,000 GPD per foot.
3 Q Okay. How did you derive 50,000 from the
4 figures you just dictated?
5 A (Mr. Peery) Just taking a conservative
6 approach.
7 Q Okay.
8 A (Mr. Peery) And that calculates out to -- and
9 a pumping well is an additional decline of approximately a
10 tenth of a foot per year, actually a little bit less than
11 that. So over a 30-year period, I would say that it has a
12 de minimis effect.
13 Q So you'd multiply that figure times 30 to
14 calculate the 30-year effect?
15 A (Mr. Peery) No. I actually calculated a 30-
16 year effect.
17 Q You calculated a 30-year effect.
18 A (Mr. Peery) Uh-huh.
19 Q And was that a tenth of a foot? You said a
20 tenth of a foot per year.
21 A (Mr. Peery) It was a little over two feet for
22 30 years.
23 Q Would there be -- apart from the decline in the
24 water level, which I take you calculated, would there be
25 any other impact on the aquifer from the pumping you

1 hypothesized?

2 A (Mr. Peery) No.

3 Q Do you intend to have your calculations peer-

4 reviewed?

5 A (Mr. Peery) If I'm requested to submit them,

6 certainly they would have to be peer-reviewed.

7 Q Do you intend to write up your calculations?

8 A (Mr. Peery) I hadn't really considered it.

9 Q Okay. Do you intend to do any other

10 calculations in connection with the issues of water

11 supply, broadly speaking, in the LES case?

12 A (Mr. Peery) Not that I can currently think of.

13 Q Do you intend to offer any testimony on any

14 other subjects in connection with the, broadly speaking,

15 water supply issues here?

16 A (Mr. Peery) As I mentioned, I might be able to

17 provide some information on water supply as it relates to

18 administrative -- the State Engineer's administrative

19 criteria for the basin.

20 Q What do you propose to testify concerning at

21 the administrative criteria of the State Engineer?

22 A (Mr. Peery) The fact that -- basically all I

23 was going to do was summarize the fact that the State

24 Engineer's office originally had declared that basin and

25 managed it in such a fashion that it was to be a totally

1 mined groundwater basin. They had intended for that
2 entire basin and let enough water rights out to be mined
3 over a 40-year period.
4 Q Over a what year?
5 A (Mr. Peery) Forty-year period. And we're
6 certainly past the 40-year period at this point, and it
7 hasn't occurred yet.
8 Q What hasn't occurred?
9 A (Mr. Peery) The complete mining of the
10 Ogallala Aquifer. The other thing I would like to say is
11 that the lower portion of the Lea County Underground Water
12 Basin, the Ogallala water, is reserved for municipal and
13 domestic use.
14 Q Reserved by whom?
15 A (Mr. Peery) The State Engineer's office.
16 Q When you say, the lower portion, what do you
17 mean by that?
18 A (Mr. Peery) The lower 40 feet of the aquifer.
19 Q Are you saying that there's a declared policy
20 to set apart the lower 40 feet for only municipal and
21 domestic uses on the part of the State Engineer?
22 A (Mr. Peery) Yes, I am.
23 Q And so you would assume that would not be
24 available for any industrial plant. Is that right?
25 A (Mr. Peery) No. Quite the opposite actually.

1 If an industrial plant were -- any activity where the
2 water's provided from a municipal system, that would be
3 reserved as part of the reservation for the municipal
4 rights.
5 Q Oh, so you're saying that it would be available
6 for a municipality to sell then to an industrial user.
7 A (Mr. Peery) Absolutely.
8 Q Okay. When did the State Engineer declare a
9 basin here to be operated on the basis of mining the
10 aquifer? When did that happen?
11 A (Mr. Peery) Len Stokes might be able to help
12 me with this a little bit on the exact dates.
13 A (Mr. Stokes) It was declared in '51, I
14 believe. Is that correct? Or it was declared in the
15 '40s. Then it was revisited during the '50s.
16 A (Mr. Peery) Reopened in the '50s.
17 A (Mr. Stokes) It was closed and -- when it was
18 first declared, it was closed in reappropriations. Then
19 it was expanded and reopened in '51 for new
20 appropriations. But they -- there's -- all mined basins
21 have criteria for mining. All closed basins do.
22 Q You say they have criteria for mining. What do
23 you mean? Criteria addressing what?
24 A (Mr. Stokes) That we -- every closed basin in
25 the state, which is a basin that has no surface-water

1 discharge from it is called a close basin. All of those
2 basins in the state of New Mexico that are administered by
3 the Engineer -- and I think with the inclusion of the Salt
4 Basin, they all are now -- have criteria that regulates
5 mining. They are all -- withdraws are made in all of them
6 that exceed recharge. The State Engineer administers
7 those withdraws through criteria in each of those basins.
8 Q Okay. And concerning what you've said about
9 the Engineer Office's administrative criteria, what
10 conclusion do you reach that you want to express to the
11 Board hearing this case?
12 A (Mr. Peery) The conclusion is that there will
13 be an ample supply of water for the LES facility, for its
14 proposed 30-year life.
15 Q Do you know what terms LES has reached, if any,
16 with municipal water suppliers?
17 A (Mr. Peery) No, I don't.
18 Q You haven't seen any documentation of that?
19 A (Mr. Peery) I've seen some documentation, but
20 it was not the focus of my studies. I know that they've
21 reached agreements with Eunice and Hobbs, but the
22 specifics of those agreements, I'm probably not the right
23 one to ask.
24 Q Okay. Mr. Woomer, what do you propose to
25 testify about to the Board hearing this case?

1 A (Mr. Woomer) I'm just here to discuss the
2 situation with the water system in Hobbs, the City of
3 Hobbs, and its ability to deliver water and willingness to
4 deliver water to the NEF site.
5 Q Uh-huh. Are you going to testify as an expert
6 on any matters involving the availability of the water to
7 Hobbs to resell?
8 A (Mr. Woomer) I'll be testifying about the
9 knowledge that I have on the Hobbs water system and the
10 ability for Hobbs to deliver the required GPD to the plant
11 site.
12 Q Okay. Well, essentially what are your
13 conclusions going to be?
14 A (Mr. Woomer) My conclusions are that Hobbs has
15 the water rights and the water available and the systems
16 available to deliver the water required by the NEF site.
17 Q And how much water is required by NEF site?
18 A (Mr. Woomer) The requirements for the NEF on
19 what we've been looking at is 65,000 gallons per day,
20 approximately 72 acre-feet per year.
21 Q And what is the duration of that requirement?
22 A (Mr. Woomer) A 30-year period.
23 Q And what investigation have you undertaken to
24 determine that Hobbs has the rights on the water and the
25 systems to deliver that amount?

1 A (Mr. Woomer) Hobbs holds the right to 20,066.4
2 acre-feet of water. We are currently using between -- a
3 little less than 8,000 acre-feet per year.
4 Q Is that all you've done?
5 A (Mr. Woomer) The 72 acre-feet per year
6 probably equates to less than 1 percent of our total
7 usage.
8 Q Uh-huh.
9 A (Mr. Woomer) Which is minimis.
10 Q Have you done any calculations of what the
11 situation will be, say, 30 years after the plant begins
12 operation?
13 A (Mr. Woomer) I have not done any calculations
14 personally. We do have a 20-year plan that accounts for
15 population growth of about 1.4 percent per year. And it
16 describes the system that would be needed at that time.
17 Q And -- all right. Twenty years out, what will
18 the water usage of the Hobbs system be?
19 A (Mr. Woomer) I can't recall exactly what that
20 number is.
21 Q Do you remember what it -- well, is there any
22 projection for what it will be 30 years out?
23 A (Mr. Woomer) For 30 years out?
24 Q Yes.
25 A (Mr. Woomer) No, sir.

1 Q You don't know. And are there any projections
2 of what water will actually be available to Hobbs, say, 20
3 years out, as distinguished from rights?
4 A (Mr. Woomer) For 30 years out? No, sir.
5 Q Twenty --
6 A (Mr. Woomer) Oh, 20? No, sir.
7 Q The question is to 20. Okay.
8 A (Mr. Woomer) No.
9 Q Mr. Stokes --
10 A (Mr. Stokes) Yes, sir.
11 Q Can you give us the substance of the facts and
12 opinions you propose to testify to the Board about?
13 A (Mr. Stokes) Facts and opinions: The fact
14 that the City of Eunice has 4,003 acre-feet of random
15 water rights as recognized by the State Engineer Office.
16 Current usage or usage in 2000, metered usage, was just a
17 little over 2,000 acre-feet per year, and the provision of
18 an additional 75 acre-feet per year water to the site
19 could be done with no problem to the water rights or the
20 well capacities. And that the provision of water by the
21 municipalities to the facility is authorized under Chapter
22 3 of the statutes.
23 Q Have you done any estimates of the ability of
24 Eunice to deliver water to the NEF out, say, 30 years from
25 today?

1 A (Mr. Stokes) The -- I have done so straight
2 calculations. The 40-year water plan has information in
3 it dealing with the wells and the rights -- when those
4 rights are permitted, the administration of those rights
5 are done on a 40-year period, and there will be water,
6 according to the State Engineer administrative policy, for
7 water to be available for 30 years. The State Engineer
8 does those calculations. I don't.
9 Q So it's his problem then.
10 A (Mr. Stokes) No. It is based -- the supply of
11 water is based upon the administrative criteria and the
12 models developed by the State Engineer Office.
13 Q Okay. So they've done that model.
14 A (Mr. Stokes) That's correct.
15 Q And you're relying on their model in that
16 respect.
17 A (Mr. Stokes) The water rights -- the modeling
18 was done to ensure the viability of the 4,000 acre-feet of
19 withdrawals, and the additional 75 acre-feet fits very
20 well into that 4,000 number.
21 Q Okay. You speak of a 40-year water plan. What
22 is this plan?
23 A (Mr. Stokes) The regional plan that you have
24 in front of you.
25 Q The Lea County plan.

1 A (Mr. Stokes) That's correct.

2 Q Okay. Are you going to offer testimony on any

3 other subjects in this proceeding, other than what you've

4 just described?

5 A (Mr. Stokes) Only if I'm asked.

6 Q Okay. Do you know if the City of Eunice or the

7 utility for the City of Eunice has entered into a

8 commitment to deliver water to the NEF?

9 A (Mr. Stokes) I believe that Mr. Krich is

10 probably the person to answer that question, as he has

11 been in negotiations with the City of Eunice and with

12 Hobbs.

13 Q Okay. Mr. Campbell, can you tell us the

14 substance of the opinions and facts that you're going to

15 testify to the Board about in this case?

16 A (Mr. Campbell) I'll be testifying in regards

17 to what Lockwood Greene did to determine the water usage

18 for the facility. We were also somewhat instrumental in

19 determining the source of water, i.e., Eunice and Hobbs.

20 I will discuss that if necessary and any other things that

21 I may be asked to discuss.

22 Q Okay. Well, what are you going to testify to

23 about the efforts of Lockwood Greene to identify the water

24 demand?

25 A (Mr. Campbell) We will discuss the methodology

1 that we used to determine water quantities, from both the
2 process engineering perspective and the mechanical
3 engineering perspective.
4 Q. And where can I find these calculations in
5 writing since I don't want to ask you to try to recall
6 them?
7 A (Mr. Campbell) They're all submitted in our
8 design documents, the basis of design documents, our
9 narratives, et cetera.
10 Q Are they in the materials submitted to the NRC?
11 A (Mr. Campbell) Yes, sir.
12 Q They are? Okay.
13 MR. CURTISS: I believe that's the case.
14 BY MR. LOVEJOY:
15 Q Are they in the application or in response to
16 RAIs?
17 A (Mr. Campbell) They are in the application.
18 Q Okay. Now, what was the bottom line, so to
19 speak, of water demand at the -- you attributed to the
20 facility?
21 A (Mr. Campbell) Total water quantity was 63.5
22 thousand gallons per day for all water usage.
23 Q And was that pure drinking water?
24 A (Mr. Campbell) I'm sorry?
25 Q Was that drinking water that was required,

1 potable water?

2 A (Mr. Campbell) Yes, sir.

3 Q Okay. And I think you said there was some

4 other matter that you were going to testify about, in

5 addition to Lockwood Greene's efforts to calculate the

6 water demand. There's something about the acquisitions of

7 rights.

8 A (Mr. Campbell) We were instrumental -- not the

9 acquisition of rights. We were involved with discussions

10 with the City of Eunice and Hobbs on initial discussions

11 on obtaining water from both of those.

12 Q And did you describe the proposed plant's needs

13 to officials of Eunice of Hobbs?

14 A (Mr. Campbell) When we began our discussions

15 with both, we had preliminary numbers as to usage, and we

16 discussed preliminary numbers. As time progressed, we

17 finalized and got down to the last number of the 63.5

18 thousand a day.

19 Q Were your earlier numbers bigger or smaller?

20 Do you remember?

21 A (Mr. Campbell) Earlier numbers were larger.

22 Q In the discussions with Hobbs and Eunice, did

23 you, on behalf of -- working on behalf of LES, did you

24 characterize the assurance of supply that was necessary

25 for this facility?

1 A (Mr. Campbell) We did discuss the criticality
2 of the reliability of the supply.
3 Q And what did you say?
4 A (Mr. Campbell) We explained to them what the
5 water was for and the necessity of having a reliable water
6 source.
7 Q Did you discuss with them what kind of priority
8 among users the NEF would have?
9 A (Mr. Campbell) Not that I could recollect.
10 Q And have you reached agreement with both cities
11 now concerning water supply?
12 A (Mr. Campbell) Yes, sir. We have a memorandum
13 of understanding from both Hobbs and Eunice.
14 Q And what is your understanding of the assurance
15 of supply contained in the memorandum, let's say, first
16 for Hobbs?
17 A (Mr. Campbell) Both entities have agreed to
18 supply 100 percent of the water quantity necessary.
19 Q Sometimes utilities assign to certain customers
20 or classes of customers relative priorities as users. Do
21 you understand whether the proposed NEF has any particular
22 priority assigned to it by either Hobbs or Eunice?
23 A (Mr. Campbell) I recollect having read
24 something that the NEF would be a high-priority user, and
25 if I recollect correctly, if water rationing began, it

1 would be one of the last facilities to be rationed on the
2 water plan.
3 Q And where did you read that?
4 A (Mr. Campbell) I'm sorry. I don't remember.
5 Q Did that relate to supply from Hobbs or from
6 Eunice?
7 A (Mr. Campbell) I'm fairly confident it was
8 from Hobbs.
9 Q All right. Mr. Krich, in this proceeding as
10 regards matters of water supply, what subjects are you
11 going to be testifying on?
12 A (Mr. Krich) Same subject pretty much as Randy.
13 That is, the analysis that led to the determination of how
14 much water the plant will need.
15 Q Are you going to testify about the supply
16 obtained?
17 A (Mr. Krich) I was involved in -- as a manager
18 for the overall project. I was the one who agreed or gave
19 the go-ahead for these MOUs to be signed.
20 Q Okay. And what is the substance of your
21 testimony going to be concerning the calculation of water
22 requirements?
23 A (Mr. Krich) That the calculation that was done
24 is a -- has been thoroughly reviewed. It uses standard
25 methods that in our analysis we have included in the

1 design of the plant, water conservation measures to
2 minimize the amount of consumptive use of water at the
3 plant, and that our usage is on the order of about 71, 72
4 acre-feet per year, which is by comparison to other common
5 usage pretty low. And what I mean, common usage, such as
6 farms or golf courses.
7 Q And what is the duration of the water supply
8 commitments that you've obtained for this facility?
9 A (Mr. Krich) Both the memorandum of
10 understanding from City of Hobbs and the City of Eunice
11 state explicitly that the supply will be for 30 years.
12 Q Starting when?
13 A (Mr. Krich) Starting when the plant operates,
14 I believe. Starting when we request, I think is the way
15 it reads.
16 Q And when do you expect that request to be made?
17 A (Mr. Krich) When we're going to start needing
18 the water.
19 Q And in what year?
20 A (Mr. Krich) What year? We have said in the
21 Hobbs -- in the memorandum of understanding with the City
22 of Hobbs, we've estimated that initial use will start
23 about 2007, so we'll obviously need water on the site as
24 we go through construction.
25 Q Have you done anything to determine that water

1 will, in fact, be available for 30 years from that point?
2 A (Mr. Krich) We have looked at the amount of
3 water, the capacity of water, from both the City of Hobbs
4 and the City of Eunice. The numbers that Mr. Woomer and
5 Mr. Stokes gave and that satisfied us that our usage was
6 so small as to be inconsequential to the supply of water
7 for a long period of time, certainly to cover 30 years.
8 Q When you say capacity, what are you referring
9 to?
10 A (Mr. Krich) I'm referring to the numbers that
11 Mr. Woomer gave for the amount of water that the City of
12 Hobbs has at their -- that they have right to. I think --
13 and, Tim, you'll have to help me out. It's 20,000 acre-
14 feet?
15 A (Mr. Woomer) 20,066.4 acre-feet.
16 Q So you judged the capacity based on water
17 rights.
18 A (Mr. Krich) We judged the capacity based on
19 what both the City of Hobbs and the City of Eunice told us
20 that they had in terms of water capacity.
21 Q Expressed in what units?
22 A (Mr. Krich) In acre-feet per year.
23 Q Water rights. Is that what you're saying?
24 A (Mr. Krich) I -- we didn't get into whether
25 they were water rights or what they were. We just were

1 interested in their capacity.

2 MR. LOVEJOY: Okay. I'd like to mark these as

3 Exhibits 1, 2, and 3. These are the resumes that we've

4 been supplied.

5 (The documents referred to were

6 marked for identification as

7 Exhibits NIRS-Panel-1 through

8 NIRS-Panel-3.)

9 BY MR. LOVEJOY:

10 Q I'd like the witnesses just to identify these.

11 Mr. Krich, would you please identify Exhibit 1? Mr.

12 Stokes, would you please identify Exhibit 2, and Mr.

13 Peery, Exhibit 3. We can take it in numerical order.

14 Mr. Krich, would you state for the record what

15 is Exhibit 1?

16 A (Mr. Krich) Exhibit 1 is my resume.

17 Q Okay. Mr. Stokes, is Exhibit 2 you resume?

18 A (Mr. Stokes) It is.

19 Q And, Mr. Peery, is Exhibit 3 yours?

20 A (Mr. Peery) Yes, it is.

21 MR. LOVEJOY: All right. Let's hand these back

22 to the reporter, for the record.

23 Let's mark this as -- this will be Number 4.

24 (The document referred to was

25 marked for identification as

1 Exhibit NIRS-Panel 4.)

2 MR. LOVEJOY: Do you have Number 4?

3 THE REPORTER: Yes.

4 MR. LOVEJOY: The witness needs it.

5 BY MR. LOVEJOY:

6 Q Mr. Campbell, would you look at Number 4 and

7 tell us if you can identify that, please.

8 A (Mr. Campbell) Yes, sir. These are meeting

9 minutes from the meeting that we had with the officials at

10 Hobbs.

11 MR. LOVEJOY: Okay. Let's mark this one also.

12 So it would be Number 5.

13 (The document referred to was

14 marked for identification as

15 Exhibit NIRS-Panel 5.)

16 BY MR. LOVEJOY:

17 Q Mr. Campbell, would you also please look at

18 Number 5 and identify that if you can.

19 A (Mr. Campbell) Yes, sir. These are meeting

20 minutes from our meeting with the officials at Eunice.

21 Q Did you prepare Number 4 and Number 5?

22 A (Mr. Campbell) Yes, sir.

23 MR. LOVEJOY: Okay. Let's move right ahead and

24 mark this one. This will be Number 6.

25 (The document referred to was

1 marked for identification as
2 Exhibit NIRS-Panel 6.)
3 BY MR. LOVEJOY:
4 Q And this one seems to be signed by Mr. Woomer,
5 so let's ask him to identify it if he can. Mr. Woomer,
6 can you identify that as a copy of a document that you
7 signed?
8 A (Mr. Woomer) Yes, it is.
9 Q Is this the memorandum of understanding with
10 Lockwood Greene on behalf of NEF concerning water
11 supply --
12 A (Mr. Woomer) Yes, it is.
13 Q -- by the City of Hobbs? Okay.
14 MR. LOVEJOY: Let's mark this one, too.
15 (The document referred to was
16 marked for identification as
17 Exhibit NIRS-Panel 7.)
18 BY MR. LOVEJOY:
19 Q Mr. Stokes, would you take a look at Number 7
20 and tell us if you can identify that.
21 A (Mr. Stokes) No. I'm not the one to identify
22 it. I did not negotiate this or sign this.
23 Q Okay. Let's hand it to Mr. Krich. Maybe he
24 knows.
25 A (Mr. Stokes) (Handing document.)

1 Q Can you identify that document?
2 A (Mr. Krich) Yes, I can.
3 Q What is that?
4 A (Mr. Krich) This is the memorandum of
5 understanding that we have signed between us, with John
6 Shaw acting as our agent, and the City of Eunice.
7 Q Okay. Mr. Woomer, do you have Number 6?
8 A (Mr. Woomer) Yes, sir.
9 Q Under this agreement, what priority of water
10 usage would the proposed NEF as a utility customer?
11 A (Mr. Woomer) As part of our agreement, the NEF
12 site would have first priority of the water going down to
13 the Eunice site.
14 Q Eunice site being the NEF site. Is that what
15 you mean?
16 A (Mr. Woomer) Yes, sir.
17 Q Do you have any other utility customers that
18 have first priority?
19 A (Mr. Woomer) We have a ordinance in place, a
20 rationing ordinance in place for the City of Hobbs that
21 prioritizes from non-essential use such as irrigation is
22 the first to be curtailed.
23 Q Uh-huh.
24 A (Mr. Woomer) Then the next tier of
25 nonessentials would be car washes, operations of that

1 nature. Of course, in the meantime, there is rationing on
2 lawn irrigation for residents.
3 Q Uh-huh.
4 A (Mr. Woomer) And that's pretty much the
5 priority scale.
6 Q You said irrigation is ranked among the
7 nonessential uses. Is that --
8 A (Mr. Woomer) It is the first to be --
9 Q -- agricultural irrigation or --
10 A (Mr. Woomer) This is municipal use. There is
11 no agricultural use on our system.
12 Q Okay. So how many categories of priority are
13 there under your system?
14 A (Mr. Woomer) I don't recall exactly. I would
15 have to review the ordinance to give you that exact
16 answer.
17 Q Well, how many users exist in the same category
18 that NEF has under this agreement?
19 A (Mr. Woomer) I don't recall that exact number.
20 They would be grouped as an industrial user, which is a
21 new category that we just instituted to handle our
22 pretreatment program.
23 Q All right.
24 A (Mr. Woomer) That will be a combination which
25 will be garnered out of our commercial classification of

1 customers that we currently have.

2 Q So this is a new category, and is NEF the first

3 one in --

4 A (Mr. Woomer) Yes.

5 Q -- this category?

6 A (Mr. Woomer) And the rationing is based on

7 usage, not exactly classification for billing.

8 Q Did you say the rationing is based on usage?

9 A (Mr. Woomer) That's what I --

10 Q What do you mean?

11 A (Mr. Woomer) Irrigation usage is the first to

12 be rationed.

13 Q Yes. Okay. Mr. Krich, looking at Exhibit 7,

14 can you tell us what priority you believe the NEF would

15 have under this commitment by the City of Eunice?

16 A (Mr. Krich) I can't. There is no -- there's

17 no priority specified in the MOU.

18 Q Have you been advised of any particular

19 priority that you would have?

20 A (Mr. Krich) Not that I'm aware of. No. Nor

21 have we requested a priority.

22 Q Did you request a particular priority in the

23 City of Hobbs?

24 A (Mr. Krich) No.

25 Q But it was expressed to Hobbs and to Eunice on

1 behalf of NEF that assurance of supply was important, was
2 it not?
3 A (Mr. Krich) Assurance of supply or reliability
4 of supply is important for asset protection.
5 Q The asset being the NEF.
6 A (Mr. Krich) Well, being the machines in the
7 NEF. It's not required for safety. It's required for
8 asset protection.
9 MR. LOVEJOY: This is Exhibit 8, I believe.
10 (The document referred to was
11 marked for identification as
12 Exhibit NIRS-Panel 8.)
13 BY MR. LOVEJOY:
14 Q Okay. Mr. Campbell, would you look at Exhibit
15 8 and tell us if you can identify that as something you've
16 seen.
17 A (Mr. Campbell) (Perusing document.) Yes, sir.
18 I have seen it.
19 Q And is this document the audit, the Lea County
20 Municipal Water Audit document?
21 A (Mr. Campbell) As far as I'm aware, yes, sir.
22 Q Okay. I've got a number of questions for
23 different people about this. Could you hand it over to
24 Mr. Stokes, please.
25 A (Mr. Campbell) (Handing document.)

1 Q Would you look at the page captioned, LES-1184
2 in the lower right corner.
3 A (Mr. Stokes) Yes.
4 Q Under, Water Production -- you may want to read
5 that paragraph -- there's a reference to wells in an area
6 called Nadine.
7 A (Mr. Stokes) That's correct.
8 Q Are you familiar with that area?
9 A (Mr. Stokes) Yes, sir.
10 Q Where's it located?
11 A (Mr. Stokes) It's about halfway between Hobbs
12 and Eunice.
13 Q And --
14 A (Mr. Stokes) It's on the very southern end of
15 the Ogallala Aquifer.
16 Q There's a statement that, "When the Nadine
17 wells became contaminated, water production was shifted
18 north." Are you aware of contamination of the wells at
19 Nadine?
20 A (Mr. Stokes) Yes, I am.
21 Q What's the cause of the contamination?
22 A (Mr. Stokes) There was some hydrocarbon
23 contamination in the wells.
24 Q How did that happen?
25 A (Mr. Stokes) Well, they're in the middle of an

1 oil patch.

2 Q Was there an accident, or was this --

3 A (Mr. Stokes) Just over time --

4 Q -- a natural phenomenon?

5 A (Mr. Stokes) Just over time -- Roger may know

6 more about the Nadine contamination out of the water deal,

7 but it's a hydrocarbon contamination. It's a low-level

8 contamination, but they did move their production source

9 further northwest of Hobbs.

10 Q These wells are now out of use -- is that

11 right? -- at Nadine.

12 A (Mr. Stokes) Those wells are not being used at

13 the current time. However, the rights from those wells

14 are valid, and those -- water was used there for water-

15 plug purposes in a lease that just expired last year.

16 Q It was used for what purpose?

17 A (Mr. Stokes) Water-plug purposes for oil

18 extraction purposes. It was leased by the City of Eunice,

19 I believe, to Conoco. That lease expired in 2003. That

20 water is available.

21 Q But it's not potable water, is it?

22 A (Mr. Stokes) It is available and could be made

23 potable with treatment.

24 Q Mr. Peery, are you better informed about the

25 origins of contamination at the Nadine wells?

1 A (Mr. Peery) No, I'm not. I don't have
2 anything to add to what Len said.
3 Q Okay. Mr. Woomer, Hobbs has a so-called
4 increasing block or rate structure in system for water
5 consumption, doesn't it?
6 A (Mr. Woomer) Inclining block --
7 Q Inclining block?
8 A (Mr. Woomer) -- rate structure. Yes, sir.
9 Q And what's the purpose of that?
10 A (Mr. Woomer) It is -- its main purpose is to
11 make sure that the utilities is solvent fiscally through a
12 rate structure and rate analysis for cost of service. And
13 there are several different rate structures that you can
14 put into place: flats, volumetric, inclining or declining
15 block. And Hobbs chose to institute an inclining block to
16 encourage conservation of water resources.
17 Q Does the inclining block -- does the same rate
18 structure apply to all customers of the water system at
19 Hobbs?
20 A (Mr. Woomer) Yes, it does.
21 Q Is there any witness here who is knowledgeable
22 in the rate structure for Eunice?
23 A (Mr. Stokes) No.
24 Q So there's nobody who knows whether Eunice has
25 an inclining block system. Okay. Let me just check

1 something here.

2 (Pause.)

3 BY MR. LOVEJOY:

4 Q Does any one of the witnesses here know what

5 changes in water usage in Lea County are projected to

6 occur over, say, the next 40 years?

7 A (Mr. Peery) I think it's in the regional water

8 plan there.

9 Q And you worked on the plan, didn't you?

10 A (Mr. Peery) Yes, I did.

11 Q And what projection of water usages is there

12 contained for the next 40 years, 40 years from the report?

13 A (Mr. Peery) It projects an increase in water

14 use.

15 Q To what extent?

16 A (Mr. Peery) I don't have the specific figures

17 in front of me.

18 Q Let me be fair to you and show you the report.

19 On the second page of the executive summary, you can see

20 the highlighted provision. See if that refreshes your

21 recollection.

22 A (Mr. Peery) (Perusing document.) I'm just

23 going to read this out loud --

24 Q Please, please.

25 A (Mr. Peery) It says, "Over the next 40 years,

1 if unrestrained, water use in Lea County is estimated to
2 increase to approximately 360,000 acre-feet, 105 percent
3 greater than the 1995 totals."
4 Q Okay.
5 A (Mr. Peery) And I think the key point there is
6 "if unrestrained."
7 Q And why do you say that's the key point?
8 A (Mr. Peery) As I mentioned earlier, the State
9 Engineer does have provisions in to save the lower part of
10 the aquifer, if it should become necessary, for municipal
11 and domestic use. So obviously the State Engineer's
12 administration would require them to stop other uses to
13 save that water for the municipal and domestic uses.
14 Q And what other uses do you have in mind when
15 you say that?
16 A (Mr. Peery) Agriculture. That would be the
17 primary one, since it accounts for something on the order
18 of -- I don't remember the exact number -- maybe 80
19 percent of the basin use.
20 Q And do you foresee that within the 40 years
21 from this report, it's going to be necessary to stop some
22 agricultural use, to restrain it?
23 A (Mr. Peery) It's hard to predict the future.
24 We don't know who is going to put their water rights into
25 play and who is not going to use their water rights. The

1 report basically assumed that the vast majority of
2 existing water rights and declarations for water -- which
3 aren't true water rights; they're just a declaration of
4 the water right -- would be used for agricultural
5 purposes.
6 MR. CURTISS: Lindsay, can we take a break at
7 this point, if we could?
8 MR. LOVEJOY: Sure. Let's take a break.
9 (Whereupon, a short recess was taken.)
10 THE WITNESS: (Mr. Peery) Mr. Lovejoy, if I
11 could try to --
12 BY MR. LOVEJOY:
13 Q Please, go right ahead.
14 A (Mr. Peery) -- try to clarify where I was
15 headed when we took a break. What the report did was look
16 at a worst-case scenario for water use in a Lea County
17 Underground Water Basin. As I was mentioning, it was
18 assuming that all the declared and permitted water rights
19 would be used for agricultural lands.
20 In addition to all the lands that are currently
21 in the CRP, which is the Crop Reserve Program, which
22 allows agricultural lands to be taken out of production,
23 but the water rights to be -- not lost, but to remain with
24 the land going back into production. So it was really
25 looking at worst-case scenario for the basin.

1 Q Can you --

2 A (Mr. Peery) And the fact of the matter is that
3 as water levels declined, it's more and more difficult for
4 the agricultural industry to continue on, because it
5 becomes uneconomical for them. So what happens eventually
6 is when the saturated thickness drops, starts to drop too
7 much for them to make money, because it's more expensive
8 to pump water to the surface where they need more wells to
9 make the same amount of water, then agricultural uses
10 naturally slow down also.

11 Q Can you point to the place in this plan where
12 it says that it's describing a worst-case scenario?

13 A (Mr. Peery) No. I can't -- I don't think that
14 it says in the plan that it is a worst-case scenario. But
15 it certainly is the worst-case scenario.

16 A (Mr. Stokes) May I interject one thing?

17 Q Please.

18 A (Mr. Stokes) You probably, being with the AG
19 Office, understand why the 40-year regional water plans
20 were developed. Statutory reasons to develop those water
21 plans was it was a way that the regions in the state of
22 New Mexico could put on paper that they needed every drop
23 of water in a certain basin of New Mexico for use in New
24 Mexico, so that it would not have to be exported to Texas.
25 It is definitely a worst-case scenario. I managed the

1 project.

2 Q Okay. Mr. Peery, you gave your calculations of

3 the impact, assuming one single well were used as a

4 source.

5 A (Mr. Peery) Uh-huh. That's really unlikely.

6 Q How many wells does Eunice have?

7 A (Mr. Peery) They currently have four they're

8 operating, and I don't recall the number that Hobbs has.

9 Q Uh-huh. Let me draw your attention to the

10 highlighted language on page 6-9 of the regional water

11 plan. You can read it into the record for clarity.

12 A (Mr. Peery) "Because pumping is in excess of

13 the Ogallala's recharge rate, elevation at the top of the

14 aquifer has declined or experienced drawdown. The recent

15 groundwater flow model indicated that, in response to

16 heavy pumping in Texas, the most severe drawdowns occur

17 along Lea County's east border, the Texas line.

18 "In this area, draw-downs in excess of 60 feet

19 have occurred since 1940. The model predicts that the

20 saturated thickness will decrease by another 50 to 100

21 feet in the area between the state line and the

22 communities of Hobbs, Lovington and Tatum in the next 40

23 years. Actual drawdowns could be much greater than this

24 amount."

25 Q If drawdowns occur at the rate projected there,

1 say -- rather, a decrease in saturated thickness by 50 to
2 100 feet in the area of the well that you hypothesized,
3 would your calculations still reach the same result?
4 A (Mr. Peery) Oh, yes. My calculation would
5 have reached the same result, but the fact of the matter
6 is, the area --
7 (Interruption at door.)
8 THE WITNESS: (Mr. Peery) Let me clarify my
9 last comment. Naturally the hydraulic properties of the
10 aquifer are related to the saturated thickness, so it
11 could have had an impact if it was 100 or 150 foot of
12 drawdown over a period of time.
13 There is ample saturated thickness in the
14 Ogallala in the areas west of Hobbs, and primarily, in all
15 actuality, throughout the westernmost portion of the
16 basin, there's very little agriculture in the western
17 portion of the basin, because there's very little soil, so
18 it's very difficult to grow anything there.
19 And if you want to look at the perspective of
20 the amount of water that's going to be needed at the LES
21 facility in terms of the current water in storage in the
22 Lea County Basin, Underground Water Basin, there's
23 approximately 31 million acre-feet of water in storage in
24 the Lea County Underground Water Basin. If you look at
25 LES's --

1 BY MR. LOVEJOY:

2 Q What was that number? Sorry.

3 A (Mr. Peery) 31 million acre-feet. If you

4 compare LES's needs to that quantity, you're looking at

5 well less than .01 percent of available water from the Lea

6 County Underground Water Basin.

7 Q And what amount would be in storage in, say,

8 20/40?

9 A (Mr. Peery) I would have to look at that.

10 (Perusing document.)

11 Referring to your highlighted section, it says,

12 "It follows that approximately only 8 million acre-feet of

13 recoverable water will exist in 2040 if continuation of

14 1998 pumping rates occur. The bulk of this figure will

15 also probably be located away from existing well fields

16 due to drawdown in the aquifer." So it still is a

17 substantial amount of water.

18 Q And would --

19 A (Mr. Peery) And that 8 million acre-feet of

20 recoverable water was taken as 45 percent of the water in

21 storage. So it says here, "Approximately 14 million acre-

22 feet of water would still be in storage, 8 million

23 recoverable." So still a significant quantity.

24 Q And would your calculation as to the extent of

25 drawdown attributable to the facility be the same under

1 those circumstances, the ones you just referred to?

2 A (Mr. Peery) It would be specific to the

3 drawdown at the particular site, so I would have to look

4 at the projected drawdown at the end of the 40-year period

5 and calculate that.

6 Q You'd have to do a new calculation. Is that

7 right?

8 A (Mr. Peery) I'd have to review my

9 calculation --

10 Q Would your --

11 A (Mr. Peery) -- because those drawdowns don't

12 occur evenly throughout the basin, so that's the important

13 thing to know.

14 Q Would the figure you used for transmissivity be

15 the same if there were significant drawdowns as described

16 in the document?

17 A (Mr. Peery) Since I already started with a

18 conservative transmissivity, I'm not sure.

19 Q Okay. Were there -- in the calculations you

20 did, were there any boundary conditions with respect to

21 the single well that you've assumed?

22 A (Mr. Peery) No.

23 Q Nothing. Okay.

24 A (Mr. Peery) Again, looking at one well -- I

25 mean, you're talking about all the water coming out of one

1 well, when the fact of the matter is it's going to come
2 out of two well fields -- does provide a conservative
3 estimate.
4 MR. LOVEJOY: Okay. That's all I have. Thank
5 you all.
6 MR. CURTISS: That's it.
7 THE WITNESS: (Mr. Krich) One point of
8 clarification, which I'm not sure is there, and that is
9 simply that the supply from Hobbs and the supply from
10 Eunice are redundant supply for the plant, and I don't
11 know whether you're aware of that, but either supply will
12 provide enough for the plant to operate, both are not
13 needed at the same time.
14 MR. CURTISS: We're done?
15 MR. LOVEJOY: We're done.
16 (Whereupon, at 3:15 p.m., the taking of the
17 instant deposition was concluded.)
18
19
20
21
22
23
24
25

CERTIFICATE

This is to certify that the foregoing proceedings

in the matter of: The Deposition of
George R. Campbell
Rod Krich
Roger L. Peery
Len Stokes
Tim Woomer

held on: September 17, 2004

at the location of: Santa Fe, NM

were duly recorded and accurately transcribed under my direction; further, that said proceedings are a true and accurate record of the testimony given by said witness; and that I am neither counsel for, related to, nor employed by any of the parties to this action in which this deposition was taken; and further that I am not a relative nor an employee of any of the parties nor counsel employed by the parties, and I am not financially or otherwise interested in the outcome of the action.

Carol Oppenheimer

Carol Oppenheimer

AUTHENTICATION BY SIGNATURE

I, the undersigned, do hereby certify by my signature hereunder that I have read the foregoing deposition of testimony given by me on September 17, 2004, and find said transcription to be a true and accurate record, as corrected.

George R. Campbell

George R. Campbell

Sworn to and subscribed before me this 13 day of OCTOBER, 2004.

Harriet L. Davis

Notary Public

My commission expires My Commission Expires January 23, 2014.

0917LOVE

NEAL R. GROSS & CO., INC.
1323 RHODE ISLAND AVENUE, NW
WASHINGTON, D.C. 20005
TELEPHONE (202) 234-4433

ERRATA ERRATA

RE THE DEPOSITION OF GEORGE R. CAMPBELL
(deponent's name)

TAKEN ON SEPT. 17, 2004,
(date)

IN THE MATTER OF

_____ v. _____
(party) (party)

DOCKET NO._____.

IN_____.
(name of court)

PAGE NO.	LINE NO.	CORRECTION
		NO CORRECTIONS NECESSARY
		George R Campbell

AUTHENTICATION BY SIGNATURE

I, the undersigned, do hereby certify by my signature hereunder that I have read the foregoing deposition of testimony given by me on September 17, 2004, and find said transcription to be a true and accurate record, as corrected.

_____
Rod Krich

Sworn to and subscribed before me this _____day of _____, 20__ __.

_____
Notary Public

My commission expires _____.

AUTHENTICATION BY SIGNATURE

I, the undersigned, do hereby certify by my signature hereunder that I have read the foregoing deposition of testimony given by me on September 17, 2004, and find said transcription to be a true and accurate record, as corrected.

_____
Roger L. Peery

Sworn to and subscribed before me this _____day of _____, 20__ __.

_____
Notary Public

My commission expires _____.

AUTHENTICATION BY SIGNATURE

I, the undersigned, do hereby certify by my signature hereunder that I have read the foregoing deposition of testimony given by me on September 17, 2004, and find said transcription to be a true and accurate record, as corrected.

Len Stokes

Sworn to and subscribed before me this 3rd day of November, 2004.

Terri Hemphill
Notary Public

My commission expires March 31, 2006.

0917LOVE

NEAL R. GROSS & CO., INC.
1323 RHODE ISLAND AVENUE, NW
WASHINGTON, D.C. 20005
TELEPHONE (202) 234-4433

ERRATA ERRATA

RE THE DEPOSITION OF Len Stokes
(deponent's name)

TAKEN ON _____,
(date)

IN THE MATTER OF

_____ v. _____
(party) (party)

DOCKET NO. _____.

IN _____.
(name of court)

PAGE NO.	LINE NO.	CORRECTION
18	18	Closed to new appropriations
~~20~~ 18	20	Delete But they -- there's -- Capitalizing All
	24	Delete - That we (Cap) Every
19	3	Engineer (s)
~~6~~ 19	5	They are all (mined.) Withdrawals
		~~or pumping~~
	7	WITHDRAWALS
23	1	Delete: The -- ; STRAIGHT
		I have done no calculations
	3	Delete -- add and
	4	permitted. The
	5	Del. are - add is
	6	Delete , for
	7	Delete water to be available
	10	Delete It is based --
	17	Delete The water rights
39	~~20~~ 17	WATER FLOOD

AUTHENTICATION BY SIGNATURE

I, the undersigned, do hereby certify by my signature hereunder that I have read the foregoing deposition of testimony given by me on September 17, 2004, and find said transcription to be a true and accurate record, as corrected.

Tim Woomer

Tim Woomer

Sworn to and subscribed before me this 20th day of October, 2004.

Elizabeth A. Sujer

Notary Public

My commission expires Oct. 2, 2007.

ANL/EAD/TM-110

Evaluation of UF_6-to-UO_2 Conversion Capability at Commercial Nuclear Fuel Fabrication Facilities

Environmental Assessment Division
Argonne National Laboratory

Operated by The University of Chicago,
under Contract W-31-109-Eng-38, for the

United States Department of Energy

Argonne National Laboratory

Argonne National Laboratory, with facilities in the states of Illinois and Idaho, is owned by the United States Government and operated by The University of Chicago under the provisions of a contract with the Department of Energy.

This technical memorandum is a product of Argonne's Environmental Assessment Division (EAD). For information on the division's scientific and engineering activities, contact:

Director, Environmental Assessment Division
Argonne National Laboratory
Argonne, Illinois 60439-4832
Telephone (630) 252-3107

Presented in this technical memorandum are preliminary results of ongoing work or work that is more limited in scope and depth than that described in formal reports issued by the EAD.

Publishing support services were provided by Argonne's Information and Publishing Division (for more information, see IPD's home page: http://www.ipd.anl.gov/).

Disclaimer

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 The University of Chicago, nor any of their employees or officers, 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 document authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, Argonne National Laboratory, or The University of Chicago.

Available electronically at http://www.doe.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

ANL/EAD/TM-110

Evaluation of UF_6-to-UO_2 Conversion Capability at Commercial Nuclear Fuel Fabrication Facilities

by N.L. Ranek and F.A. Monette

Environmental Assessment Division
Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439

May 2001

Work sponsored by U.S. Department of Energy, Office of Environmental Management, Office of Site Closure, Oak Ridge Office, Oak Ridge, Tennessee

This report is printed on recycled paper.

CONTENTS

NOTATION v

ABSTRACT 1

1 INTRODUCTION 1

1.1 Purpose 1
1.2 Background 2

2 CHARACTERIZATION OF COMMERCIAL NUCLEAR FUEL FABRICATION FACILITIES 3

2.1 Overview of U.S. Facilities 3
2.1.1 Westinghouse Electric Company LLC – Columbia Fuel Fabrication Facility 3
2.1.2 BWX Technologies, Inc. – Naval Nuclear Fuel Division 5
2.1.3 CE Nuclear Power LLC – Hematite Fuel Manufacturing Operations 7
2.1.4 Framatome ANP Richland, Inc. – Engineering and Manufacturing Facility 7
2.1.5 Framatome ANP, Inc. – Lynchburg Manufacturing Facility 9
2.1.6 Global Nuclear Fuel – Americas, LLC 10
2.1.7 Nuclear Fuel Services, Inc. – Erwin Facility 12
2.1.8 Honeywell International – Metropolis Works 13
2.2 Overview of Non-U.S. Facilities 14
2.2.1 France 14
2.2.2 United Kingdom 15
2.2.3 Japan 16
2.2.4 Germany 16
2.2.5 Belgium 16
2.2.6 Sweden 17
2.2.7 Korea 17
2.2.8 Brazil 17
2.2.9 Other Countries 18

3 TRANSPORTATION 19

4 REGULATORY CONSIDERATIONS 21

4.1 United States 21
4.2 Foreign Countries 22
4.3 Transportation 22

5 ANALYSIS AND CONCLUSIONS 24

CONTENTS (Cont.)

6 REFERENCES 26

APPENDIX: Records of Telephone Survey A-1

TABLES

1 Summary of UF_6-to-UO_2 Conversion Capabilities at U.S. Fuel Fabrication Facilities and the Metropolis Works Pilot Plant 4

2 Summary of UF_6-to-UO_2 Conversion Capabilities at Non-U.S. Fuel Fabrication Facilities 15

3 Summary of Transportation Route Distances from ETTP, Portsmouth, and Paducah to Commercial Fuel Fabricators 20

NOTATION

The following is a list of the acronyms and abbreviations, including units of measure, used in this report. Some abbreviations used only in tables are defined in those tables.

ABB	Asea Brown Boveri
ADU	ammonium diuranate
AEA	Atomic Energy Act
ANF	Advanced Nuclear Fuel BmbH
ANP	Advanced Nuclear Power
ANSI	American National Standards Institute
AUC	ammonium uranyl carbonate
Bq/g U	becquerel(s) per gram of uranium
BWXT	BWX Technologies, Inc.
CFFF	Columbia Fuel Fabrication Facility
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EIA	Energy Information Administration
ETTP	East Tennessee Technology Park (formerly the Oak Ridge K-25 site)
FBFC	Franco-Belge de Fabrication de Combustibles
FCF	Framatome Cogema Fuels
g	gram(s)
GE	General Electric
GNF-A	Global Nuclear Fuel - Americas, LLC
HEU	highly enriched uranium
IAEA	International Atomic Energy Agency
INB	Industrias Nucleares do Brasil
kg	kilogram(s)
KNFC	Korea Nuclear Fuel Co., Ltd.
μg	microgram(s)
mCi	millicurie(s)
MNFC	Mitsubishi Nuclear Fuel Co., Ltd.
NFS	Nuclear Fuel Services, Inc.
NNFD	Naval Nuclear Fuel Division
NRC	U.S. Nuclear Regulatory Commission
psia	pound(s) per square inch absolute
Pu	plutonium
PWR	pressurized water reactor
SPC	Siemens Power Corporation
tHM/a	metric ton(s) of heavy metal per annum
tU/a	metric ton(s) of uranium per annum
tUF_6/a	metric ton(s) of uranium hexafluoride per annum

tUO_2/a	metric ton(s) of uranium dioxide per annum
U.S.	United States
U-235	235 isotope of uranium
UF_6	uranium hexafluoride
UO_2	uranium dioxide
UO_3	uranium trioxide
U_3O_8	triuranium octaoxide (uranyl uranate)
WEC	Westinghouse Electric Corporation
wt%	weight percent

EVALUATION OF UF_6-TO-UO_2 CONVERSION CAPABILITY AT COMMERCIAL NUCLEAR FUEL FABRICATION FACILITIES

by
N.L. Ranek and F.A. Monette

ABSTRACT

This report examines the capabilities of existing commercial nuclear fuel fabrication facilities to convert depleted uranium hexafluoride (UF_6) to uranium oxide (UO_2). The U.S. Department of Energy (DOE) needs this information to determine whether using such capacity to convert DOE's inventory of depleted UF_6 to a more stable form is a reasonable alternative that should be considered in the site-specific environmental impact statement for construction and operation of depleted UF_6 conversion facilities. Publicly available information sources were consulted to ascertain the information summarized in this report. For domestic facilities, the information summarized includes currently operating capacity to convert depleted UF_6 to UO_2; transportation distances from depleted UF_6 storage locations near Oak Ridge, Tennessee, Portsmouth, Ohio, and Paducah, Kentucky, to the facilities; and regulatory requirements applicable to nuclear fuel fabrication and transportation of depleted UF_6. The report concludes that the total currently operating capability of U.S. commercial nuclear fuel fabricators to convert UF_6 to UO_2 is approximately 5,200 metric tons of UF_6 per annum (tUF_6/a). This total includes 666 tUF_6/a scheduled for shutdown by the end of 2001. However, only about 300 tUF_6/a of this capacity could be confirmed as being possibly available to DOE. The report also provides some limited descriptions of the capabilities of foreign fuel fabrication plants to convert UF_6 to uranium oxide forms.

1 INTRODUCTION

1.1 PURPOSE

This report examines the capabilities of existing commercial nuclear fuel fabrication facilities to convert uranium hexafluoride (UF_6) to uranium dioxide (UO_2). The document includes information about current operating capacity for conversion of UF_6 to UO_2, information about transportation of depleted UF_6 to facilities in the United States, and information about regulatory requirements applicable to nuclear fuel fabrication and depleted UF_6 transportation. The U.S. Department of Energy (DOE) needs this information to determine whether using existing

capacity at commercial fuel fabrication facilities to convert the inventory of depleted UF_6 located at Oak Ridge, Tennessee, Paducah, Kentucky, and Portsmouth, Ohio, would be a reasonable alternative for consideration in the site-specific environmental impact statement for construction and operation of depleted UF_6 conversion facilities.

1.2 BACKGROUND

Nuclear fuel fabrication is the final step in the process used to produce uranium fuel for commercial light-water nuclear power reactors. During fabrication, UF_6 (typically enriched to between 2% and 5% U-235) is converted to UO_2 powder. A ceramic process is then used to convert the UO_2 powder to pellets, which are mechanically loaded into metal rods. The rods are then constructed into finished fuel assemblies for nuclear reactors.

In December 1998, nuclear fuel fabrication capacity existed at a total of 24 facilities in 13 countries. However, at that time, the world capacity for light-water reactor fuel fabrication was estimated at 150% of requirements, and significant consolidation was occurring, apparently as a result of widespread electric power industry restructuring. Faced with the cost of developing innovative products and services to continuously improve the performance of reactor fuel, some fabricators were choosing to exit the business or to seek mergers or joint venture partnerships (EIA 1998). This continuing trend is reflected in the information provided in this report about light-water reactor fuel fabricators in the United States.

Section 2 briefly describes each light-water reactor fuel fabrication facility located in the United States and provides information pertinent to assessing the facility's capability to convert UF_6 to UO_2. Section 2 also includes information about the UF_6-to-UO_2 conversion capability of a pilot plant constructed at the Honeywell International Metropolis Works for research purposes in cooperation with DOE. The capabilities of foreign fuel fabrication plants to convert UF_6 to uranium oxide are described to the extent information could be found. Section 3 discusses transportation considerations. Section 4 discusses relevant regulatory considerations, and Section 5 provides analysis and conclusions.

2 CHARACTERIZATION OF COMMERCIAL NUCLEAR FUEL FABRICATION FACILITIES

2.1 OVERVIEW OF U.S. FACILITIES

Table 1 summarizes information about the UF_6-to-UO_2 conversion capabilities of fuel fabrication facilities in the United States. The table also includes information about a pilot plant located at the Honeywell International Metropolis Works in Metropolis, Illinois. While the Metropolis Works does not currently operate a UF_6-to-UO_2 conversion process, in 1997 a pilot plant jointly funded by DOE and the facility's owner was constructed there to demonstrate a technology for converting natural UF_6 to U_3O_8 and UO_2. Hence, because of DOE's prior involvement with the project, it seemed appropriate to report any potential conversion capacity that facility might provide.

Sections 2.1.1 through 2.1.8 provide more detailed discussions for each facility, including corporate ownership information, facility description, facility address, currently operating capacity, and capacity potentially available to DOE. The results of informal telephone interviews conducted during January 2001 with representatives at most of the U.S. fuel fabrication facilities are reported in the Appendix.

2.1.1 Westinghouse Electric Company LLC – Columbia Fuel Fabrication Facility

Corporate Ownership: Westinghouse Electric Company LLC (WEC) is 100% owned by BNFL Nuclear Services Inc., which is a wholly owned subsidiary of BNFL plc.

Facility Description: The Columbia Fuel Fabrication Facility (CFFF) is primarily engaged in the manufacture of fuel assemblies for commercial nuclear reactors. The CFFF holds a license from the U.S. Nuclear Regulatory Commission (NRC) (SNM-1107; Docket No. 70-1151) authorizing, among others, the following activities:

- Receipt of low-enriched (less than or equal to 5.0% by weight [wt%]) uranium-235 (U-235) in the form of UF_6;
- Conversion of UF_6 to UO_2 powder; and
- Processing of UO_2 through pellet pressing and sintering, fuel rod loading and sealing, and fuel assembly fabrication.

TABLE 1 Summary of UF_6-to-UO_2 Conversion Capabilities at U.S. Fuel Fabrication Facilities and the Metropolis Works Pilot Plant

Facility	Location	Capability to Convert UF_6 to UO_2	Capacity Potentially Available to DOE
Westinghouse Electric Company LLC – Columbia Fuel Fabrication Facility	Columbia, South Carolina	Current operating capacity = 1,150 tHM/a (1,700 tUF_6/a).	Unknown. Westinghouse Electric Company did not respond to phone messages.
BWX Technologies, Inc. – Naval Nuclear Fuel Division	Lynchburg, Virginia	No existing UF_6 conversion capability.	None.
CE Nuclear Power LLC – Hematite Fuel Manufacturing Operations	Hematite, Missouri	Current operating capacity = 450 tHM/a (666 tUF_6/a); operations to be discontinued after 2001.	None.
Framatome ANP Richland Division, Inc. (formerly Siemens Power Corp.) – Engineering and Manufacturing Facility	Richland, Washington	Approx. current operating capacity = 700 tHM/a (1,035 tUF_6/a).	Possibly 300 tUF_6/a. This is capacity currently reserved for unexpected orders.
Framatome ANP, Inc. (formerly Framatome Cogema Fuels) – Lynchburg Manufacturing Facility	Lynchburg, Virginia	Fuel assembly only; no existing UF_6 conversion capability.	None.
Global Nuclear Fuel – Americas, LLC	Wilmington, North Carolina	Current operating capacity = 1,200 tHM/a (1,775 tUF_6/a).	None.
Nuclear Fuel Services – Erwin Facility	Erwin, Tennessee	No existing low-enriched uranium conversion capability.	Negotiable; modification of equipment and facilities would be required.
Honeywell International, Metropolis Works	Metropolis, Illinois	Pilot plant is currently shut down, but could be reactivated; estimated capacity of pilot plant, if operating = 300 to 400 tons (U.S.) (270 to 360 metric tons) of UF_6/a.	Unknown. Converdyn did not respond to phone messages.

In addition, the license authorizes the CFFF to possess, among other things, the following materials, which are possibly relevant to conversion of the depleted UF_6 inventory:

- No more than 5 g of plutonium in feedstock containing transuranics and fission products.

- No more than 75,000 kg of U-235 in any chemical and/or physical form of uranium (except metal) that has been enriched to no more than 5 wt%.

Two processes are installed at the CFFF for converting UF_6 to UO_2 powder: the ammonium diuranate (ADU) process and the integrated dry route process. However, the integrated dry route process has been mothballed.

Facility Address:	Commercial Nuclear Fuel Division Westinghouse Electric Company LLC Drawer R Columbia, SC 29250
Currently Operating Capacity:	1,150 metric tons heavy metal per annum (tHM/a) (1,700 tUF_6/a)
Capacity Potentially Available to DOE:	Unknown; Westinghouse Electric Company did not respond to phone messages.

2.1.2 BWX Technologies, Inc. – Naval Nuclear Fuel Division

Corporate Ownership: BWX Technologies, Inc. (BWXT) is a wholly owned subsidiary of Babcock & Wilcox Investment Company, Inc., which is a wholly owned subsidiary of McDermott Incorporated, which is a wholly owned subsidiary of McDermott International, Inc.

Facility Description: The BWXT, Naval Nuclear Fuel Division (NNFD), is located in Campbell County, Virginia, on an oxbow of the James River, approximately 5 miles east of Lynchburg, Virginia. The primary mission of the NNFD has been fuel fabrication for the naval reactor program, research and university reactor programs, and compact reactors. In addition, the NNFD purifies highly enriched uranium (HEU) and recovers uranium from scrap fuel and manufacturing waste streams.

The NNFD holds a license from the NRC (SNM-42; Docket No. 70-27) authorizing, among others, the following activities at the NNFD site:

- Fabrication of nuclear fuel and components for the naval reactor program, research and university reactor programs, and compact reactors;
- Recovery/disposal of scrap fuel generated by NNFD and other organizations, including irradiated fuel;
- Enrichment adjustment operations of authorized material; and
- Receipt and cleaning (to recover uranium from the UF_6 heels) of UF_6 shipping containers that have been exhausted of UF_6 prior to receipt.

In addition, the license authorizes the NNFD to possess the following materials, which are possibly relevant to conversion of the depleted UF_6 inventory:

- No more than 80,000 kg of U-235 contained in uranium having any enrichment or form (except UF_6);
- Less than 1,000 kg of UF_6 having any enrichment, provided that no container contains more than 50 kg of UF_6;
- No more than 200,000 kg of source material (e.g., natural uranium) in any chemical and/or physical form; and
- No more than 20 mCi each of fission products and transuranium elements in any physical and/or chemical form, provided that the total does not exceed 100 mCi.

Conversion of UF_6 to UO_2 is not an activity specifically authorized by the NNFD's NRC license, and the facility currently has no capability to convert UF_6 to UO_2.

Facility Address:	BWX Technologies, Inc. Naval Nuclear Fuel Division P.O. Box 785 Lynchburg, VA 24505-0785
Currently Operating Capacity:	None; facility has no process capability to convert UF_6 to UO_2.

Capacity Potentially Available to DOE: None.

2.1.3 CE Nuclear Power LLC – Hematite Fuel Manufacturing Operations

Corporate Ownership: CE Nuclear Power LLC is a wholly owned subsidiary of Westinghouse Electric Company LLC, which is a wholly owned subsidiary of BNFL Nuclear Services Inc., which is a wholly owned subsidiary of BNFL plc.

Facility Description: The Hematite Fuel Manufacturing Operations is currently scaling down with the goal of discontinuing manufacturing operations by the end of 2001 (WEC 2000a).

Facility Address: 3300 State Road P
Festus, MO 63028

Currently Operating Capacity: 450 tHM/a (666 tUF_6/a)

Capacity Potentially Available to DOE: None; facility operations scheduled to discontinue by the end of 2001.

2.1.4 Framatome ANP Richland, Inc. – Engineering and Manufacturing Facility

Corporate Ownership: Effective Thursday, February 1, 2001, Siemens Power Corporation (SPC), the owner/operator of the nuclear fuel Engineering and Manufacturing Facility located at 2101 Horn Rapids Road, Richland, Washington, changed its name to Framatome Advanced Nuclear Power (ANP) Richland, Inc. The name change coincided with the signing in Europe of the closing documents for the merger of the worldwide nuclear business of the former SPC's parent company, Siemens AG, with that of the French company, Framatome S.A. The resulting joint venture company, Framatome ANP SAS, exists retroactive to January 1, 2001 (Maas 2001).

Effective March 19, 2001, the stock of Framatome ANP Richland, Inc., was transferred to Framatome ANP, Inc., headquartered in Lynchburg, Virginia. Framatome ANP, Inc., in turn is owned by Framatome ANP SAS. In addition to owning the Richland facility, Framatome ANP, Inc., owns the former Framatome Cogema Fuels (FCF) nuclear fuel fabrication plant in Lynchburg, Virginia (Maas 2001).

Facility Description: The Engineering and Manufacturing Facility is located 0.9 miles west of the intersection of Stevens Drive and Horn Rapids Road within the north boundary of the city of Richland, Washington. Uranium is processed primarily within the dry conversion, UO_2, and Specialty Fuels Buildings. Storage of UF_6 cylinders is conducted outside, and packaged fuel elements or other uranium products are stored outside or in a warehouse while awaiting shipment.

The Engineering and Manufacturing Facility holds a license from the NRC (SNM-1227; Docket No. 70-1257) that allows for the possession of no more than 25,000 kg of U-235 in uranium compounds that have been enriched to no more than 5 wt%. The license authorizes, among others, the following activities:

- Manufacturing of nuclear fuel, including all operational steps from UF_6 to UO_2 conversion through packaging finished fuel elements; uranium compounds up to 5 wt% U-235;
- All operational steps of dry UF_6-to-UO_2 conversion and UO_2 powder preparation; uranium compounds up to 5 wt% U-235;
- Storage of a planar array of closed containers of uranium oxide (up to 5 wt% U-235) pellets that are externally free of significant contamination;
- Unloading from shipping containers and storage of containers of uranium compounds up to 5 wt% U-235 (product, scrap and waste materials);
- Loading into shipping containers and storage of containers of uranium compounds up to 5 wt% U-235 (product, scrap, and waste materials);
- Outside storage of UF_6 cylinders (full and empty); UF_6 up to 5 wt% U-235;
- Outside storage of fuel (UO_2 up to 5 wt% U-235) packed for shipment; the transport containers are closed, sealed, and properly labeled for shipment; and
- UF_6 (solid and in waste solution up to 5 wt% U-235) cylinder recertification activities.

In addition, Framatome ANP Richland's State of Washington Radioactive Materials License (WN-I062-1) authorizes the Engineering and Manufacturing Facility to possess the following materials, which are possibly relevant to conversion of the depleted UF_6 inventory:

- No more than 85,000 kg of source material (includes natural and depleted uranium).

In July 2000, Siemens Power Corporation received approval of an amendment to the Engineering and Manufacturing Facility's NRC license to allow receipt, processing, storage, and shipping of uranium containing plutonium and other transuranic isotopes as follows (Maas 2001):

- The concentration of transuranic isotopes (i.e., the alpha activity of plutonium and neptunium) in reprocessed uranium shall be limited to less than 50 Bq/g U or, for uranium enriched to less than 2.18% U-235, to a lesser value which assures that the limit of 1 microgram of plutonium per gram of U-235 (• g Pu/g U-235) is not exceeded.

Before the merger of Siemens AG and Framatome S.A., Siemens Power Corporation advised the NRC that all licensed activities at the Engineering and Manufacturing Facility would continue without interruption after the merger, and that there are no planned changes in the operational organization, location, facilities, equipment or procedures associated with the facility's license (Siemens 2000).

Facility Address:	Framatome ANP Richland 2101 Horn Rapids Road Richland, WA 99352-0130
Currently Operating Capacity:	700 tHM/a (1,035 tUF_6/a)
Capacity Potentially Available to DOE:	Possibly 300 tUF_6/a

2.1.5 Framatome ANP, Inc. – Lynchburg Manufacturing Facility

Corporate Ownership: In anticipation of the merger of the worldwide nuclear business of Framatome S.A. with the worldwide nuclear business of Siemens AG, Framatome Cogema Fuels merged into Framatome Technologies Group, Inc., which now has become Framatome ANP, Inc. (a Delaware corporation). Framatome ANP, Inc., is a wholly owned subsidiary of Framatome USA, which is a wholly owned subsidiary of Framatome ANP SAS (a French corporation).

Facility Description: The Lynchburg Manufacturing Facility is located in Campbell County, Virginia, on State Route 726. The facility primarily manufactures fuel assemblies for use in commercial pressurized water nuclear reactors. The facility holds a license from the NRC (SNM-1168; Docket No. 70-1201), authorizing the following activities, among others:

- Receipt of UO_2 pellets;
- Receipt of sealed fuel rods and fuel assemblies;

- Loading of UO_2 pellets into fuel rods;
- Fabrication of fuel rods into fuel assemblies;
- Downloading of UO_2 fuel pellets from incoming fuel rods and assemblies; and
- Shipping of products, scrap, or waste for off-site disposition.

The NRC license also authorizes the Lynchburg Manufacturing Facility to receive, acquire, possess, and transfer the following materials, which are relevant to conversion of the depleted UF_6 inventory:

- No more than 15,000 kg of U-235 in the form of oxide pellets composed of uranium enriched up to 5.1 wt% U-235 (and enriched processed uranium containing plutonium and other transuranic isotopes);
- No more than 100,000 kg of natural or depleted uranium in the form of oxide pellets or powder; and
- Less than 1,000 kg of natural UF_6, with no container exceeding 50 kg.

Uranium conversion from any form to another form is *not* an activity authorized by the Lynchburg Manufacturing Facility's NRC license, and the facility has no capability to conduct such conversion.

Facility Address:	3315 Old Forest Road Lynchburg, VA 24506-0935
Currently Operating Capacity:	None; facility conducts only fuel component assembly.
Capacity Potentially Available to DOE:	None; facility has no UF_6-to-UO_2 conversion capability.

2.1.6 Global Nuclear Fuel – Americas, LLC

Corporate Ownership: Global Nuclear Fuel – Americas LLC is a wholly owned subsidiary of Global Nuclear Fuel Holding Co., LLC, which is a joint venture of General Electric (GE) Company, Toshiba, and Hitachi, with General Electric holding the majority ownership interest.

Facility Description: The Global Nuclear Fuel – Americas, LLC facility (GNF-A) is located on U.S. Highway 117 approximately 6 miles north of Wilmington, North Carolina. The following major facilities are situated on the GNF-A property:

- The GE Aircraft Engine facility, which is not involved in the nuclear fuel manufacturing operation;
- The GE Services Components Operation facility, where nonradioactive reactor components are manufactured;
- The Fuel Components Operation facility, where nonradioactive components for reactor fuel assemblies are manufactured; and
- The fuels complex containing the fuel manufacturing facility, which includes the Fuel Manufacturing Operation and Dry Conversion Process buildings and supporting facilities.

The GNF-A holds a license from the NRC (SNM-1097; Docket No. 70-1113) authorizing it to conduct the following activities, among others:

- Conversion of UF_6 to uranium oxides by the ADU process and the dry conversion process;
- Operation of process technology for the purpose of converting UF_6 to UO_2 and other intermediate compounds by chemical and dry processes;
- Storage of unirradiated fuel assemblies and uranium compounds and mixtures in areas arranged specifically for maintenance of criticality and radiological safety;
- Design, fabrication, and testing of uranium prototype processing equipment; and
- Maintenance and repair of uranium processing equipment and auxiliary systems.

The NRC license also authorizes receipt, acquisition, possession, use in the specified manner, and transfer of the following materials, which are relevant to conversion of the depleted UF_6 inventory:

- No more than 50,000 kg U-235 contained in uranium (in any chemical and/or physical form) enriched to no more than 5 wt% U-235.

Facility Address:	3901 Castle Hayne Road Wilmington, NC 28401
Currently Operating Capacity:	1,200 tHM/a (1,775 t UF_6/a)
Capacity Potentially Available to DOE:	None; Global Nuclear Fuel – Americas stated that the company is not interested in converting depleted UF_6 at this facility.

2.1.7 Nuclear Fuel Services, Inc. – Erwin Facility

Corporate Ownership: Nuclear Fuel Services, Inc.

Facility Description: The Nuclear Fuel Services, Inc. (NFS) facility is located on Banner Hill Road in Erwin, Tennessee. Current process work at the facility includes production of nonirradiated nuclear fuel and other products from both low- and high-enriched uranium. The NFS facility holds a license from the NRC (SNM-124; Docket No. 70-143), which authorizes the following activities, in addition to the manufacture of highly enriched uranium fuel:

- Recovery of low and highly enriched uranium from uranium materials having any enrichment, chemical composition, and physical form (except pyrophoric). This activity includes washing of UF_6 cylinders and recovery of UF_6 heels.
- Downblending of highly enriched, liquid uranyl nitrate to low-enriched uranyl nitrate.
- Conversion of low and highly enriched uranyl nitrate to uranium oxide.
- Laboratory operations for manufacturing.
- Research and development.
- Waste treatment and packaging for shipment.

The NRC license also authorizes the NFS facility to possess the following materials, which are possibly relevant to conversion of the depleted UF_6 inventory:

- No more than 7,000 kg U-235 in uranium enriched up to 100 wt%. This uranium may contain as contaminants up to 1×10^{-6} grams of plutonium per

gram of uranium, 0.25 millicuries (mCi) of fission products per gram of uranium, and 1.5×10^{-5} grams of transuranic materials (including plutonium) per gram of uranium.

NFS has an installed line for converting high-enriched UF_6 to UO_2, but it is not currently operating. Significant licensing activity would be required to permit operations. No low-enriched UF_6-to-UO_2 capability currently exists, although NFS has produced ton quantities of low-enriched UO_2 in the past. Conversion of UF_6 to UO_2 is not an activity specifically authorized by the NFS facility's NRC license.

Facility Address:	1205 Banner Hill Road Erwin, TN 37650
Currently Operating Capacity:	None; facility has no existing low-enriched UF_6 conversion capability.
Capacity Potentially Available to DOE:	Negotiable; Nuclear Fuel Services, Inc., is interested in converting depleted UF_6 at this facility, but modification of equipment and facilities would be required.

2.1.8 Honeywell International – Metropolis Works

Corporate Ownership: Honeywell International, Inc. [Note: Converdyn, a general partnership between affiliates of Honeywell and General Atomics, is the exclusive agent for conversion sales from the Metropolis Works. Also, on November 30, 2000, Honeywell International and General Electric Company requested the NRC's consent for the proposed indirect transfer of ownership and control of the Metropolis Works from Honeywell International to General Electric Company. However, completion of the transfer of ownership and control has been delayed pending resolution of an in depth probe by the European Commission (Chicago Tribune 2001).]

Facility Description: The Metropolis Works, located near Metropolis, Illinois, converts natural U_3O_8 to UF_6. The plant has no full-scale capacity to convert UF_6 to uranium oxide. However, in 1997, DOE entered into an agreement with the owners of the Metropolis Works (then Allied Signal, Inc. and General Atomics) to fund 50% of the cost of a pilot plant as a demonstration of a proposed dry process (patented by General Atomics) for converting UF_6 into U_3O_8 or UO_2 and anhydrous hydrofluoric acid. The pilot plant was constructed at the Metropolis Works, and test runs were conducted with UF_6 feed between early February and July 1998. The program was considered successful in that UF_6 was successfully converted to uranium oxide, and anhydrous hydrofluoric acid was recovered and successfully recycled in the main conversion plant at the site. Upon completion

of the program, the pilot plant was secured, emptied, flushed, cleaned, and otherwise mothballed. The capacity of the pilot plant, if it were operational, was estimated at 300 to 400 tons (U.S.) UF_6/a.

The Metropolis Works holds a license from the NRC (SUB-526; Docket No. 40-3392), which authorizes, among other things, operation of the pilot plant. The NRC license also authorizes the Metropolis Works to possess the following materials that are relevant to conversion of the depleted UF_6 inventory:

- No more than 68 million kg of natural uranium in the following forms: U_3O_8, UO_2, UO_3, UF_4, and UF_6.

Facility Address:	P.O. Box 430 Metropolis, IL 62960
Currently Operating Capacity:	None; facility has been mothballed.
Capacity Potentially Available to DOE:	Unknown; Converdyn, the exclusive agent for conversion sales from the Metropolis Works, did not respond to phone messages.

2.2 OVERVIEW OF NON-U.S. FACILITIES

Table 2 summarizes information about the UF_6-to-UO_2 conversion capabilities of fuel fabrication facilities in other countries. Sections 2.2.1 through 2.2.8 provide more details (to the extent available). No attempt was made for this report to contact these non-U.S. facilities.

2.2.1 France

France hosts the COGEMA W Plant, which is not a fuel fabrication facility, but which converts depleted UF_6 to U_3O_8. This plant has a design capacity of approximately 20,000 tons of uranium per year (tU/a) (IAEA 2001a).

Contact Address:	Cogema Pierrelatte B.P. 16 26700 Pierrelatte Cedex France

TABLE 2 Summary of UF_6-to-UO_2 Conversion Capabilities at Non-U.S. Fuel Fabrication Facilities

Facility	Location	Capability to Convert UF_6 to UO_2
COGEMA – W Plant	France	This plant, which is not a fuel fabrication facility, converts depleted UF_6 to depleted U_3O_8; approx. capacity = 20,000 tU/a (29,600 tUF_6/a).
BNFL plc – Springfields Works	United Kingdom	Dry conversion process; approx. capacity = 550 tHM/a (813 tUF_6/a).
Mitsubishi Nuclear Fuel Co., Ltd. – Tokai-mura	Japan	UF_6 to UO_2 conversion process could not be identified; approx. capacity = 450 tU/a (665 tUF_6/a).
Advanced Nuclear Fuels GmbH – Lingen Facility	Germany	Dry conversion process; approx. capacity = 400 tU/a (592 tUF_6/a).
FBFC – Dessel Plant	Belgium	UF_6 to UO_2 conversion process could not be identified; approx. capacity = 500 tHM/a (740 tUF_6/a).
Westinghouse Atom – Nuclear Fuel Factory	Sweden	UF_6 to UO_2 conversion process could not be identified; approx. capacity = 600 tHM/a (887 tUF_6/a).
Korea Nuclear Fuel Co., Ltd. – Taejon	Korea	Dry conversion process; approx. capacity = 400 tHM/a (592 tUF_6/a).
Industrias Nucleares do Brasil (INB) – Resende Unit 2	Brazil	AUC (CO_2-NH_3) process; approx. capacity = 160 tHM/a (237 tUF_6/a).

2.2.2 United Kingdom

The United Kingdom hosts one light water reactor fuel fabrication plant: the Springfields Works. This facility is owned and operated by BNFL plc. It converts UF_6 to UO_2 powder, produces pellets from the UO_2 powder, and fabricates fuel rods and assemblies from the UO_2 pellets. The Springfields Works fuel fabrication plant currently has an operating UF_6-to-UO_2 conversion capacity of approximately 550 tHM/a (IAEA 2001b).

Contact Address:

British Nuclear Fuels plc
Springfields Works
Salwick, Preston
Lancashire PR4 OXJ
United Kingdom

2.2.3 Japan

One nuclear fuel manufacturing facility in Japan converts UF_6 to UO_2. Mitsubishi Nuclear Fuel Co., Ltd. operates this plant, which has a currently operating conversion capacity of 450 tU/a. (IAEA 2001c).

Contact Address: Mitsubishi Nuclear Fuel Co., Ltd.
622-1 Funaishikawa, Tokai-mura, Naka-gun,
Ibaraki Prefecture, Japan 319-1197

2.2.4 Germany

In Germany, Advanced Nuclear Fuels GmbH, a subsidiary of Siemens AG, operates the Lingen facility, which fabricates nuclear fuel for light water reactors by converting UF_6 to UO_2 using the dry conversion process, pressing and sintering the UO_2 powder into pellets, sealing the pellets in fuel rods, and assembling the rods into fuel elements. This plant has a conversion capacity of approximately 400 tU/a. However, the fuel production capacity is 650 tHM/a, which is achieved by receiving some UO_2 from off-site (ANF 2000).

Contact Address: Advanced Nuclear Fuels GmbH
Am Seitenkanal 1
49811 Lingen
Germany

2.2.5 Belgium

Belgium hosts the FBFC International nuclear fuel fabrication plant at Dessel. This plant handles fuel fabrication operations, ranging from conversion of UF_6 to UO_2 powder through delivery of completed fuel assemblies. It has an output capacity of approximately 500 tHM/a (IAEA 2001d).

Contact Address: FBFC International SA
Europalaan 12
B-2480 Dessel
Belgium

2.2.6 Sweden

The Nuclear Fuel Operations of Westinghouse Atom manufacture light-water reactor fuel at the Nuclear Fuel Factory situated in the city of Vasteras, Sweden. This facility was formerly owned by Asea Brown Boveri (ABB), whose commercial nuclear power businesses were acquired by BNFL's Westinghouse Electric Company in May 2000 (WEC 2000b). The Nuclear Fuel Factory has an output capacity of 400 tHM/a. The UF_6-to-UO_2 conversion capacity is limited to 600 tHM/a (WEC 2000c).

Contact Address:

Westinghouse Atom
SE-721 63 Västerås
Sweden

2.2.7 Korea

In Korea, the Korea Nuclear Fuel Company, Ltd. (KNFC) operates a fabrication facility for pressurized-water reactor (PWR) fuel. It has the capacity to produce 400 tHM/a (KNFC 2000a). This facility, located at Taejeon, was modified in 1998 by replacing the ammonium uranyl carbonate (AUC) process with the dry conversion process for converting UF_6 to UO_2 (KNFC 2000b).

Contact Address:

Korea Nuclear Fuel Company, Ltd.
150 Deogjin-Dong, Yusong-ku
Taejeon City, Republic of Korea

2.2.8 Brazil

In Brazil, Industrias Nucleares do Brasil (INB) operates the Resende plant, which consists of two separate units. Unit 1 is a fuel assembly production line. Unit 2, which began operations during 2000, is a chemical processing facility that accepts enriched UF_6, converts it to UO_2, and processes the UO_2 into pellets. This conversion plant is based on the AUC (CO_2-NH_3) process and has a capacity of 160 tHM/a (IAEA 2001e).

Contact Address:

Industrias Nucleares do Brasil (INB)
Av. Presidente Wilson 231
9-11 Pav., Centro, CEP 20.030-021
Rio de Janeiro, Brazil

2.2.9 Other Countries

In addition to the fuel fabrication facilities described in Sections 2.2.1 through 2.2.8, the countries of Spain, China, India, Kazakhstan, and Russia have been reported to host nuclear fuel fabrication facilities. However, information could not be located to verify that the fuel fabrication plants in these countries are capable of converting UF_6 to UO_2.

3 TRANSPORTATION

The use of commercial fuel fabrication facilities to convert depleted UF_6 would require the off-site shipment of some or all of the depleted UF_6 cylinders stored at East Tennessee Technology Part (ETTP) (formerly the Oak Ridge K-25 site), Portsmouth, and Paducah. Shipments could be made by legal-weight truck to all commercial facilities. Also, it is possible that shipments could be made by rail if the commercial facilities have rail access on-site or nearby. Because railcars have larger payload capacity than truck trailers, transportation by rail could significantly reduce the total number of shipments required. However, a full investigation of the transportation infrastructure available at the commercial facilities was beyond the scope of this report.

Commercial fuel fabricators typically receive UF_6 in 30B cylinders. A 30B cylinder has a 30-inch diameter and a loaded weight of slightly less than 3 metric tons. In comparison, depleted UF_6 is stored and would be shipped primarily in 48-inch-diameter cylinders with a gross weight of approximately 14 metric tons. Consequently, it is likely that commercial facilities would have to upgrade or modify their shipping and receiving facilities (such as fixed or mobile cranes) before depleted UF_6 shipments could be received.

In general, the distance over which depleted UF_6 cylinders are shipped is a primary factor in determining both the cost and the risk associated with a shipment. Federal regulations do not place route restrictions on the movement of depleted UF_6 on U.S. highways or railroads. For purposes of comparison for this report, representative shipment routes from the three current storage sites to commercial facilities were generated with standard route prediction models. Representative shipment routes were identified by using the Transportation Routing Analysis Geographic Information System (WebTragis) (Johnson and Michelhaugh 2000). The routes were selected to be reasonable and consistent with routing regulations and general practice, but are considered representative because the actual routes to be used would likely be chosen by the shipper.

The results of route predictions for both truck and rail shipment modes are summarized in Table 3. Considering all origins and destinations, truck route lengths would range from a minimum of 19 miles to a maximum of 2,527 miles; rail route lengths would range from 20 miles to 2,620 miles. In general, risk will vary proportionally with the overall shipment length.

TABLE 3 Summary of Transportation Route Distances from ETTP, Portsmouth, and Paducah to Commercial Fuel Fabricators

Origin/Destination	Summary of Route Distance (miles)	
	Truck	Rail
From ETTP to:		
Westinghouse, Columbia, S.C.	314	327
BWX Technologies, Lynchburg, Va.	354	385
Framatome ANP, Richland, Wash.	2,481	2,620
Global Nuclear Fuel, Wilmington, N.C.	579	490
Nuclear Fuel Services, Erwin, Tenn.	159	170
Metropolis, Ill.	293	590
From Portsmouth to:		
Westinghouse, Columbia, S.C.	486	581
BWX Technologies, Lynchburg, Va.	382	372
Framatome ANP, Richland, Wash.	2,527	2,418
Global Nuclear Fuel, Wilmington, N.C.	622	700
Nuclear Fuel Services, Erwin, Tenn.	369	333
Metropolis, Ill.	544	566
From Paducah to:		
Westinghouse, Columbia, S.C.	628	722
BWX Technologies, Lynchburg, Va.	646	783
Framatome ANP, Richland, Wash.	2,207	2,295
Global Nuclear Fuel, Wilmington, N.C.	871	914
Nuclear Fuel Services, Erwin, Tenn.	451	648
Metropolis, Ill.	19	20

4 REGULATORY CONSIDERATIONS

4.1 UNITED STATES

Commercial nuclear fuel fabrication facilities in the United States must obtain licenses from the NRC to manufacture, produce, receive, acquire, own, possess, use, or transfer byproduct, source, and special nuclear material (10 CFR 30.3; 10 CFR 40.3; 10 CFR 70.3). Each license specifies the authorized byproduct, source, and special nuclear materials, their chemical and/or physical forms, and the maximum quantity of each material that the licensee is allowed to possess at any one time. Each license further designates the purposes for which the authorized materials may be used. Hence, if DOE elects to transfer depleted UF_6 to a commercial nuclear fuel fabrication facility for conversion to UO_2, the NRC license held by the facility would need to authorize receipt, storage, conversion, and transfer of depleted uranium.

To evaluate whether a fuel fabrication facility's NRC license authorizes receipt, storage, conversion, and transfer of depleted uranium compounds, it is important to recognize that depleted uranium is source material,[1] while uranium enriched in the isotope U-235 is special nuclear material.[2] As such, authorizations for depleted uranium are typically specified separately in a facility's NRC license from authorizations for enriched uranium.

In Section 2, four commercial nuclear fuel fabrication facilities located in the United States were identified as having the capability to convert UF_6 to UO_2: Westinghouse Electric Company LLC – Columbia Fuel Fabrication Facility; Framatome ANP Richland Division, Inc. – Engineering and Manufacturing Facility; Global Nuclear Fuel – Americas, LLC; and CE Nuclear Power LLC – Hematite Fuel Manufacturing Operations. In addition, the Honeywell International Metropolis Works pilot plant has this capability. Because the Hematite facility is scaling down operations and will shut down after 2001, NRC license provisions for that facility were not investigated. The remaining three fuel fabrication facilities are authorized to receive uranium enriched up to 5 wt% U-235. However, none of the three has an NRC license that expressly authorizes receipt, storage, conversion, or transfer of depleted uranium in any form. Similarly, the Metropolis Works is authorized to receive natural uranium, but not depleted uranium. Therefore, it appears that a license amendment for appropriate authorizations regarding depleted uranium might have to be obtained by

---

[1] "Source material" means: (1) uranium or thorium, or any combination thereof, in any physical or chemical form, or (2) ores which contain by weight one-twentieth of one percent (0.05%) or more of: (i) uranium, (ii) thorium, or (iii) any combination thereof. Source material does not include special nuclear material (40 CFR 40.4).

[2] "Special nuclear material" means: (1) plutonium, uranium-233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the NRC determines to be special nuclear material, but does not include source material; or (2) any material artificially enriched by any of the foregoing, but does not include source material (10 CFR 70.4).

these facilities from the NRC before DOE could transfer depleted UF_6 to them. Such an amendment would be routine and is unlikely to significantly deter using the conversion capacity at one or more of the facilities, provided the facilities are interested in supplying conversion services to DOE.

4.2 FOREIGN COUNTRIES

Sections 54, 64, 82, and 91 of the Atomic Energy Act (AEA) authorize DOE to export nuclear material under certain circumstances without obtaining an export license from the NRC. However, none of these circumstances appears to arise if DOE elects to transfer depleted UF_6 to a foreign nuclear fuel fabrication facility for conversion to UO_2. Therefore, in such a situation, Section 111 of the AEA would require DOE to obtain an export license from the NRC.

The regulations in 10 CFR Part 110, "Export and Import of Nuclear Equipment and Material," govern issuance by the NRC of export and import licenses. Such licenses may be general or specific. A general license, if applicable, is effective without the filing of an application or the issuance of licensing documents to a particular person. A specific license is issued to a named person and is effective upon approval by the NRC of an application and the issuance of licensing documents.

Because of the quantities of depleted UF_6 in the DOE inventory requiring conversion, no general license would apply to the export of such material. Accordingly, a specific license for export would be required (10 CFR 110, Subpart C). However, the subsequent return of the converted UO_2 to DOE should be covered by the general license for imports in 10 CFR 110.27(a), which authorizes any person to import byproduct, source, or special nuclear material if the consignee is authorized to possess the material.

Absent political considerations, obtaining a specific export license from the NRC should not be a significant deterrent to using conversion capacity at a foreign commercial fuel fabrication facility, if the foreign country does not object and the facility is willing to provide the service to DOE.

4.3 TRANSPORTATION

Shipments of UF_6 to a commercial facility (see Section 3) would be made in accordance with all applicable transportation regulations. Shipment of depleted UF_6 is regulated by the Department of Transportation (DOT) in 49 CFR Part 173, Subpart I, "Class 7 (Radioactive) Materials." Among other things, 49 CFR 173.420 requires that each UF_6 cylinder be designed, fabricated, inspected, tested, and marked in accordance with the version of American National Standard N14.1, "Uranium Hexafluoride – Packaging for Transport" (ANSI N14.1) that was in effect

at the time the cylinder was manufactured. Although a detailed discussion of depleted UF_6 transportation requirements is not included in this report, three provisions in 49 CFR 173.420 and ANSI N14.1 are particularly important relative to depleted UF_6 cylinder shipments: (1) a cylinder must be filled to less than 62% of the certified volumetric capacity (the fill-limit was reduced to 62% from 64% around 1987); (2) the pressure within a cylinder must be less than 14.8 psia; and (3) a cylinder must be free of cracks, excessive distortion, bent or broken valves or plugs, and broken or torn stiffening rings or skirts, and must not have shell thicknesses that have decreased below a specified minimum value. Cylinders not conforming to these requirements are referred to as overfilled, overpressurized, and substandard, respectively. Any depleted UF_6 currently stored in a nonconforming cylinder cannot be transported without some type of prior preparation, such as placement of the nonconforming cylinder in a DOT-approved overpack, or transfer of the depleted UF_6 to a conforming cylinder.

Although definitive information is not currently available, preliminary reports suggest that many cylinders currently stored at ETTP, Portsmouth, and Paducah would either not meet DOT transportation requirements, or extensive time and effort would be required to demonstrate that they do (LLNL et al. 1997). This situation suggests that prior preparations, which may themselves be quite expensive and time consuming, are likely to be needed before transport could occur for a potentially large percentage of the stored cylinders in DOE's depleted UF_6 inventory.

5 ANALYSIS AND CONCLUSIONS

The current operating capability of commercial nuclear fuel fabricators to convert UF_6 to UO_2 in the United States is reported to be approximately 5,200 tUF_6/a, which includes 666 tUF_6/a of capacity scheduled for shutdown by the end of 2001. The pilot plant at the Honeywell International Metropolis Works could add an average of about 320 tUF_6/a, if it were restarted and operated at its full capacity. Hence, the maximum rate of UF_6 conversion, assuming all currently operating capacity in the United States could be devoted to converting DOE's depleted UF_6 inventory, would be approximately 5,500 tUF_6/a. In comparison, DOE's depleted UF_6 inventory consists of approximately 700,000 metric tons of depleted UF_6. Consequently, more than 125 years would be required to convert this legacy inventory using commercially available capacity, even if all currently operating capacity were devoted to the task.

In an informal survey of U.S. commercial fuel cycle facilities conducted during preparation of this report, only about 300 tUF_6/a of existing capacity could be confirmed as being possibly available to DOE. While additional capacity at commercial facilities might later become available, there seems to be a general lack of interest on the part of the facility owners in committing existing operating or mothballed capacity[3] to conversion of the DOE depleted UF_6 inventory.

Route length is the primary factor in distinguishing both cost and risk associated with shipment of depleted UF_6 to different locations. Therefore, the distance between the U.S. commercial fuel cycle facilities and the DOE depleted UF_6 storage sites would be one factor to consider in evaluating whether any particular commercial fuel cycle facility should be used. As this report indicates, such distances vary considerably.

It appears that NRC license amendments might be needed before U.S. commercial fuel cycle facilities could receive and process depleted UF_6. However, this should not be a significant deterrent to using the conversion capacity at one or more of the facilities, provided the facilities are interested in furnishing conversion services to DOE. A greater regulatory concern may arise with respect to transporting a large percentage of the depleted UF_6 inventory to such facilities. Although definitive information is not currently available, preliminary reports suggest that many cylinders currently stored at ETTP, Portsmouth, and Paducah would either not meet DOT transportation requirements, or extensive time and effort would be required to demonstrate that they do. This situation suggests that prior preparations, which may be quite expensive and time-consuming, are likely to be needed before transport could occur for a potentially large percentage of the stored cylinders.

---

[3] No publicly accessible information indicated the amount of mothballed capacity at any facility investigated for this report. Also, no information was solicited directly from such facilities regarding mothballed capacity.

The current operating capability of commercial nuclear fuel fabricators in foreign countries to convert UF_6 to UO_2 is reported to total approximately 23,000 tUF_6/a. For the purpose of this report, no effort was made to determine whether any of this foreign capacity could be available to DOE. However, even if all of it were available, about 30 years would be needed to convert DOE's depleted UF_6 inventory at this rate. If only 10% of the foreign capacity were available, it would take about 300 years to complete the effort. In addition, there would be regulatory and political considerations that would need to be factored into any decision to utilize foreign facilities for conversion of DOE's depleted UF_6 inventory.

6 REFERENCES

ANF, 2000, "Beitrebsstätte Lingen," Advanced Nuclear Fuels GmbH, available from: http://lingen-ems.de/firmen/advanced.html (accessed on Dec. 28, 2000).

Chicago Tribune, 2001, "EC Probe Delays Honeywell Buyout," published on February 28, 2001, available from: http://chicagotribune.com/tools/search/archives/form (accessed on April 18, 2001).

EIA, 1998, *Challenges of Electric Power Industry Restructuring for Fuel Suppliers*, DOE/EIA-0623, Energy Information Administration, U.S. Department of Energy, Washington, D.C., September.

IAEA, 2001a, "Nuclear Fuel Cycle Facility - Report, W Defluorinat (Depl. UF6)," International Atomic Energy Agency, Nuclear Fuel Cycle Information System, available from: http://www-nfcis.iaea.org/NFCFacilityReport.asp?WhichFacility=78 (accessed on April 18, 2001).

IAEA, 2001b, "Nuclear Fuel Cycle Facility - Report, BNFL Springfield OFC IDR UO2 Line," International Atomic Energy Agency, Nuclear Fuel Cycle Information System, available from: http://www-nfcis.iaea.org/NFCFacilityReport.asp?WhichFacility=585 (accessed on April 18, 2001).

IAEA, 2001c, "Nuclear Fuel Cycle Facility - Report, Mitsubushi Nuclear Fuel Ltd. (MNF)," International Atomic Energy Agency, Nuclear Fuel Cycle Information System, available from: http://www-nfcis. iaea.org/NFCFacilityReport.asp?WhichFacility=709 (accessed on April 18, 2001).

IAEA, 2001d, "Nuclear Fuel Cycle Facility - Report, FBFC International," International Atomic Energy Agency, Nuclear Fuel Cycle Information System, available from: http://www-nfcis.iaea.org/NFCFacilityReport.asp?WhichFacility=110 (accessed on April 18, 2001).

IAEA, 2001e, "Nuclear Fuel Cycle Facility - Report, Resende - Unit 2,"International Atomic Energy Agency, Nuclear Fuel Cycle Information System, available from: http://www-nfcis.iaea.org/NFCFacilityReport.asp?WhichFacility=784 (accessed on April 18, 2001).

Johnson P.E., and R.D. Michelhaugh, 2000, *Transportation Routing Analysis Geographic Information System (WebTragis) User's Manual*, ORNL/TM-2000/86, Oak Ridge National Laboratory, Oak Ridge, Tenn., April.

KNFC, 2000a, "Supply of Nuclear Fuel & Production Capacity," Korea Nuclear Fuel Co., Ltd., available from: http://www.knfc.co.kr/home/ecapa.htm, Production (accessed on Dec. 28, 2000).

KNFC, 2000b, "PWR Fuel Fabrication Process," Korea Nuclear Fuel Co., Ltd., available from: http://www.knfc.co.kr/home/epwrpro.htm (accessed on Dec. 28, 2000).

LLNL et al., 1997, *Depleted Uranium Hexafluoride Management Program; the Draft Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride*, UCRL-AR-124080, Volumes I and II, prepared by Lawrence Livermore National Laboratory, Science Applications International Corporation, Bechtel, and Lockheed Martin Energy Systems for U.S. Department of Energy, 1997.

Maas, L.J., 2001, Comments on "Excerpt from Draft Evaluation of UF_6-to-UO_2 Conversion Capability at Commercial Nuclear Fuel Fabrication Facilities," fax to Nancy L. Ranek, Argonne National Laboratory, March 21.

Siemens Power Corporation, 2000, Letter (from L.J. Maas) to the U.S. Nuclear Regulatory Commission (Document Control Desk) regarding Request for NRC Consent for Transfer of Siemens Power Corporation's (SPC's) Materials License (Docket 70-1257) and Related Licenses, Certificates and Approvals, Sept. 29.

WEC, 2000a, Letter from Westinghouse Electric Company (R.W. Sharkey) to the U.S. Nuclear Regulatory Commission (Director, Office of Nuclear Materials Safety and Safeguards) regarding Amendment Request to License SNM-33 Application Pages, June 2.

WEC, 2000b, "BNFL/Westinghouse Complete Acquisition of ABB's Nuclear Businesses," Press Release (May 1, 2000), Westinghouse Electric Company, available from: http://www.westinghouse.com (accessed on Dec. 28, 2000).

WEC, 2000c, "Nuclear Fuel," Westinghouse Electric Company, available from: http://www.westinghouse.com/atom, Products (accessed on December 28, 2000).

APPENDIX

RECORDS OF TELEPHONE SURVEY

Between January 29 and February 2, 2001, Argonne National Laboratory staff contacted most of the commercial nuclear fuel fabrication facilities in the United States, as well as the Honeywell International Metropolis Works Plant, which converts natural uranium oxide to UF_6. The primary purpose of this informal verbal survey was to inquire about whether these facilities have conversion capacity that they would consider dedicating for use by DOE if, hypothetically, DOE were to decide to use such capacity to convert some or all of its depleted UF_6 inventory. During March 2001, each facility was asked to review and suggest corrections and additions to the record of the telephone survey and the section of the main report pertaining to its operations. The final records of the telephone survey are provided in this appendix.

Westinghouse Electric Company LLC – Columbia, South Carolina

Individual Contacted: David Precht

Phone: 803/647-3485

Date and Time of Contact: Mr. Precht did not respond to messages.

Contacted By: Nancy L. Ranek

BWX Technologies, Inc. – Lynchburg, Virginia

Individual Contacted: Arne F. Olsen, Licensing Officer

Phone: 804/522-5174

Date and Time of Contact: January 30, 2001; 9:00 a.m. Eastern

Contacted By: Nancy L. Ranek

Mr. Olsen reported that BWXT has no process capability to convert UF_6 to UO_2. However, at one time, BWXT was bidding on a contract to clean heels from empty UF_6 cylinders. For this reason, the license that BWXT holds from the NRC was amended to authorize receipt of UF_6 heels.

Even so, BWXT did not receive the contract, and consequently, has no experience with handling of UF_6.

Mr. Olsen was unable to say whether BWXT would be interested in making process changes to accommodate conversion of UF_6 from the DOE inventory to UO_2 at the Lynchburg facility.

Mr. Olsen indicated he would pose this question to others at BWXT and call back later.

On February 27, 2001, Mr. Olsen called to report that BWXT is investigating the possibility of process changes that would accommodate depleted UF_6 conversion at its Lynchburg plant.

CE Nuclear Power LLC – Hematite, Missouri

Individual Contacted: None.

Phone:

Date and Time of Contact: Because this facility plans to discontinue operations by the end of 2001, no contact was made.

Contacted By:

Framatome Advanced Nuclear Power Richland Division, Inc.
(formerly Siemens Power Corporation) – Richland, Washington

Individual Contacted:
(1) L.J. Maas, Manager, Regulatory Compliance
(2) Mr. Robin Feuerbacher,
Vice President for Engineering and Manufacturing

Phone:
(1) 509/375-8537
(2) 509/375-8267

Date and Time of Contact:
(1) January 29, 2001; 12:36 p.m. Eastern
(2) January 31, 2001; 12:15 p.m. Eastern

Contacted By: Nancy L. Ranek

Mr. Maas indicated that Siemens is a member of one of the teams responding to the DOE Request for Proposals to construct and operate UF_6 conversion facilities at Portsmouth and Paducah.

Mr. Maas was unable to say whether Framatome ANP would be interested in dedicating any excess capacity to conversion of UF_6 from the DOE inventory to UO_2 at the Richland facility.

Mr. Maas stated that he would pose the question to others at Framatome ANP and call back.

Mr. Robin Feuerbacher called back on January 31, 2001.

Mr. Feuerbacher stated that Framatome ANP has three process lines at the Richland facility. They may be willing to devote one of these lines to converting DOE's depleted UF_6, although this is reserve capacity for unexpected orders from customers or affiliates. This would provide capacity to convert approximately 300 metric tons/year of UF_6 to UO_2. However, Mr. Feuerbacher indicated that the Richland plant receiving facilities are designed for Model No. 30B cylinders. Modifications and associated license amendments would be required to receive 48-inch cylinders.

Currently the Richland facility processes very little depleted UF_6, because it is a neutron poison which, if not completely cleaned from the process lines, can contaminate the plant's normal fuel product. In addition, because the normal product is enriched uranium fuel, the plant is designed for criticality control. Mr. Feuerbacher noted that such control is not needed for depleted UF_6, and utilizing equipment designed for enriched uranium reduces the efficiency with which the depleted UF_6 could otherwise be processed.

Regarding transportation access, Mr. Feuerbacher indicated that the plant currently handles all incoming and outgoing shipments by truck. However, he reported that the plant is about 0.5 mile from a rail line and about 3 miles from the Columbia River. Therefore, he believes that truck, rail, and barge are all possible modes of transport for incoming depleted UF_6 and outgoing uranium oxide product.

Regarding the Richland facility's NRC license, Mr. Feuerbacher stated his belief that the existing license, which authorizes receipt of uranium enriched up to 5%, would cover receipt of depleted uranium, but the State of Washington license may have to be amended to increase the possession limit for source material.

Framatome Advanced Nuclear Power, Inc.
(formerly Framatome Cogema Fuels) – Lynchburg, Virginia

Individual Contacted: Robert S. Freeman, Manager, Regulatory Affairs

Phone: 804/832-5268

Date and Time of Contact: January 29, 2001; 7:10 p.m. Eastern

Contacted By: Nancy L. Ranek

Mr. Freeman confirmed that the Framatome ANP facility in Lynchburg, Virginia, has no on-site conversion capability. Therefore, the facility would not be able to provide UF_6 conversion services to DOE.

Global Nuclear Fuel – Americas, LLC – Wilmington, North Carolina

Individual Contacted: Charles M. Vaughn, Manager, Facility Licensing

Phone: 910/675-5656

Date and Time of Contact: January 29, 2001; 3:40 p.m. Eastern

Contacted By: Nancy L. Ranek

Mr. Vaughn stated that Global Nuclear Fuel – Americas would not be interested in dedicating any excess capacity to conversion of UF_6 from the DOE inventory to UO_2 at the Wilmington facility.

Nuclear Fuel Services, Inc. – Erwin, Tennessee

Individual Contacted: Frank J. Hahne, Vice President, Business Development & Projects

Phone: 423/743-1789

Date and Time of Contact: January 29, 2001; 1:15 p.m. Eastern

Contacted By: Nancy L. Ranek

Mr. Hahne indicated that the NFS facility has some limited capability to convert UF_6 to UO_2. However, the facility handles primarily highly enriched uranium. Furthermore, the facility has no capability to handle 48-inch UF_6 cylinders.

Mr. Hahne stated that NFS would be interested in making facility and equipment modifications to accommodate conversion of depleted UF_6 from the DOE inventory to UO_2 at the Erwin facility.

Mr. Hahne pointed out that the NRC license held by NFS allows receipt of empty UF_6 cylinders containing heels. Accordingly, Mr. Hahne expressed his belief that NFS would be interested in receiving empty UF_6 cylinders containing enriched heels, if DOE decides to seek such services.

Honeywell International, Metropolis Works – Metropolis, Illinois

Individual Contacted: J. William Lessig, Plant Manager

Phone: 618/524-2111

Date and Time of Contact: February 1, 2001; 11:30 a.m. Eastern

Contacted By: Nancy L. Ranek

Mr. Lessig stated that the pilot plant that was built at the Metropolis Works and operated during the late 1990s is shut down. Notwithstanding, he stated that some of the plant's customers have from time to time expressed an interest in obtaining UF_6 to uranium oxide conversion services for small amounts of UF_6. He was unable to say, however, whether Converdyn (the marketer of Metropolis Works products) would be willing to restart the plant for the purpose of providing conversion services for DOE's depleted UF_6 inventory. He requested that ANL contact Mr. Jim

Graham at Converdyn's Denver, Colorado, offices [303/930-4901]. Mr. Lessig reported that if the pilot plant were operated at full capacity, it could convert between 300 and 400 tons (U.S.) per year of UF_6 to UO_2.

Mr. Graham (at Converdyn) did not respond to messages.

THE FRENCH APPROACH FOR MANAGEMENT OF DEPLETED URANIUM A CONSTANTLY IMPROVED TECHNOLOGY

Didier HARTMANN
PhD
R&D engineer
COGEMA
26700 Pierrelatte Cedex
France

Brigitte LE MOTAIS
Marketing and Sales Department
Business Unit Chemistry
COGEMA
26700 Pierrelatte Cedex
France

Bernard DUPERRET
Project Manager
COGEMA
26700 Pierrelatte Cedex
France

INTRODUCTION

The uranium enrichment industry generates large amounts of depleted uranium hexafluoride (DUF_6), as a by-product, whether using gaseous diffusion or centrifuge technology. About 1.2 million tons of U has already accumulated throughout the world since the beginning by the uranium enrichment industry. Future annual production rates are estimated between forty-five and sixty thousand tons of depleted uranium, depending upon the operational tails assay of the enrichment plants and the effective use of MOX fuel and down-blended HEU.

Depleted UF_6 is mostly stored as a solid in metal cylinders. But storage of depleted UF_6 may pose environmental risks: contact with moisture (in case of cylinder integrity defect) can lead to chemical reactions producing hydrofluoric acid (HF), a hazardous material. For long-term storage, the ideal solution is therefore to convert the depleted UF_6 into a stable, non-corrosive and easily re-usable form such as uranium oxide, and to sell it as much as possible to the commercial sector.

However, only a few hundred tons per year of depleted uranium are currently re-used, mostly included in MOX fuel for light water reactors. This application might be potentially extended in the future if the option of fast breeder or high temperature reactors is eventually developed for power production, when the earth ore and gas resources become scarce. Therefore, at least for the several decades to come, depleted uranium must be preserved as a potential energetic resource either because of its high fertile content (~ 99.7% U-238) or its remaining fissile content (~ 0.3% U-235). The challenge for the nuclear community is to secure a safe and reversible storage of depleted uranium during this period of time.

COGEMA provides uranium enrichment services to the nuclear industry worldwide. To meet general French safety requirements related to environmental protection issues, COGEMA has developed, as an extension of the enrichment operation, a facility to convert DUF_6 into a stable, fluorine-free compound.

After 5 years demonstration of the process on a pilot plant, COGEMA placed a facility in industrial operation in 1984 to convert DUF_6 into stable oxide U_3O_8 ; a second facility was commissioned in 1993, doubling the capacity.

Each year, the COGEMA plant allows to convert ("defluorinate") about 21,000 tons of DUF_6 into uranium sesquioxide (U_3O_8) and high purity aqueous hydrofluoric acid (70% HF). Up to date, about 220,000 tons of depleted UF_6 have been defluorinated. The U_3O_8 form allows safe interim storage of depleted uranium, as evidenced by about 20 years of COGEMA storage experience. The high purity aqueous 70% HF is sold in the European commercial sector under rigorous safety conditions.

Since the beginning of its industrial defluorination operations, COGEMA has ever been concerned to make its technology as reliable and as cost effective as possible. Accordingly, an improvement work has been constantly under way which already benefited to the construction of the second facility, completed in 1993. This paper will give an overview of the improvement work performed over the years, relating not only to the technology (optimizing the defluorination output, reducing the corrosion inside the kilns, improving the uranium oxide powder compaction factor...), but also to the process itself (hydrodynamic modeling of the process reactions inside the kiln) and maintenance issues (systematic monitoring of filters plugging, recycling of cartridge filters...).

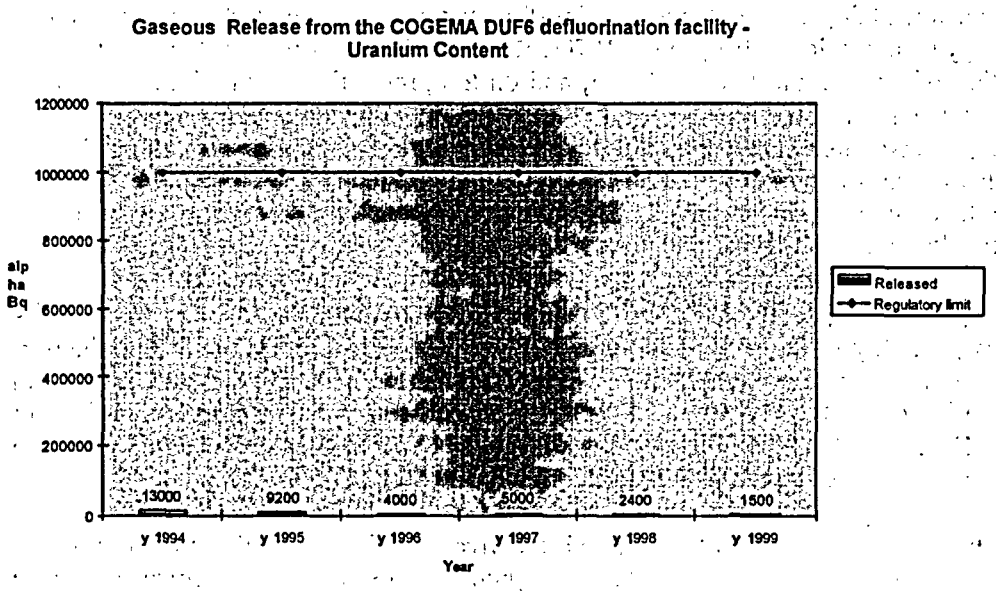
COGEMA'S DEFLUORINATION PROCESS

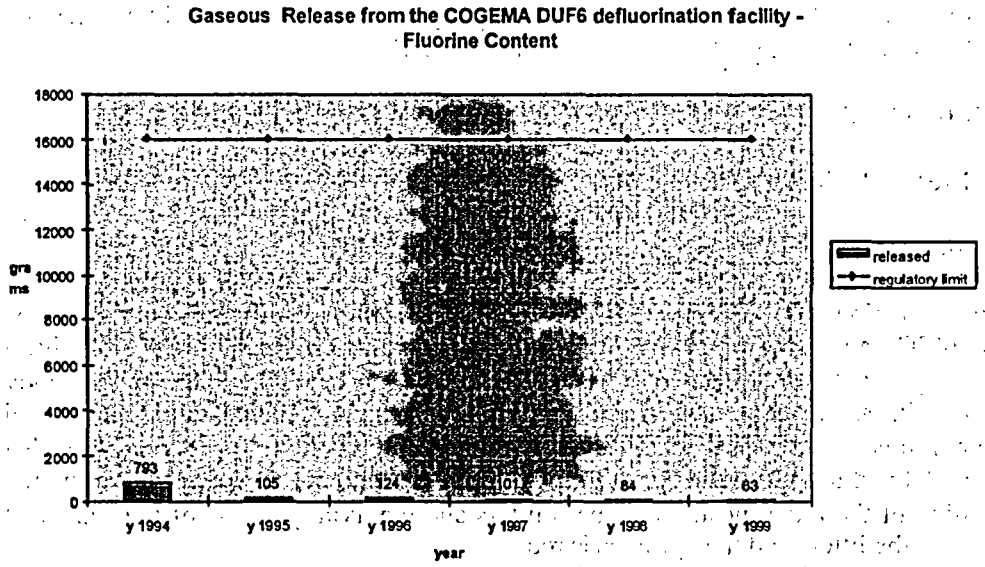
The basics of the process was already presented by COGEMA at several other U.S. conferences. The process will then be only summarized here in order to better emphasize on the technical improvements already undertaken.

Cylinders of depleted UF_6 are transferred from the enrichment facility and inserted into airtight autoclaves where UF_6 is turned to vapor using wet steam and is directed to the defluorination kiln. In the first part of the kiln, gaseous UF_6 reacts with overheated steam. The hydrolysis exothermic reaction generates intermediate solid uranyl fluoride, UO_2F_2 and gaseous HF. The solid UO_2F_2 falls into the second part of the kiln through a screw conveyor and reacts at a higher temperature with hydrogen and overheated steam. The conditions of this endothermic pyrohydrolysis reaction are optimized to produce a U_3O_8 oxide with a low residual fluoride content and a valuable co-product, hydrofluoric acid, which contains the excess water from the reaction.

The mixture of hydrogen fluoride and steam leaves the kiln through a filtration chamber, which removes uranium oxide from the gas. This gas is then condensed and scrubbed in such a way that a 70 % HF is obtained. After monitoring, the HF is pumped to a dedicated storage area consisting of 20 m^3 tanks. The product is then transferred to road or rail tanks for final shipment to customers.

The CEA-COGEMA process is a dry process, which does not generate any liquid process effluent. Twenty years of operation have shown that its impact on the environment is very limited. COGEMA has patented an efficient filtration device at the exit of the defluorination kiln. As a result, gaseous releases are negligible and well under the regulatory limits for uranium and fluorine contents. And the chemical hazards associated with long-term storage of depleted uranium are reduced to a minimum by COGEMA's choice of the stable U_3O_8 form and the use of specially designed storage 10m^3 containers called DV70.


Gaseous Release from the COGEMA DUF6 defluorination facility - Uranium Content
1200000
1000000
800000
600000
400000
200000
0
alpha Bq
13000
9200
4000
5000
2400
1500
y 1994
y 1995
y 1996
y 1997
y 1998
y 1999
Year
Released
Regulatory limit


Gaseous Release from the COGEMA DUF6 defluorination facility - Fluorine Content
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
grams
793
105
124
101
84
63
y 1994
y 1995
y 1996
y 1997
y 1998
y 1999
year
released
regulatory limit

THE FRENCH MANAGEMENT OF DEPLETED URANIUM: A CAREFULLY-PREPARED INDUSTRIALIZATION

Studies to convert DUF_6 into a stable, fluorine-free compound were started by the French Atomic Energy Commission (CEA) in the 1970s. Research focused on a dry process, to avoid the generation of undesirable liquid effluent, and on the production of uranium oxide with recovering of the fluorine component in a re-usable form. Various alternatives of the dry process were investigated. One process that received special attention was to distill the aqueous HF to obtain anhydrous acid and to recycle the remaining azeotrope by direct re-injection in the defluorination kiln. This alternative was eventually discarded since it required more sensitive kiln technology and was more corrosive.

The CEA registered a patent on its dry process. CEA's oxide product, preferred for its stability, low solubility in water and low corrosiveness, is sesquioxide U_3O_8, close to the pure chemical form of uraninite or pitchblende, the prevailing natural form of the uranium found in ore. The fluorine content is recovered in the form of marketable aqueous hydrofluoric acid (with a 70% HF content). The decision to industrialize the CEA process was concomitant with the beginning of construction of the EURODIF enrichment facility.

First, industrial feasibility was demonstrated for five years on a full-scale pilot plant. Important parameters, such as the resistance of process materials to UF_6 corrosion, were tested and optimized. In 1984, just two years after full commissioning of the EURODIF facility, the first COGEMA industrial defluorination unit started its operations in Pierrelatte (South of France). A second unit, benefiting of improvements from the operation experience of the first facility, was commissioned a few years later, in 1993. The full COGEMA plant today allows to process 21,000 metric tons of DUF_6 per year (14,000 MT uranium), yielding roughly 17,000 Mt of U_3O_8 and 10,000Mt of 70% hydrofluoric acid per year.

IMPROVEMENTS OF THE PROCESS TECHNOLOGY OVER THE YEARS

Examples of technological improvements

<u>On the defluorination kiln :</u>

- The corrosion of the kiln shell, due to high temperatures in the central section (~ 900°C) and very aggressive atmosphere (gaseous HF), has been extensively investigated. An optimization of basic parameters such as shell thickness, shell alloy composition, ... has allowed to reach a satisfactory technical and economical compromise with regard to the shell lifetime. Maintenance procedures have also been defined to reduce the corrosion of the kiln equipment: for instance, the annual shifting of the radial position of the 6 lifters and the axial position of the rings that support the lifters and the pyrometric rod.
- The geometry of the injection nozzle (for the UF_6, vapor and intermediate nitrogen flow rates) has been adjusted to prevent clogging at the end of the nozzle and to ensure an instantaneous UF_6 hydrolysis reaction inside the reaction chamber.
- In the second defluorination facility completed in 1993, the filtration unit located at the top of the hydrolysis chamber was re-designed to allow the integration of a systematic monitoring of filters plugging. Since then, studies have been performed for optimizing the counter-current unplugging cycle, in order to increase the lifetime of the filters.

- The air-tightness at the kiln ends has been increased, thanks to the use of especially designed materials and a torque wrench.
- The stroke frequency of the hammer placed at the exit end of the rotary kiln has been adjusted to prevent the very cohesive UO_2F_2 powder to stick on the walls of the kiln. Soon, additional vibrating devices will be set up on the external surface of the kiln to even more limit this sticking phenomenon. The positions of these future vibrating devices on the kiln surface will be determined by numeric simulation.
- Recently, a hydrodynamic study has started to characterize the flow pattern inside the hydrolysis chamber using Computational Fluid Dynamics. The aims are to optimize the working conditions in order to reduce plugging occurrences through a scientifically justified position of sensors (thermocouples, vibrating devices) and to tentatively control the size distribution and quality of UO_2F_2 aggregates.

Gas process :

- The condensers are designed to cool down the gaseous $HF + H_2O + N_2$ stream exiting the defluorination kiln through the filtration chamber. A close collaboration between COGEMA and the manufacturer of this equipment has allowed to design condensers with a geometry and a material structure specifically adapted to our technology requirements.

U_3O_8 collection :

- The performance of the U_3O_8 powder compaction unit has been increased by a factor of 40% over the years (up to a current average content of 10.5 Mt U_3O_8 per storage DV70 container). Improvements have included: adjustment of the scrappers conveying the powder to the rollers, monitoring of the input by adjusting the speed of the feeding screw, modification of the vibration table to increase the powder density inside the DV70 containers up to a value over 3.

HF processing and management :

- The 70% HF produced by the COGEMA defluorination plant is very pure thanks to an efficient patented filtration device at the exit of the defluorination kiln. Studies have been carried out to convert this 70% HF to anhydrous HF, which can be sold on the European market at a much higher price. Five different processes have been technically compared. Direct distillation has been discarded because of the lack of commercial market for the 38% azeotrope by-product and the problems associated with its direct re-injection inside the defluorination kiln (such as the design of a special super-heating system). The currently preferred process consists in liquid-liquid extraction but no investment decision has been taken yet due to the present very high demand on the European market for the high purity-grade 70% HF produced by the COGEMA defluorination plant.

Process modeling

Several PhD studies have been conducted for a better understanding of the phenomena occurring in the rotary kiln during the conversion of UO_2F_2 to an oxide. Most of this modeling research work is described in master's theses:

- The kinetics of the pyrohydrolysis reaction[1]
- The establishment of a model to describe the operation of the first CEA defluorination rotary kiln[2]
- The establishment of a numerical code describing the flow pattern inside the CEA kiln as well as the temperature and the composition of solids and gases at different axial positions[3]
- The establishment of a numerical model for the COGEMA defluorination kiln with the goal to describe as accurately as possible the various phenomena inside this kiln and to propose optimizing ways for working conditions and design of new kilns. The movements of solids in rotary kilns equipped with lifters was studied thoroughly; a method, based upon geometrical considerations, and on experiments, was developed to calculate the average distribution of powder in transverse sections of the kiln and the bed depth profile. A kinetic model was set up to calculate the conversion of solid at each axial position. The thermal conductivities of powder beds, the emissivity of walls and powders and some heat transfer coefficients were experimentally measured[4].

R&D on other "defluorination" processes

- Several reactions allowing to convert UF6 into U3O8 with a concomitant production of valuable fluorine products have been studied and tested at a laboratory scale. Interesting results were obtained for the reaction $UF_6 \rightarrow SiF_4$, but none has been implemented due to a large number of secondary problems.

CONCLUSION

Owners of depleted uranium have the responsibility to store it safely and minimize the risk of chemical hazards. COGEMA safely removes the fluorine component from DUF_6, recovering fluorine in the form of an easily marketable product and rendering the uranium into a stable oxide appropriate for safe storage and easy re-use in the nuclear fuel cycle or any other potential application. In more than 16 years of industrial experience, COGEMA has optimized the operational parameters and the preventive maintenance program of the defluorination facility, making this operation not only safe, but also cost-effective by increasing the service life of many process equipment. As exemplified by this paper, a pro-active R&D approach has been followed by COGEMA over the years in a constant concern to better manage the technical issues associated with the implementation of a simply-written process in aggressive reaction conditions. Even now, new R&D programs are under way or in project.

[1] P. FAVRE PhD Thesis, Claude Bernard University, Lyon (France), June 1977
[2] P. MUREAU PhD Thesis, Institut National Polytechnique de Toulouse, July 1992
[3] S. BOUTIN-LA COMBE, PhD thesis, Rouen University (France), March 1995
[4] M. DEBACQ, PhD thesis, Institut National Polytechnique de Nancy (France), January 2001

National Transportation Safety Board
Washington, D.C. 20594

Railroad Accident Brief

Accident Number:	DCA-01-MR-004
Location:	Baltimore, Maryland
Date and Time:	July 18, 2001, 3:08 p.m.
Accident Type:	Derailment and fire
Companies:	CSX Transportation
Injuries:	5 (minor)
Fatalities:	None
Cost:	$12 million

Synopsis

On Wednesday, July 18, 2001, at 3:08 p.m., eastbound CSX[1] freight train L-412-16 derailed 11 of its 60 cars while passing through the Howard Street Tunnel in Baltimore, Maryland. Four of the 11 derailed cars were tank cars: 1 contained tripropylene, a flammable liquid; 2 contained hydrochloric acid; and 1 contained di(2-ethylhexyl) phthalate, which is a plasticizer and an environmentally hazardous substance. The derailed tank car containing tripropylene was punctured, and the escaping tripropylene ignited. The fire spread to the contents of several adjacent cars, creating heat, smoke, and fumes that restricted access to the tunnel for several days. A 40-inch-diameter water main directly above the tunnel broke in the hours following the accident and flooded the tunnel with millions of gallons of water. Five emergency responders sustained minor injuries while involved with the on-site emergency. Total costs associated with the accident, including response and clean-up costs, were estimated at about $12 million.

The Accident

The train, en route with 31 loaded and 29 empty cars from West Baltimore, Maryland, to Philadelphia, Pennsylvania, departed the CSX West Baltimore Yard, about 6 miles west of the derailment site, at 2:37 p.m. on July 18, 2001. Within its consist, the train had eight fully loaded tank cars containing hazardous materials regulated by the U.S. Department of Transportation (DOT).

On the day of the accident, 11 trains went through the Howard Street Tunnel before the accident train. The crewmembers of the accident train reported that their train

[1] CSX is more formally known as CSX Transportation or CSXT, a subsidiary of CSX Corporation.

entered the west end of the tunnel (Camden end)[2] at a speed of 23 mph. The locomotive event recorders indicated that the locomotives were in throttle position 5 and that the train's speed was less than the timetable speed of 25 mph as the train entered the tunnel.

About 1,343 feet into the 8,700-foot-long tunnel (station 73+57),[3] the track grade changes from a slight descending grade to a slight ascending grade. The event recorders showed that at the dip, the train's speed was 24 mph in throttle position 4. As the train passed through the dip, the engineer gradually increased the throttle to position 8 as the train started the ascending grade. While the train was moving about 21 mph, the locomotive tractive effort increased, and the train slowed to 18 mph. At 3:08 p.m., an uncommanded emergency air brake application[4] was recorded, and the lead locomotive stopped in the tunnel about 1,850 feet from the east portal.

Unknown to the crew at the time, the train had derailed. The emergency application of the train air brakes had occurred when the train became uncoupled ahead of the first car to derail, causing the train air brake line to separate.

The derailment also resulted in the puncturing of a derailed tank car carrying tripropylene and the subsequent ignition of this product. The puncture was a 2-inch-diameter hole located near the bottom of the tank on the B-end (the leading end), left side, and on line with the interior end of the stub sill. Postaccident inspection of the tank car indicated that a braking system linkage bar had disconnected and that the disconnected end of the linkage bar, when lifted upward, aligned with the hole in the tank. The fire spread to cargo in adjacent cars, which included paper and wood products, and generated heavy smoke and fumes that quickly filled the tunnel. Additionally, 2,554 gallons of hydrochloric acid were released from another derailed tank car. (See figure 1 for a diagram showing the positions of the derailed cars.)

[2] For identification purposes, the timetable tunnel orientations are used. The geographic south end (Camden) of the tunnel is designated as the west end in the timetable, and the geographic north end (Mt. Royal) is designated as the east end.

[3] CSX uses station numbers to identify specific locations within the Howard Street Tunnel. Each station represents a distance of 100 feet measured from the east end (Mt. Royal portal) of the tunnel. Locations in the tunnel are identified by indicating the number of feet they are west of the nearest station marker. For example, station 73+57 is about 7,357 feet from the east portal of the tunnel.

[4] Railroads typically refer to any emergency brake application not specifically initiated by the engineer as an "undesired" emergency brake application.

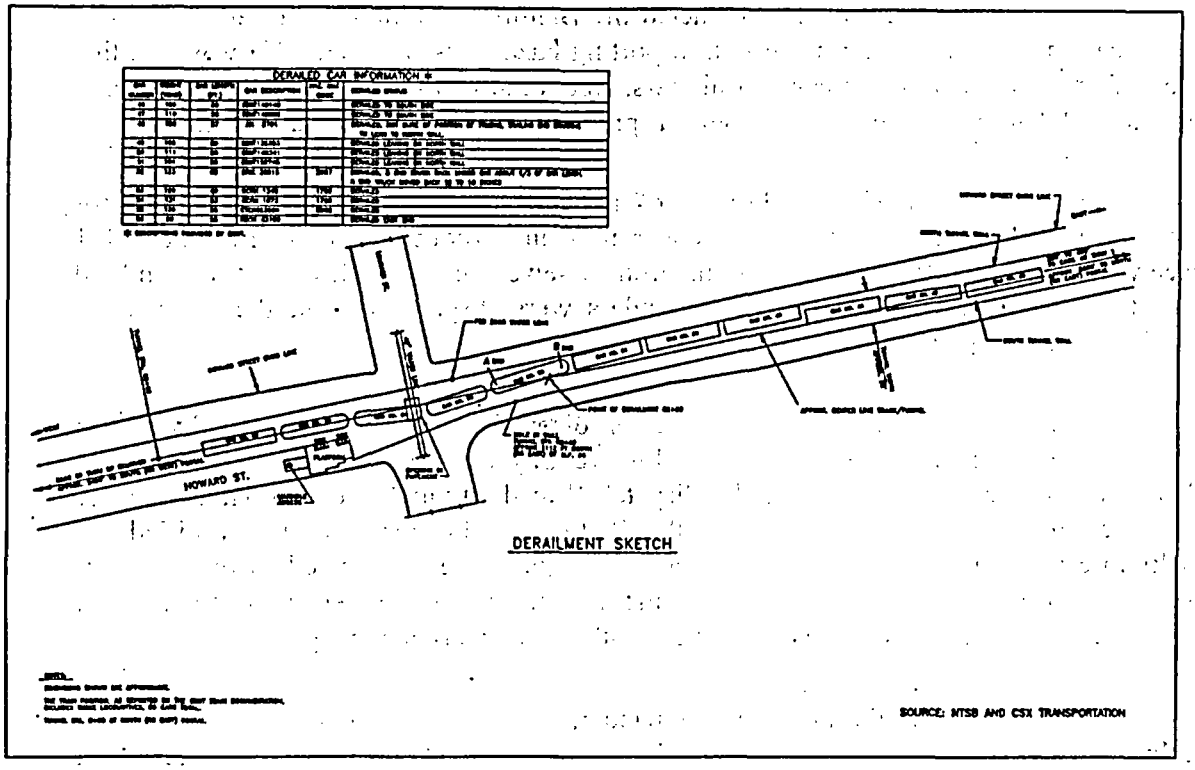


Figure 1. Positions of derailed cars.

The lead locomotive stopped inside the tunnel about 1,850 feet west of the Mt. Royal portal. For some time, the train crewmembers remained unaware that a derailment had taken place. When the crewmembers attempted to notify the CSX dispatcher while their locomotive was still in the tunnel, they found they could not establish radio contact.[5] About 3:13 p.m., the conductor used his personal cell phone to contact a Baltimore area trainmaster, who relayed information regarding the emergency stop to the train dispatcher. About 3:26 p.m., the crew moved the locomotives eastward out of the tunnel, stopping about 450 feet beyond the east tunnel portal.

Postaccident Events and Emergency Response

At 3:26 p.m., the director of security at a hotel above and adjacent to the derailment site in the tunnel called 911 and reported an unusual disturbance near his facility. The security director then called the Baltimore Department of Public Works to report the disturbance. About 3:34 p.m., he called the CSX communications center to advise them of a strong "rumbling" that had occurred at his building. He told the communications center that he suspected the rumbling had originated in the Howard Street railroad tunnel. About 3:36 p.m., the communications center operator forwarded the call directly to the CSX chief dispatcher.

[5] It was later learned that derailing equipment had rendered the radio relay system inoperable.

The CSX chief dispatcher contacted the Baltimore trainmaster to advise him of the situation and ask if the train was transporting hazardous materials. He was told that the train did include hazardous materials cars. About 3:40 p.m., the CSX chief dispatcher determined that the train likely had a serious problem and had possibly derailed.

At 3:51 p.m., the CSX director of network operations issued a request for assistance to the railroad's hazardous materials team. About 4:00 p.m., Baltimore 911 received a call reporting smoke coming from a sewer near the Howard and Lombard Street intersection. Fire department responders were dispatched, and they traced the smoke to the Camden (west) tunnel portal.

Also about 4:00 p.m., the CSX chief dispatcher telephoned the CSX police communications center to ask that the Baltimore City Fire Department be notified and that emergency response personnel be dispatched to the tunnel. At 4:04 p.m., the CSX police communications center notified the Baltimore 911 operator, who notified the Baltimore City Fire Department. Fire department personnel responded to the site (Mt. Royal Station) about 4:10 p.m., but they could not enter the tunnel because of the fire and smoke. The train crew provided the train consist[6] to the emergency responders.

About 5:07 p.m., the incident commander, after deliberating with the responding technical experts, concluded that the derailment did not pose an immediate threat of a catastrophic explosion or a dangerous vapor release that would require an evacuation of the area. The incident commander thus did not believe a mass evacuation was necessary and instead decided to employ a "shelter-in-place" strategy for the several blocks on either side of the tunnel path along the principal length of the tunnel. Other precautionary measures included evacuating the Camden Yards baseball stadium, activating the public alert siren system, and employing local television and radio outlets for public notifications.

About 6:15 p.m., the water elevation began dropping at the city of Baltimore's Montebello II treatment plant. About 6:19 p.m., the water elevation at the Montebello I water treatment plant also began dropping. At Druid Park Lake, the water flow rate[7] abruptly increased from about 8.5 million to 9 million gallons per day (mgd) to about 18 mgd between about 6:15 p.m. and 6:30 p.m.

A time-stamped security camera (taking a picture every 48 seconds) showed that water had broken through to the street surface at the intersection of Howard and Lombard Streets at 6:19:38 p.m. Water flooded the intersection and flowed south on Howard Street. Water also flowed into the Howard Street Tunnel, which was below the street.

---

[6] The *train consist* shows the make-up of the train, including the placement and contents of all cars. If cars containing hazardous materials are part of the train, documentation is attached to the consist list that details emergency response information for those materials.

[7] *Flow rate* is a measurement of the volume of water leaving the reservoir and entering into the water system over a given period of time.

According to city records, notification was received of a water leak about 6:19 p.m., and the city sent a crew to investigate. The crew determined that a failure had occurred in the 40-inch-diameter cast iron water main that passes directly above the Howard Street Tunnel at station 63+15.[8] (See figure 2 showing broken water main.) The crew closed a 40-inch valve at the intersection of Lombard and Paca Streets. They also closed valves on an interconnected 20-inch-diameter water line. A 40-inch valve located 1 block to the east (as well as numerous interconnecting lines) was also closed to isolate the area of the break. The line was shut down by 11:59 p.m., about 5 hours 40 minutes after the appearance of water at street level. The city of Baltimore estimated that about 14 million gallons of water were lost from the water main between the time of the break and the time the line was shut down.

Figure 2. Broken 40-inch-diameter water main.

For the next 2 days, several groups of firefighters and railroad employees equipped with self-contained breathing apparatus ventured into the tunnel to determine the extent of the derailment and the status of burning equipment and cargo. Inside the tunnel, the first 45 railcars in the train consist had not derailed and had been pulled

[8] The city calculated the water pressure of the 40-inch pipe at the point of the tunnel crossing to be about 73 pounds per square inch.

beyond the derailment site. The next 11 railcars had derailed (positions 46 through 56). The remaining four railcars had not derailed.

The fire lasted for about 5 days as smoke emanated from both ends of the tunnel and several manholes at the Howard Street level. On Monday, July 23, at 7:42 a.m., the incident commander declared the scene officially under control. Later that morning, he authorized entry into the tunnel without self-contained breathing apparatus for qualified personnel.

Efforts to Determine Accident Cause

General

Because of the fire in the tunnel and the release of hazardous materials from tank cars, Safety Board investigators were not immediately able to enter the tunnel. By the time Safety Board investigators were able to examine the derailment area in detail, it had been disturbed by the discharge of about 14 million gallons of water from the ruptured water main, by the removal of significant sections of track, and by the use of heavy equipment to pull smoldering cars from the tunnel. Investigators therefore could not document the derailment site as would normally be done in a train derailment accident investigation. The following material considers preaccident data and information, postaccident physical testing and evidence, and statements from people who were in the tunnel during or immediately after the emergency response.

Postaccident examination did not disclose any preaccident defective rail conditions. All the fractures in the north rail initiated from the gage side, and almost all the fractures in this rail were associated with a rail anchor mark. This indicates that the fractures in the north rail were created by a common mechanism. The most likely mechanism was a wheel or wheels dropping off the gage side of the north rail and striking the anchors, driving them in an eastward direction. The anchor marks were likely created when a struck anchor, restrained by a tie, dug into the gage side of the base, creating a depression and, in many cases, initiating a shear crack at the east end of the mark. These shear cracks then propagated and fractured the north rail.

None of the fractures found after the accident contained any features that suggested a defect or a slow-growing crack. Additionally, the investigation did not find any battered rail ends, as would be expected if a rail had broken before the accident. All the fractures found in the rail removed from the accident area were typical of overstress fracture, indicating that a broken or defective rail did not cause the derailment.

Examination of the event recorder data for the accident train did not show any unusual train handling methods, and the engineer and conductor performed their assigned tasks in compliance with the CSX operating rules and special instructions applicable to this train's operation. A review of the crewmen's personnel records showed they were

current in the operating rules requirements for their positions, and their medical records did not show restrictions.

Inspections of the train equipment did not reveal any preaccident deficiencies, defects, or missing parts, with the exception of the 52nd car in the consist. The 52nd car, the derailed tripropylene tank car that ruptured, was found de-trucked, with its easternmost (lead) truck near the center of the car and the westernmost truck against the car body bolster. The center pin between the lead truck and car body was missing.[9] The Safety Board and the Association of American Railroads (AAR) used computer models to simulate the movement of this car with the center pin missing between the lead truck and car body. The simulation used the most recent CSX track geometry data for the segment of track with the train entering the west portal of the tunnel at the speed of 23 mph. The simulation did not result in a derailment of the tank car with a missing center pin.

The 40-inch-diameter cast iron water main that ran directly above the Howard Street Tunnel, which ruptured and introduced a large volume of water into the tunnel, was considered as a possible causal factor in the accident. When postaccident examination was made of the ruptured pipe, no indication of third-party damage or significant corrosion damage was found at or near the point of rupture. Metallurgical examination of the fractured pieces of the water main showed that the fractures in the pipe section were brittle, with no evidence of crack arrest positions or slow growth regions, which indicates that a sudden overstress fracture of the cast iron pipe occurred.

A photo from a time-stamped security camera at the intersection of Howard and Lombard Streets indicated that water from the broken main appeared at the street surface at 6:19:38 p.m., about 3 1/4 hours after the derailment. In addition, water elevations at several nearby water treatment plants declined between about 6:15 p.m. and 6:30 p.m. This timing information suggests that the water main broke as a result of the postaccident events, including the fire within the tunnel, rather than prior to the accident.

A finite element analysis[10] of the tunnel and surrounding area in the vicinity of the water main was performed using the ABAQUS[11] code to determine whether the fire within the tunnel could have caused the water main to fracture. The analysis concluded that the postaccident fire was responsible for thermal expansion of the tunnel and that the expansion caused the tunnel walls to heave upwards, displacing the surrounding materials and imparting significant loads upon the water pipe. Further, the unique construction

[9] A center pin does not carry or transmit load during a car's movement.

[10] *Finite element analysis* is the simulation of a physical system (geometry and loading environment) by a mathematical approximation of the real system. Using interrelated building blocks called elements, a real system with infinite unknowns is approximated with a finite number of unknowns.

[11] Hibbitt, Karlsson & Sorensen, Inc., *ABAQUS/Standard User's Manual, Version 6.2* (Pawtucket, RI: 2001).

details of the tunnel, the pipe, and the light rail foundation[12] combined to generate discontinuities in resistance to the thermal heaving, generating significant concentrations of stress within the water pipe. The location of the high stress concentrations predicted by the analysis was consistent with the location of the initiation of the fracture in the pipe, as determined through metallurgical examination. Therefore, the 40-inch water main that ran directly above the Howard Street Tunnel broke after the train had derailed, as a result of the thermal expansion of the tunnel caused by the postaccident fire within the tunnel.

Identifying the Point of Derailment

Wheel marks found on the head of the north rail during the reconstruction of rail recovered from the derailment area indicated that a wheel had moved south toward the inside of the rail about station 62+23. Additional wheel marks were found on the gage side of the base of the north rail; however, no wheel marks were found on the south rail nor were any other wheel marks identified on either rail.

A detailed postaccident examination was conducted of the first several derailed cars. Efforts were concentrated on the first several derailed cars because experience has shown that a derailed car does not cause the derailment of more than two preceding cars on straight track. The inspection of the truck side frame spring seat ribs of the derailed cars showed that the profile of the rail head was worn into the spring seat ribs on the underside of the truck side frame spring seats on one side or the other of the 46th through 48th cars, indicating that they had slid on top of the rail between the body of the side frame and the wheels. The wear varied from car to car; the more wear there was, the longer the car had been derailed before coming to a stop.

The 47th car in the consist showed the most rib wear, indicating that this car had spent the most time derailed, so it was probably the first car to derail. The trucks of the 46th car had the next most rib wear. There was less wear to the B-end (leading end) spring seat ribs of the 48th car and only scrapes to the A-end (trailing end) ribs. Therefore, it appears that the 46th car was the second car to derail (pulled off the track by the 47th car) and that its derailment was followed by the derailment of the 48th and subsequent cars.

Event recorder data showed an increase in the train's tractive effort, followed by an unexpected reduction in train line air brake pressure. Based on this information, the Safety Board determined that derailed cars were on the ground while the train traveled about 300 feet before an air brake line separation between the 45th and 46th cars caused an automatic emergency application of the train's brakes. From the event recorder data and the documented position of the derailed equipment, the 45th and 46th cars came to a stop with about 550 to 600 feet between them. Event recorder data showed that the head

[12] The Maryland Transit Administration operates a double-track light rail service on Howard Street that runs parallel to and above the Howard Street Tunnel.

end of the 47th car was at about station 62+11, about 12 feet past the wheel marks on the north rail, when the emergency application occurred.

Based on the rail reconstruction, the profile of the rail head wear found on the truck side frame spring seat ribs of the car showing the most wear, and the position of the 47th car before the train brakes automatically went into emergency, the point of derailment was near station 62+23.

Derailment Scenarios

Because no clear evidence was found that would point definitively toward a single cause of the derailment, the Safety Board examined several scenarios to determine what factors or combinations of factors may have caused or contributed to this accident.

Sand in the Tunnel. Sand was reported in the derailment area after the accident. Large quantities of sand, if deposited on the track and over the rail, could affect train passage. But none of the 11 train crews that traversed the tunnel before the accident train on the day of the derailment reported seeing unusual quantities of sand on or near the track in the tunnel. Nor did the crew of the accident train report observing any unusual sand deposits. A quantity of sand sufficient to cause a derailment would not likely have gone unnoticed. Furthermore, had such an amount of sand been present, the derailment should have occurred nearer the head end of the train than the 47th car.

Some of the witnesses who entered the tunnel on the day after the accident reported seeing little sand in the derailment area. Other witnesses reported seeing significant amounts of sand. A fire department chief reported that he inspected the undercarriages of the derailed cars and did not notice any sand.

During postaccident examination, a section of the south wall of the tunnel was found to have a bulge projecting into the tunnel near station 62+31. The bulge was about 8 feet above the tunnel floor and about 4 to 6 feet in diameter. It projected into the tunnel less than 1 foot. Within the bulged area was a hole. The hole in the first layer of brick was about 3 bricks wide by 3 bricks high. Deeper in the wall, the hole was about 2 bricks wide and 1 1/2 bricks high. A person working in the tunnel the day after the derailment reported seeing water shooting from this hole, as it was from other locations.

The Safety Board contracted with the U.S. Army Corps of Engineers (USACE) to perform a geotechnical investigation in the area of the tunnel fire and water main break. In its report to the Safety Board, the USACE concluded that any significant quantity of sand in the tunnel was almost certainly carried into the tunnel as a result of the piping action from the ruptured 40-inch water main. Further, the USACE reported that, even if the hole had opened in the south tunnel wall bulge near station 62+31 after the head end of the train had passed, insufficient sand could have been deposited on the track to cause a derailment in the 2 minutes 15 seconds that elapsed from the time the locomotives

passed until the first car derailed. The sand on the tunnel floor reported by some observers days after the derailment most likely resulted from the postaccident rupture of the 40-inch water main above the tunnel and the release of 14 million gallons of water.

Wide-gage Track. Wide-gage track can lead to a derailment if the defect is sufficient to allow the train wheels to drop inside the rails. In this accident, wheel markings found after the accident on the north rail could indicate a wide-gage derailment; that is, the markings show that derailed wheels did drop into the gage side of the north track. Other evidence, however, was not consistent with a wide-gage derailment.

Typically, in wide-gage derailments, either the wheels on both sides of the solid axle fall within the gage of the track or the wheels on one side drop in while the opposing wheels remain on the rail. In other cases, a wheel drops in and the opposite wheel forces the other rail to "roll-over" with that wheel then riding along the web of the rolled rail.

Physical evidence did not support any of the wide-gage derailment scenarios. The south wheels of the derailed cars neither fell within the gage of the track nor remained on the rail; they were found derailed to the field side (outside) of the track. Also, the evidence of the profile of the rail head worn into the spring seat ribs on the underside of the truck side frame spring seats on one side or the other of the 46th through 48th cars indicates that neither the north nor south rails immediately rolled during the derailment.

Postaccident track inspection did not identify any crosstie deficiencies within the undisturbed track leading to the derailment area. Inspection of the undisturbed track crosstie population immediately after the accident and again after completion of a rail renewal project did not show any signs of gage widening for the straight track outside or within the limits of the derailment footprint. No evidence was found to suggest that the condition of the ties that had been destroyed in the fire was significantly different from the condition of the other crossties in the area. The condition of the recovered crossties was also consistent with that of the non-defective resident crosstie population, taking into consideration the damage the recovered crossties received from the derailed equipment. The fasteners and tie plates on the recovered crossties appeared to be affixed solidly on almost every crosstie, indicating that the crossties were likely of sufficient strength not only to sustain the postaccident damage but also to maintain gage within the standards for Federal Railroad Administration (FRA) class 2 track.

Records showed that CSX tested and/or measured the track geometry through the Howard Street Tunnel an average of three times per year. The Safety Board reviewed the seven previous track geometry tests, which took place over a time span of about 2 years.[13] The seven track geometry tests between July 13, 1999, and February 2, 2001, showed that the rate of change in gage during the 2-year period was negligible; during this time, the gage never reached problematic proportions in the area of the straight track,

[13] The specific test dates were February 2, 2001; January 30, 2001; July 17, 2000; July 12, 2000; March 20, 2000; March 15, 2000; and July 13, 1999.

including the area of the derailment. In addition, preaccident track inspections by both CSX and the State of Maryland did not identify any gage deficiencies within the tunnel.

Track Geometry. A train/track dynamic simulation study was undertaken to examine the interactions of the track, train, and environment within the Howard Street Tunnel. When computer simulations were performed using the most recent preaccident CSX track geometry data (taken on February 2, 2001) and incorporating the condition of the equipment and the dynamic forces applied by the accident train to the track structure, no simulated derailment occurred. But because an actual derailment did occur, and because a broken rail, the mechanical condition of the train, and train operations had not been identified as likely factors in the accident, investigators had to consider whether the derailment could have been caused by one or more deficiencies in the track structure.

The CSX track geometry data for the seven most recent previous tests showed that the gage, cross-level, alignment, profile, and warp measurements were within FRA regulatory thresholds for class 2 track. In fact, the track structure in the straight portion of track in and around the point of derailment consistently met standards for FRA class 5 track (a maximum speed of 80 mph allowable for freight trains),[14] even though CSX elected to operate its trains at 25 mph through the tunnel. Thus, it is unlikely that a train traveling at less than 25 mph, as was the accident train, would have derailed solely due to track geometry as measured before the accident. The track geometry test data reviewed were representative of an approximately 2-year-long period before the derailment. The data show that the track alignment fluctuated within a range of about 0 to 1 1/8 inch during the entire 2-year period. Further, the track in the tunnel underwent maintenance for spot surfacing with crosstie renewal installation. The surfacing of track is consistent with normal crosstie installation, and it is likely that the surfacing helped to maintain or improve the track alignment for the straight stretch of track in the tunnel.

Rail cross-level measurements for the same 2-year period also showed improved measurements, from a 0- to 1-inch range on July 13, 1999, to a 0- to 3/4-inch range for the same portion of straight track on July 17, 2000, almost exactly 1 year before the derailment. The range of the cross-level measurements (0 to 3/4 inch) remained constant for the year preceding the derailment. These measurements do not represent only the actual derailment area but rather the overall area of straight track, beginning east of the curves at station 71+00 and extending eastward on the straight track, through and past the point of derailment.

None of the track warp measurements had exceeded 1 1/8 inch in the previous 2 years. Track warp fluctuated from one test with a range of 0 to 1 1/8 inch in July 1999 to an improved range (a lessening of measurement) of 0 to 1/2 inch for two consecutive test

[14] It should be noted that although this specific portion of track could have been designated as class 5, due to practical engineering considerations concerning physical aspects of the Howard Street Tunnel, trains could not have been safely operated at speeds of 80 mph within the tunnel because of physical characteristics and operational considerations.

dates; then track warp increased to a range of 0 to 3/4 inch and remained constant during the last three tests prior to the derailment. In each case, the track geometry data consistently showed that the higher number in the range of measurements was the exception rather than the rule.

Computer simulations were performed to determine what changes in track geometry would be required to effect a derailment. The simulations were intended to re-create the accident train's movement over the track and, by varying the range of track geometry conditions, to produce a derailment.

Simulations were performed in which only one track geometry anomaly was introduced, without varying the other track geometry parameters. None of these simulations, when based on realistic anomaly data, resulted in a derailment.

Simulations were also performed using various combinations of anomalies in track cross-level, alignment, profile, and warp. These simulations showed that the minimum values necessary to create a wheel lift derailment were 2 1/2 inches of cross-level deviation and 2 1/2 inches of misalignment. But to match these values on the day of the accident, the geometry of the accident track would have to have deteriorated at least 1 3/4 inch vertically and horizontally from the maximum values registered during the most recent track geometry car readings, which had been taken about 5 months before the accident.

The accident train crew and the crew of the train that had traversed the tunnel before the accident train both reported water dripping onto their locomotives and water seepage down the tunnel wall near the derailment area, but neither train crew took exception to the track conditions within the tunnel. The fact that the 46th and 47th cars of the accident train were among the first to derail shows that much of the train had successfully traversed the area of the derailment. Thus, any combination of track anomalies would have had to occur under the passage of the accident train. But the essentially consistent track geometry data recorded during the previous 2 years of testing did not support the likelihood of extreme or rapid track geometry degradation.

The investigation showed that the tunnel had chronic water intrusion, particularly at the east, or Mt. Royal, end. The intrusion of water would be an outside factor affecting the track geometry. CSX was aware of the problem at the Mt. Royal end of the tunnel and performed periodic track maintenance to address it. Water from leaks in water distribution lines, from storm drains, and from naturally occurring groundwater can seep into the tunnel via the various pipeline and electrical conduit paths and accumulate in the voids behind the tunnel walls. However, according to the USACE, the Baltimore area had been suffering from an extended drought at the time of the derailment, and the levels of groundwater were probably lower than normal. There had been rainfall of about 1/4 inch in the early morning of July 18 in downtown Baltimore. The USACE's report stated that this rainfall would not have contributed a significant amount to either the groundwater or the storm water budget in the area.

Track Structure Defects and Foreign Object. In the previously described scenario, a derailment would have required the track at the point of derailment to have deteriorated at least 1 3/4 inch vertically and horizontally from the maximum values registered during the most recent track geometry car inspection. Because such a rapid deterioration would be inconsistent with the inspection history, investigators considered whether a foreign object, when combined with smaller track misalignments, could have induced a derailment.

When a single foreign object was introduced onto the track structure during a computer simulation using the most recent track geometry test data, the wheel climbed the obstruction, but the car returned to the rail without derailing. Simulation data showed that to derail a car, an obstruction on the track would have to be combined with deterioration in the track geometry sufficient to produce a "steering function." The simulated obstruction lengths varied from 6 to 12 inches.

The simulations showed that the combination of a 6-inch obstruction on the inside of the north rail with a 1 1/2-inch cross-level (vertical) deviation of the south rail and 1 1/2-inch alignment (lateral) displacement of the track would derail the lead truck of the car to the south. To obtain the 1 1/2-inch vertical and lateral displacement values, the track geometry would have had to deteriorate only 3/4 inch vertically and horizontally from the maximum values recorded before the accident.

A significant factor in this scenario is that the obstruction accounts for the "suddenness" of the accident. The simulated obstruction lifted the north wheel, and because of the steering mechanism of the 1 1/2-inch vertical and lateral track geometry, the north wheel derailed to the south (the gage side) of the north rail; the solid axle construction also caused the south wheel to lift, and the steering mechanism caused it to pass over the head of the south rail and derail to the south (the field side) of the south rail. This is consistent with the wheel markings on the north rail indicating a departure from the rails and physical evidence indicating that the 47th car (likely the first car to derail) derailed to the south side. However, wheel markings would also be expected on the south rail after the wheels passed the obstruction, but none were identified during the examination of the recovered rail.

Investigators considered possible sources of a foreign object or material that could have caused an obstruction. For example, the postaccident tunnel inspection noted a 2- by 4-foot void about 5 inches deep in the tunnel ceiling at station 63+15,[15] where the 40-inch water line passes directly above the ceiling with a special saddle section. A CSX consultant stated that he believed a previous repair had been made using two layers of wire mesh and a mix of brick and a concrete-like substance and that the repair materials were likely already gone when the fire was burning, because smoke damage was found on the surface underneath the repair. No pieces of a repaired section could be linked to

[15] About 70 to 80 bricks (one brick without mortar measures about 2 1/4 inches by 3 1/2 inches by 7 1/2 inches) could have been contained in the void.

the void during the investigation. Smoke damage within the void can be explained by the fire and smoke that were in the tunnel for several days following the accident.

Previously damaged or deteriorated car parts have been known to fall to the track and cause derailments when a moving train strikes them. No car parts were missing when a postaccident inspection of the first 45 cars of the train was conducted. Additionally, the accident train crew did not report seeing debris on the track.

No convincing evidence was found of a foreign material from the tunnel, a previous train, or other source having been present on the track as the accident train passed. Further, there is no evidence that the train could have derailed solely based on degraded track geometry. Computer simulations indicate that a foreign material between a wheel and the rail, in combination with certain track geometry degradations, could have caused a derailment.

Tunnel Maintenance and Inspections

No CSX records were found that described or defined the extent or nature of the repairs and modifications that had been made to the tunnel over the years. One CSX official told investigators that no records were kept of general maintenance for the Howard Street Tunnel. At least some repairs in the tunnel apparently went unrecorded. For example, there was the previously cited void in the tunnel's arch at station 63+15, immediately below the 40-inch water main. At some time before the accident, the void appears to have been filled with bricks or repair materials, such as concrete patches. However, no records of such repairs could be found.

Water in the tunnel was a common condition. But wet conditions are not unique to the Howard Street Tunnel. A report by the Transit Cooperative Research Program[16] states:

> The number one problem affecting tunnels and underground structures is groundwater intrusion and the subsequent damage caused by the presence of tunnel leaks. This groundwater intrusion is responsible for more problems affecting a tunnel's concrete liners and steel reinforced concrete than all other tunnel structural problems combined.

It is not known how much of the water intrusion in the Howard Street Tunnel comes from water supply lines, storm sewers, and other sources.

The USACE postaccident geotechnical evaluation showed multiple structural anomalies, including voids and delaminations behind the tunnel walls and within the

[16] Transit Cooperative Research Program, *Inspection Policy and Procedures for Rail Tunnels and Underground Structures* (Washington, DC: National Academy Press, 1997).

walls themselves. The timing of the voids' development could not be determined with reasonable certainty.

The CSX tunnel inspection procedures and documentation were neither thorough nor detailed.

On July 23, 2001, a team of about 25 people who were, according to CSX, mostly engineers, entered the Howard Street Tunnel to perform an inspection to determine the tunnel's structural integrity. The team included engineers from CSX and representatives of the city of Baltimore, the Maryland Transit Administration, and other organizations. The team split into smaller groups to examine the sides and ceiling of the tunnel. A lift truck was used to allow close inspection of the tunnel ceiling. After the inspection, CSX determined that the tunnel was structurally sound. A follow-up inspection was performed on August 27, 2001. Again, no structural problems were found.

On July 28, 2001, CSX had an engineering firm conduct two soil borings at the intersection of Lombard and Howard Streets, near the 40-inch water main found broken above the Howard Street Tunnel. To obtain core samples of the tunnel ceiling in the area of the water main, test bores were made through the street above the tunnel and into the brick lining of the tunnel ceiling about 10 feet to either side of the water main. The core samples of the brick lining indicated that the brick and mortar were solid.

Planning and Coordination

CSX and City of Baltimore Coordination

During the course of the investigation, it became apparent that information about modifications and construction in or near the tunnel had not been reliably documented or exchanged among interested parties. For example, there was an opening in the tunnel's arch immediately below the 40-inch water main where a repair had at least been started. Safety Board investigators attempted to obtain information about this void and repair, but neither CSX nor the city of Baltimore knew of or had documentation about when the void was first discovered or who had initiated the repair.

In another instance, information used by the city of Baltimore indicated that a storm sewer was 19 feet below the surface near a test drilling. However, during the drilling project, the drill struck the storm sewer, which was actually only about 8 feet below the surface. Also during the drilling project, it was discovered that a manhole had been moved and the move was not documented.

Documentation and information regarding construction and other alterations to the infrastructure in proximity to the Howard Street Tunnel are unreliable, and the exchange of such information between CSX and the city of Baltimore is inadequate. CSX railroad structures, portions of the Maryland Transit Administration light rail system and

the Metro subway, and municipal and private utility lines and structures all coexist within a relatively compact area around the tunnel. Repairs and modifications to structures and utilities near the tunnel could have a significant effect on the tunnel's structural integrity and therefore on the structures of other nearby facilities.

Transportation of Hazardous Materials Through the Tunnel

During the derailment, a tank car released more than 28,600 gallons of tripropylene. The flammable tripropylene was ignited, and the subsequent fire led to the ignition of paper and wood products in adjacent freight cars. The burning wood and paper products sustained the fire over the next several days. The release of the tripropylene initiated the fire and increased the severity of the accident.

Immediately behind the ruptured tripropylene car were two tank cars containing hydrochloric acid and one tank car loaded with di(2-ethylhexyl) phthalate, which is an environmentally hazardous substance. Exposure of the hydrochloric acid tank cars to high temperatures for the duration of the fire resulted in thermal degradation of the cars' rubber linings and corrosive penetration of one of the cars by the acid.

The CSX route through Baltimore and the Howard Street Tunnel is a major rail artery and is a designated hazardous materials key route for all types and classes of hazardous materials. Congress recognized the significance of this rail route when it mandated that the DOT conduct a rail infrastructure study[17] for passenger and freight routes in the Baltimore corridor. Although the FRA had not completed the final report for the study as of August 2004, it has indicated that three options for improving the freight infrastructure through Baltimore have been considered. All three options involve the construction of new, modern tunnels with estimated costs ranging from $1 billion to $3 billion. Because of the scope and expense of these options, replacement of the Howard Street Tunnel is not assured, and at best, several years will be required to complete such a project.

Given these factors, improving the safety of the transportation of hazardous materials through the Howard Street Tunnel and minimizing the potential for more serious hazardous materials incidents in the tunnel will, in the Safety Board's view, depend upon shared communication and coordination between CSX and the city of Baltimore about the volumes and types of hazardous materials that are transported through the tunnel, anticipation of the types of incidents that might occur, and the capabilities and/or limitations of the city to access the tunnel and respond to any hazardous materials incident in it. The desired level of communication and coordination can be achieved through comprehensive emergency preparedness planning, including joint drills and exercises.

[17] U.S. Department of Transportation's *Baltimore, Maryland, Freight and Passenger Infrastructure Study*, per Public Law 107-87.

Emergency Preparedness Documents

Emergency preparedness documents compiled by the Baltimore Office of Disaster Control and Civil Defense that were reviewed by Safety Board investigators do not contain information on hazardous materials discharge response procedures specific to tunnel environments or infrastructure information on the Howard Street Tunnel. Although principals of the Baltimore City Fire Department and of the member organizations of the South Baltimore Industrial Mutual Aid Plan, Inc.,[18] told the Safety Board that their personnel were familiar with response procedures applicable to tunnel environments and with the infrastructure of the Howard Street Tunnel, such information was not in the written plans.

Investigators reviewed the existing *Hazardous Materials Action Plan* for the city of Baltimore. Although the plan had detailed infrastructure response information on virtually all the industrial facilities within the city of Baltimore, it did not have any information on the Howard Street Tunnel, which could easily present situations as dangerous to responders as some of the industrial facilities that are addressed in the plan.

Despite the representations of the Baltimore City Fire Department and the South Baltimore Industrial Mutual Aid Plan, Inc., organizations that their employees were familiar with the Howard Street Tunnel, during the emergency response, the CSX dispatcher had to tell responding fire department personnel where to find a street-level manhole access to the tunnel at the intersection of Howard and Lombard Streets. The fire department later determined this access point to be instrumental to the fire suppression effort.

Baltimore officials told the Safety Board that they had initiated revisions of their Emergency Response Plan and Emergency Operations Plan to address a number of issues that were identified during the tunnel incident. The city has not yet provided the Safety Board specific information on the expected revisions.

It has long been known that emergency responders should be provided with comprehensive information to effectively and efficiently discharge their emergency response duties. This is particularly true for those responding to hazardous materials incidents. The information should include not only specific emergency response protocols for addressing hazardous materials discharges that occur in a conventional (outdoor) environment but also protocols for discharges that occur in an unusual

[18] The South Baltimore Industrial Mutual Aid Plan, Inc., is an association of private industries and government agencies with the primary purpose of providing "a system of cooperative action whereby assistance to the public sector and other member companies may be available in an emergency...." It has a membership of about 88 active private industrial facilities in the greater Baltimore area. Members provide technical maintenance support for periodically updating the city of Baltimore's *Hazardous Materials Action Plan*, contribute technical expertise, foster emergency preparedness, and render mutual aid in the event of an emergency involving hazardous materials.

environment, such as inside a tunnel or on a long bridge at night, where conventional response protocols might not apply.

Emergency preparedness plans to address incidents within a tunnel environment could include, for example, considerations of the infrastructure, such as ambient ventilation, possible water infiltration, natural drainage, service and emergency lighting, emergency equipment, and personnel access, among other types of information that would not necessarily apply to an outdoor incident. Having such information clearly documented and instantly available is critical not only for experienced emergency responders but also for new emergency response recruits or support personnel unfamiliar with tunnel environment emergency response procedures.

The Baltimore City Fire Department told investigators that the department intended, at some future date, to coordinate with CSX to revise and update the department's *Manual of Preparedness* and training manuals to include infrastructure information on the Howard Street Tunnel and its potential access sites. Department officials also said they plan to revise and update their firefighter recruit training and to include periodic practice drills appropriate to the Howard Street Tunnel.

Environmental Response and Impact

The environmental response by the Maryland Department of the Environment and U.S. Coast Guard Activities Baltimore was timely and effective. The Maryland Department of the Environment quickly mobilized its hazardous materials spill response team to perform a site assessment. Within 3 hours of the accident, Coast Guard Activities Baltimore had dispatched a field response team to assist the State and local incident command and had established two safety zones because of the potential threat from hazardous vapors. Both agencies effectively coordinated with each other and with CSX environmental contractors to ensure that water sampling and air monitoring were conducted in a timely manner.

Following the excavation of slightly more than 1,400 tons of soil and debris from the tunnel, no appreciable amounts of hydrochloric acid or tripropylene residues were found in the soil in the tunnel. Also, following the removal of 3,000 gallons of water and product from the city's storm drains in response to reports of chemical odors during the weekend of August 11 and 12, 2001, no additional chemicals (other than residual traces) were found in the storm drain system.

Probable Cause

The National Transportation Safety Board, after an exhaustive investigative effort, could not identify convincing evidence to explain the derailment of CSX freight train L-412-16 in the Baltimore, Maryland, Howard Street Tunnel on July 18, 2001.

No preaccident equipment defects or rail defects were found. Computer simulations were used to evaluate locomotive event recorder data, train profile data, track profile data, and preaccident track geometry data. These simulations indicated that neither train operations nor changes in track conditions alone likely resulted in a derailment. Available physical evidence and computer simulations also showed that the most likely derailment scenario involved an obstruction between a wheel and the rail, in combination with changes in track geometry. However, postaccident fire, flooding, and necessary emergency response activities, including removing burning freight cars from the tunnel, significantly disturbed the accident site; and, no obstruction was identified that could be convincingly connected to wheel climb and evidence was insufficient to determine changes in track geometry.

Recommendations

As a result of its investigation of the Howard Street Tunnel railroad accident, the National Transportation Safety Board makes the following safety recommendations:

To CSX Transportation, Inc.:

Maintain historical documentation of maintenance and inspection activities affecting the Howard Street Tunnel. (R-04-13)

Take action necessary to enhance the exchange of information with the city of Baltimore on maintenance and construction activities within and in the vicinity of the Howard Street Tunnel. (R-04-14)

To the city of Baltimore, Maryland:

Take action necessary to enhance the exchange of information with CSX Transportation on maintenance and construction activities within and in the vicinity of the Howard Street Tunnel. (R-04-15)

Update and revise your emergency preparedness documents to include information on hazardous materials discharge response procedures specific to tunnel environments, as well as infrastructure information on the Howard Street Tunnel. (R-04-16)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

Ellen Engleman Conners
Chairman

Mark V. Rosenker
Vice Chairman

Carol J. Carmody
Member

Richard F. Healing
Member

Deborah A.P. Hersman
Member

Adopted: December 16, 2004

Deborah A. P. Hersman, Member, filed the following concurring opinion on December 1, 2004. Richard F. Healing, Member, joined Member Hersman in this opinion.

Mark V. Rosenker, Vice Chairman, concurred in part, filing the following statement on December 16, 2004:

> While I concur in most of the sentiments offered by Member Hersman, I do not believe the need for additional safety recommendations is demonstrated, nor am I convinced that NTSB access to the scene was imprudently delayed.

Notation 7662

Member HERSMAN, concurring:

> Despite having many reservations, I have agreed with my colleagues to release this accident brief without having a Board Meeting because no probable cause was determined and this investigation is now over three years old. Considerable Safety Board resources have been dedicated to this accident investigation and we have little to show for it. While there are several issues I think could have been raised in a public forum, given the tardiness of this brief and the lack of findings, holding a Board Meeting would not likely change the outcome of the brief or our recommendations. Moreover, I have been advised that it would be a drain

on staff resources to prepare for such a Board Meeting. As such, I will instead raise the following issues, which I believe should be acknowledged with respect to this accident investigation:

1.) The four recommendations contained in the brief could have been made within one month of the accident. While there was no probable cause determination in this accident, there were significant issues raised during the investigation. I believe we should have made additional recommendations to the Department of Transportation (DOT) and the Department of Homeland Security (DHS). (See attachment.)

The Federal Railroad Administration (FRA) has no requirements for the inventory and inspection of tunnels. While railroad tunnels are generally built to last,[1] this seems to be an area where federal guidance is lacking. There are federal requirements to inspect the track, the equipment, and railroad bridges, but nothing addressing tunnels. As major railroad tunnels age, the potential risks of problems increase if maintenance is deferred. Many major tunnels in urban areas are over one hundred years old and still heavily utilized.[2] Following the accident, there were many documented areas of concern in the tunnel, with little information provided on the inspection and maintenance of the tunnel structure.

Accompanying my concerns regarding the condition and maintenance of railroad tunnels is the safe transport of hazardous materials through them. While the transport of hazardous materials has been a principal security concern, it should also be addressed as a safety issue. The Department of Transportation and the Department of Homeland Security are drafting studies and soliciting comments on the transportation of hazardous materials. Generally, the record shows that transporting hazmat is safer on the rails than on the highway. For example, in 1997, the most recent year in which we have data for the transportation of hazardous materials by mode, trucks and trains both moved approximately 75 million ton miles of hazardous materials.[3] However, there were 11,932 incidents and 12 deaths on the highway contrasted with 1,102 incidents and no deaths on the railways.

---

[1] As evidenced by the robustness of the Howard Street Tunnel that survived the derailment, explosion, subsequent fire and flooding and remains in service today.

[2] For example, CSX's Howard Street Tunnel was constructed from 1890 to 1895 and is the only north-south freight route east of Hagerstown, Maryland. Amtrak owns the First Street tunnels from the Virginia Avenue interlocking to Union Station in Washington, D.C., which date back to 1904 and are used by Amtrak and the Virginia Railway Express. Amtrak also owns the B & P tunnel in Baltimore built in 1872, which is used by the Maryland Transit Administration, as well as tunnels used by New Jersey Transit commuters and Amtrak intercity passengers under the Hudson and East Rivers between New Jersey and New York.

[3] *Commodity Flow Survey*, U.S. Department of Transportation, Bureau of Transportation Statistics/U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau (1997).

In short, the consideration of safety and security issues is often inextricably linked. While critical infrastructure and concerns about the transport of hazardous materials are central themes in current public debate surrounding security concerns, the only experience we have to date shows that they should be regarded as important safety issues. Given the long history of expertise at the Federal Railroad Administration in dealing with rail safety issues, including transportation of hazardous materials, it is imperative that any decisions made by DHS with respect to security measures also take into account relevant safety considerations.

2.) Three years have passed since the accident. In an accident investigation, much of what is important to the community, the industry, the employees, and in some cases, the victims, is identifying what happened, and for the parties involved to take actions to prevent such an accident from occurring again. I acknowledge that it is harder and more time consuming to prove all of the things that didn't happen. In this accident, significant time was spent ruling out possible accident scenarios because a probable cause with contributing factors was not determined early in the investigation. While I understand that a backlog of accident investigations has been eliminated in the last several years, there needs to be a renewed focus on timeliness and clear expectations about the process. Three years is simply too long to spend on a brief without making significant progress on the cause or recommendations.

A review of the docket shows that the bulk of the work on this investigation was completed by April of 2003, including much of the written brief. While all of the staff involved in this investigation worked diligently to determine the cause of the accident and make appropriate recommendations, a great deal of time was spent in administrative review, including two months in my office. If the delays are a result of the lack of staff resources, which compromise our ability to launch on accidents and complete our investigations in a timely manner, then a revised timetable ought to be established based on the resources available and all parties should be advised of what to expect.

3.) Lack of access to the accident scene severely compromised our ability to determine the probable cause. This was a unique accident in that much of the evidence was removed or disrupted because of the postaccident fire and subsequent flooding, which resulted in a significantly disturbed accident scene. The emergency response efforts clearly were the first priority in the hours after the accident, as they should be. However, it was almost two days before NTSB personnel entered the tunnel to assess the accident scene. If we do not have access to the scene in a timely manner, then we cannot assess damage and document the evidence. In the future, it is important to be among the first to access the accident scene as soon as it is safe to do so and ensure that other parties do not disturb the evidence.

4.) Lastly, there are general concerns, as there are in any accident investigation, about the resources available to staff. We have only 13 rail investigators at the Safety Board, working on freight rail, passenger rail, and transit accidents. Additionally, as in most of the accidents investigated by the Safety Board, we had to rely on parties to the investigation to provide significant support for our work. In this accident, we had to rely on the Association of American Railroads (AAR) to provide access to simulation software to model the accident. In this case, there was not another option, and to my knowledge, our reliance on the AAR did not pose a problem; however, it is worth noting potential drawbacks that may affect future investigations, i.e. constrained staff resources, a limited number of experts and the necessity of relying on outside sources for technical support.

Attachment to Concurring Opinion of Member Hersman

To the Federal Railroad Administration:

Work with tunnel owners to assess the safety of major railroad tunnels and provide guidance to tunnel owners and users regarding inspections, maintenance intervals and documentation.

In the aftermath of the CSX freight train derailment and subsequent fire in the Howard Street Tunnel, several important issues need to be addressed regarding the maintenance and repair of railroad tunnels. While maintenance issues may not have been a *causal* factor in the Howard Street Tunnel accident, incomplete and inaccurate information regarding recent construction and repairs to the tunnel's infrastructure represents a serious deficiency in record-keeping as well as an inability to adequately assess the conditions in the tunnel and exchange such information with other interested parties. As indicated in the brief, investigators could not locate any CSX records detailing the extent or nature of recent repairs and modifications to the tunnel over the years. This absence of maintenance and repair documentation highlights the need for comprehensive and systematic assessment and management of railroad tunnels that will accurately and reliably record this information and allow for its exchange between railroad personnel, tunnel owners, emergency response organizations, oversight agencies/administrations, and other interested parties.

Given the current state of information available on railroad tunnels, the inadequacies uncovered in the Howard Street Tunnel accident are not likely an isolated incident of poor record keeping by CSX. After conducting preliminarily searches, including requests to the FRA and the AAR, for the data on the number, age, condition, maintenance, and inspection of railroad tunnels, it appears that this information is not easily accessible or even available. Moreover, access to existing data is further complicated by its dispersion across a number of different sources. In contrast, a good deal of information is provided for road and rail transit tunnels. The Federal Transit Administration (FTA) and the Federal Highway Administration (FHWA) joined forces in March 2001 to create a comprehensive Tunnel Management System[4] for all road and rail transit tunnels in the U.S. With the goal of implementing uniform maintenance and rehabilitation practices to reduce the dangers associated with poor inspection procedures and deferred repairs, a system was implemented that provided for standardized assessments, inspections, and maintenance regulations. Additionally, a computerized database for collecting and

[4] See *Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual* (FHWA and FTA 2003).

storing all inventory, inspection, and repair data was created. By adopting uniform condition codes and prioritizations for repairs and establishing set frequencies for inspections, the FTA and FHWA have taken the necessary steps to insure adequate reporting, recording, and storage practices for both inventory and maintenance of road and rail transit tunnels.

While still in its infancy, this system promises a number of important advantages. Specifically, an effective management program, "will help tunnel owners and operators all across the country identify potential problems within their tunnels and will provide guidelines for proper maintenance to extend the life of a tunnel and/or to avoid more costly problems later." Furthermore, this system "can minimize damage, disruption of service, and traffic delays caused by typical tunnel problems such as those caused by groundwater and inadequate ventilation."[5] And perhaps most importantly, the creation of a centralized inventory and inspection database will allow for the storage and exchange of tunnel infrastructure information that can aid emergency responders and help reduce the future loss of life and environmental damage associated with these accidents.

As evidenced by the NTSB factual brief on the conditon of the Howard Street Tunnel,[6] the Army Corps of Engineers postaccident study on the structural concerns,[7] and the presence of water around the tunnel, a number of significant safety issues exist.[8] It is generally accepted that the biggest single problem affecting all tunnels is damage caused by water infiltration. According to the Transit Cooperative Research Program report, "Groundwater intrusion is responsible for more problems affecting a tunnel's concrete liners and steel-reinforced concrete than all other tunnel structural problems combined."[9] Concrete spalling and delamination, in turn, trigger a new set of complications that may make the tunnel unusable. Uncontrolled water can potentially cause electrical shorts and other dangerous situations. Therefore, adequate drainage and clearance of water from the tunnel and right-of-way is a major maintenance consideration.[10]

---

[5] *A Light at the End of the Tunnel*, Frank V. Botelho, (FHWA 2003).

[6] National Transportation Safety Board, Factual Brief on Howard Street Tunnel Construction and Condition, Dr.Joe Kolly, Group Chairman, January 7, 2003.

[7] *Engineering and Geotechnical Report*, U.S. Army Corps of Engineers (December 31, 2002).

[8] These studies address several important structural concerns, e.g., holes in the south wall, brick and mortar conditions, arch damage near Lombard Street, spalled brick lining, etc.

[9] *Inspection Policy and Procedures for Rail Transit Tunnels and Underground Structures*, TCRP Synthesis 23.

[10] See *Highway and Rail Transit Tunnel Maintenance and Rehabilitation Manual* (FHWA and FTA 2003).

Unlike the highway and transit tunnels which are often publicly owned and financed by taxpayer dollars, the private freight railroad industry owns almost all of the railroad infrastructure in the United States. However, all of the railroads' assets coexist with the public, as is evidenced by the impact of the CSX tunnel accident in July 2001 on the city of Baltimore. In many cases, what occurs on a private right-of-way may have significant consequences to the general public.

While the list of activities and expenditures required to keep a tunnel in good, safe working condition is long, at a minimum, the FRA should provide guidance on inspections and record-keeping. While the private sector has long understood the asset management process, the fact that no records exist about inspections, structural damage or repairs made to the Howard Street Tunnel raises significant questions about how determinations could be made to predict future performance and decisions for maintenance activities and capital improvement projects. The FRA should work with the railroad industry to assess the current state of major railroad tunnels and address the inspection and maintenance of tunnels.

To the Department of Transportation and the Department of Homeland Security:

Complete ongoing studies and rulemaking efforts to address the transportation of hazardous materials and coordinate future activities.

Highlighting the risks associated with the transport of hazardous materials through tunnels, the Howard Street Tunnel accident raises several important safety issues. First, is the need to develop a more comprehensive risk analysis system to assess the dangers associated with the transport of specific materials. Second, is the implementation of detailed emergency preparedness plans and appropriate training for rail employees and emergency responders. Third, is the implementation of standardized regulations for governing the transport of dangerous goods.

There are more than 240,000 tank cars in the North American railroad car fleet and rail shipment of hazardous materials accounts for 18 percent of the ton-miles of all hazardous materials shipped. In 2000, 725 of the reported railroad accidents involved trains transporting hazardous materials. Out of 6,942 cars in those trains, 979 of the cars were damaged and 75 cars released hazmat. This resulted in 5,251 people being evacuated. One fatality (a result of the accident, not due to a hazmat release), 82 injuries, and over $26 million in property damage were reported. Therefore, even with the great safety improvements made to tank

cars in the 1970s, 1980s, and 1990s, hazmat is still released during accidents.[11]

Currently, the FRA is undertaking three major projects designed to improve the safe transport of hazardous materials by rail.[12] The first of these projects, *Hazmat Transportation Safety*, has the goal of enhancing the safety and efficiency of transporting dangerous materials by rail. To accomplish this goal researchers are investigating the shipment routing of hazardous materials, specifically considering the confinement of hazmat transport to certain "classes" of tracks and rerouting dangerous shipments around major metropolitan areas. A second project, *Tank Car Structural Integrity*, is charged with the goal of ensuring that the capability of hazmat carriers to maintain structural integrity is understood. Safety issues considered by this ongoing project include the following components and elements related to overall tank car integrity: fatigue damage, welding effects, puncture resistance, steel quality, and thermal protection systems. The third project, *Damage Assessment and Improved Inspection Systems*, is intended to develop, improve, and quantify the capability to assess the condition of tank cars, in repair shops and at accident sites. In particular, the project is designed to increase safety by improving assessment of damaged tank cars and enhancing the existing inspection and repair process. Additionally, it is expected to reduce postaccident risk to emergency responders by providing them with critical information about tank car condition.[13]

In addition to the FRA's efforts to increase safety, recent actions have focused on improving the security of rail transportation, with much remaining to be done. Presidential Decision Directive (PDD) 63, "Critical Infrastructure Protection," requires federal agencies to "take all necessary measures to swiftly eliminate any significant vulnerability to both physical and cyber attacks on our critical infrastructures, including especially our cyber systems." Rail transportation has been determined to be a part of the nation's critical infrastructure. Recently, the DOT's Research and Special Programs Administration and DHS's Transportation Security Administration published a notice in the Federal Register[14] soliciting comments on measures to enhance the security of rail shipments of toxic inhalation hazardous materials. The comment period closed on October

[11] Federal Railroad Administration Website.

[12] *Railroad Research and Development Program* (Chapter 4, Sec. 4.8) <http://www.fra.dot.gov/us/content/1242>.

[13] By supplying emergency responders with up-to-date, detailed information about the condition of tank cars, the FRA hopes to avoid another tank car accident like the one in Waverly, Tennessee, in the 1970s that resulted in the death of a number of emergency responders when a tank car ruptured unexpectedly due to an undetected crack.

[14] *Federal Register*, Vol. 69, No. 157, Monday, August 16, 2004, Notices, pages 50988-50994.

18, 2004 and the NTSB submitted comments for the record.[15] At this time no further action has been taken on this notice.

A serious incident involving the transport of dangerous goods in a tunnel can be very costly in terms of human lives, the environment, tunnel damage and transport disruption. However, a decision to completely ban the transport of hazmat by rail could increase the overall societal risk of hazmat accidents by diverting the shipment to even less safe modes of transport. Simply redirecting the shipment of hazmat to alternative modes of transport or rerouting it around densely populated areas does not solve the above safety concerns. In many cases, the highest quality of track may go through major metropolitan areas, and unlike roads there are not generally bypass tracks around these areas. Moreover, additional switching and interchanges employed to avoid tunnels and metropolitan areas has inherent risk.

Reducing transportation risk should be the objective; however, quantification of risk is difficult because numerous factors and variables influence probabilities and consequences of incidents involving dangerous goods both inside and outside of tunnels. Even with expert knowledge, it is therefore difficult to assess risk for all circumstances, environments, conditions, etc. In order to rationally evaluate the risks and set regulations, current studies and rulemaking activities need to be completed and evaluated. I would urge the DOT and DHS to complete their ongoing efforts as soon as possible and coordinate their future activities to address security AND safety.

[15] National Transportation Safety Board correspondence, *Hazardous Materials: Enhancing Rail Transportation Security for Toxic Inhalation Hazard Materials*, Notation 7672 (10/13/2004).

From: Brice Smith [brice@ieer.org]
Sent: Friday, January 28, 2005 10:09 AM
To: Lindsay Lovejoy
Subject: Washington Post Article

Attachments: ATT00012.txt

washingtonpost.com

Thousands Can't Return Home After Toxic Train Wreck in S.C.

Chlorine Spill Leaves Nine Dead, Town of 5,400 Evacuated

By Darryl Fears and Sara Kehaulani Goo
Washington Post Staff Writers
Monday, January 10, 2005; Page A03

AIKEN, S.C., Jan. 9 -- Thousands of evacuees were marooned in this college town Sunday, lounging on twin beds in tiny motels for a fourth day, not knowing when they can return home to nearby Graniteville because the train cars that derailed early Thursday, choking their town with chlorine gas, had not been moved.

A tanker carrying 16,000 gallons of sodium hydroxide was temporarily covered with a lead patch, and chlorine from other tankers was transferred into containers, said Robin Chapman, a spokesman for Norfolk Southern Railroad Co. Contractors planned to lift the damaged railcars onto trucks Monday to be hauled away, and Chapman said residents may be able to start returning home on Wednesday.

That would not be too soon for Cindy Lewis, 43, who was curled on a bed at the Econo Lodge in Aiken, where she has lived for two days with daughter Missy, 23, and Missy's three children. "My dog is in the front yard," Lewis said. "I don't know if she's dead or alive."

Apparently alive but perhaps in the pound. Lt. Michael Frank, a spokesman for the Aiken County Sheriff's Department said Sunday night that 100 pets were recovered and returned to their owners -- except for two taken to an animal shelter. He said there were no reports of dead animals.

Missy Lewis said the wreck was the worst thing to have happened in Graniteville in as long as anyone could remember. Nine people died from the toxic fumes, and at least 33 of the estimated 250 injured remained hospitalized. About 5,400 people, nearly the entire town, were evacuated, authorities said. The dozen who refused to leave were kept outside the evacuation zone, within a mile radius of the derailment.

Norfolk Southern officials were trying to determine how much toxic gas leaked from the cars and how much diesel fuel spilled from the locomotive, said Thom Berry, a spokesman for the South Carolina Department of Health and Environmental Control. He said some toxic material apparently leaked down a storm drain and caused a major fish kill in Horse Creek. He said the number of fish deaths had not been determined. Eighty local, state and federal agencies have converged on Aiken to work on the spill, Berry said.

National Transportation Safety Board investigators said the engineer of the freight train with the chlorine and sodium hydroxide cars applied the emergency brakes 17 seconds before impact with railcars parked on a siding. Safety investigators learned the information after recovering the locomotive's event recorder and downloading its contents Sunday.

Like a plane's "black box," the event recorder stores data from the last 45 minutes of operation. Investigators said they hoped to also learn how fast the Norfolk Southern train was traveling before impact with the parked railcars. The speed limit in the area was 45 mph, safety board spokesman Keith Holloway said.

Safety board officials said they took photos and collected documents with information from the locomotive's cab, such as the manifest of each car and the engineer's instructions for moving through areas without signals, such as Graniteville. Like the displaced residents, investigators may not have full access to the site for several days. They are waiting for environmental officials to declare it safe.

Investigators also interviewed crew members who adjusted the rail switch a few hours before the crash. The move aligned the rail off the main tracks and to a side rail, where other railcars were parked. The train that derailed was the first to cross the track after the switch had been moved, officials said.

That seemed to suggest that the track crew had forgotten to adjust the switch back to the main track, but safety board officials said it was too soon to draw any conclusions.

"We are going to investigate everything. We're looking at what the crew was doing, looking at what their responsibilities are. We are looking at their training, their work schedules and rest schedules," said safety board member Deborah Hersman. "We don't do any analysis and don't speculate about the cause, but really we're here to gather facts. We're not here to assign blame."

Cindy and Missy Lewis live on Graniteville's Sams Street in what authorities are calling the "hot zone." Police urged people in the area to evacuate but in their door-to-door patrol missed the Lewis house. Although she could not detect any toxic gas at the time, Cindy Lewis said she smelled trouble and wanted to leave with her neighbors.

"It's a big mess," Lewis said. "I wanted to go, but we stayed there the first night because we couldn't get out. Yeah, I was scared. We had no money to get out. We had to borrow money to have a place to stay the next day."

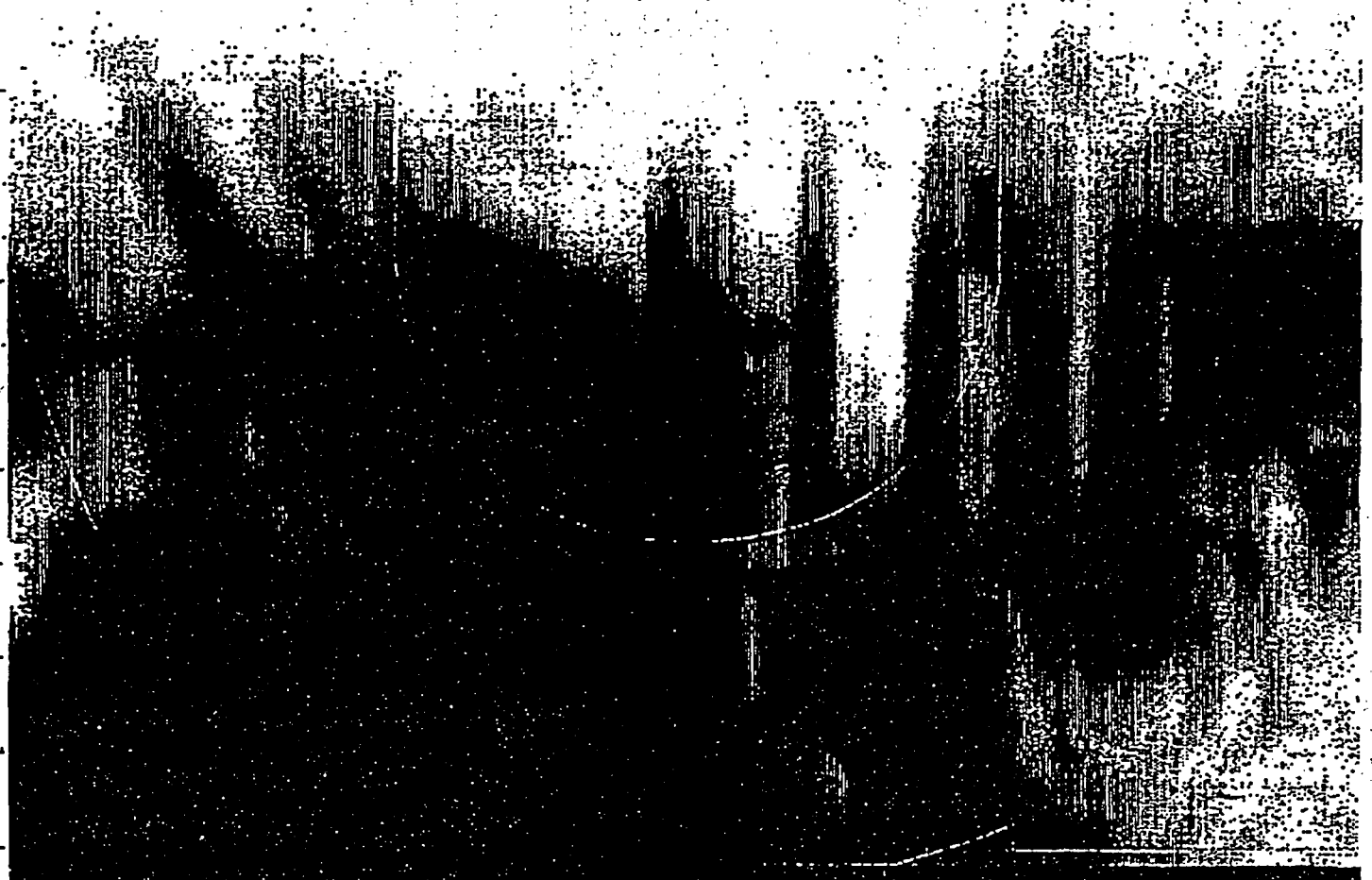
On Saturday, she left the Comfort Suites, where she had stayed for a night, and went to First Presbyterian Church of Aiken, where Norfolk Southern was handing out checks to evacuees. Cindy got $300 and Missy received $1,000, because of her children. A family friend, Idelle Lucas, 44, said she was given $600.

The company could be handing out more checks if it is found liable for the wreck. Cindy Lewis complained of chest pains resulting from stress after the crash. Lucas said she has sores around her mouth.

"I blame the railroad," Lucas said, as Lewis and her daughter nodded in agreement.

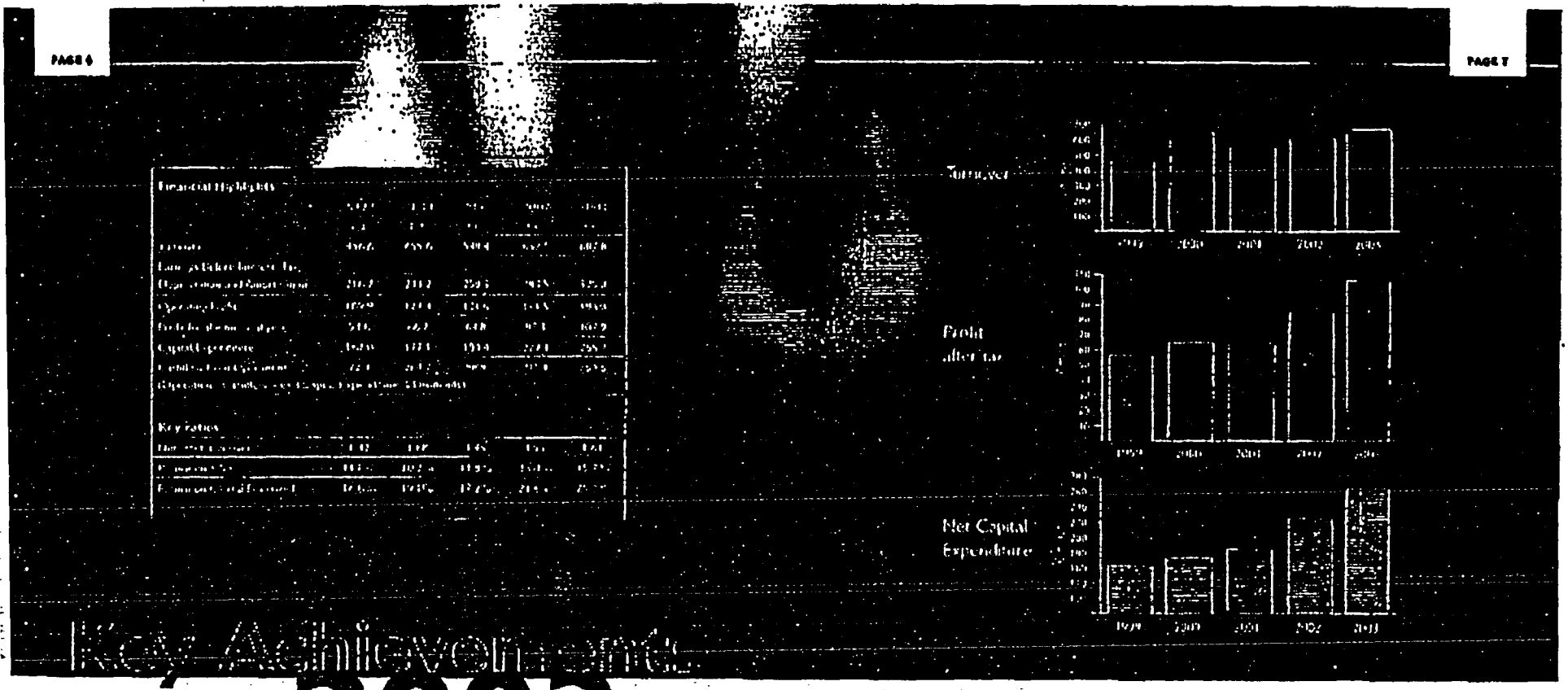
Goo reported from Washington.

© 2005 The Washington Post Company



Urenco Limited Annual Report and Accounts

Year to 31 December 2003



Key Achievements 2003

Deliveries & Production Capacity – 2003

In 2003, Urenco had another successful year of increased separative work unit ('SWU') deliveries to its customers. Urenco's market share for SWUs increased from 15% to around 18% of world demand.

Production at Urenco's three enrichment plants increased by around 10% in 2003. Production capacity increased from 5.7 million SWU in 2002 to 6.3 million SWU in 2003. Additional capacity was installed at all three locations.

Long Term Contracted Business

Long term contracted business is at a level of €4.0 billion. All planned capacity through to 2006 is contractually committed.

Net Profit – 2003

Net profit increased from €87.3 million in 2002 to €107.9 million in 2003. This represents an increase of 24%.

Re-organisation

The operational and legal re-organisation of the Urenco Group was completed in 2003. This resulted in the clear separation of the operating activities into enrichment services (Urenco Enrichment Company) and enrichment technology (Enrichment Technology Company). The new structure will allow management resource to be focused on operating activities rather than geographical location. This will lead to improved performance within both organisations, which will in turn improve Urenco's ability to supply its customers more efficiently.

The Anglo Dutch Venture

Uranium Enrichment Today in the US

Neville Chamberlain CBE

As we look back, it is clear that 2003 was a momentous year for the Urenco Group.

Chairman and Chief Executive Statement

Summary of 2003

Within UEC, greater cooperation between Urenco's three European enrichment plants is already evident. This will in future lead to enhanced services and greater flexibility being offered to our customers. Synergies will be exploited in the coming years, which will further improve Urenco's competitive position.

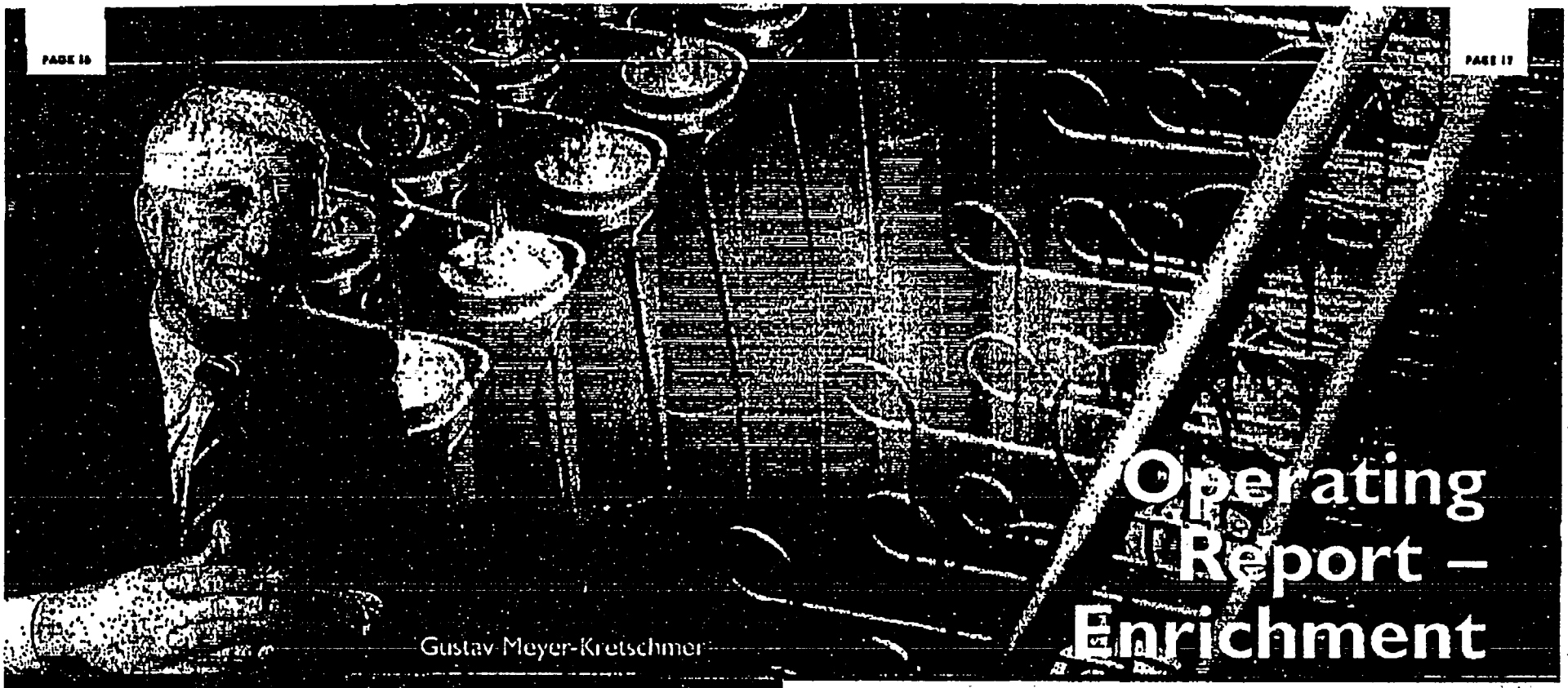
ETC has also benefited from the reorganisation with improved communication between research & development, design and manufacturing. This will mean that all customers will be provided with the optimal design of centrifuge enrichment plant.

In 2003, Urenco successfully negotiated an agreement to sell 50% of the ETC Group to the French nuclear company Areva. The resulting joint venture will ensure that Urenco maintains its ability to grow capacity and will allow Urenco's technology to build a replacement for the French gas diffusion enrichment plant. This joint venture is still expected to be completed at the end of 2004 or early in 2005, subject to governmental and competition clearance being granted.

The project to build a National Enrichment Facility in the United States has progressed well in 2003. Successful negotiations have been concluded for Westinghouse to take a 24.5% share in the project. A suitable site in New Mexico has been selected. The licence application has been completed and was submitted in December 2003. Urenco expects that the licence will take between 2 – 2½ years to be approved.

Subject to approval, this will enable the plant to go into production in 2008 and be at full capacity by 2013.

408



Operating Report – Enrichment Technology Company

The Enrichment Technology Company (ETC) was created as part of the reorganization on [illegible] 2001. ETC [illegible] fully focused group dedicated to sales, development, manufacture and [illegible] gas centrifuge enrichment capacity for Urenco and for any other potential customers. Its [illegible] are in Almelo in the Netherlands and Jülich in Germany, [illegible] development centres in Jülich and plant designs [illegible] at Capenhurst in the United Kingdom.

The aim of the group is to provide cost-effective enrichment capacity, over flexible terms, that can be installed on time and within budget to meet customer [illegible].

It is intended that in 2004 50% of ETC will be sold to the Urenco shareholders, a company Areva. The subsequent solution also will [illegible] ETC's products [illegible] into the next decade.

Achievements in 2003

- Commissioning of new capacity increased by 55% in 2003.
- The manufacturing rate for the production of centrifuges increased by 25% in 2003.
- Restructuring of activities in ETC along process lines was completed.
- The new centrifuge generation has reached the end of the qualification phase, and has already shown excellent performance.

Manufacturing

Throughout 2003 centrifuge manufacturing in Almelo and Jülich continued smoothly with all quality and cost targets being achieved. This was a significant achievement given that the manufacturing rate increased by 25% during the year. Good progress was made throughout the year to ensure that the increased manufacturing capacity planned for 2003 will be achieved.

Cascade pipework manufacturing was successfully relocated within Germany from Jülich to Gronau without interruption to the supply of cascades.

Directors' Report

Principal Activity

The Urenco Group's principal activity is providing a service by enriching uranium for nuclear power utilities. The Group has two principal subsidiaries, Urenco Enrichment Company Limited (UEC) and Enrichment Technology Company Limited (ETC). UEC provides a service by enriching uranium for nuclear power utilities on a toll basis using customer uranium. ETC provides centrifuges and centrifuge technology for uranium enrichment including plant design and future research and development.

Urenco Limited is the ultimate holding company and provides strategic support for the Urenco Group.

Results and Dividends

Net Profit amounted to €167.9 million (2002: €87.3 million).

The Directors propose a final dividend for the year of €40 million (2002: €39 million).

Appointments and Resignations

The Directors as at 31 December 2003 are listed on page 2 of this report.

- Mr Ulrich Strube resigned from the Board on 1 January 2003
- Mr Willem Talsma retired from the Board on 8 April 2003
- Mr Norman Adew resigned from the Board on 19 June 2003
- Dr Charles Pryor resigned from the Board on 26 September 2003
- Mr Lazarus de Leur retired from the Board on 10 December 2003
- Mr Antonius Vos was appointed to the Board on 1 January 2003
- Dr Helmut Engelbrecht was appointed to the Board on 8 April 2003
- Mr Victor Goodrich was appointed to the Board on 8 April 2003
- Mr John Edwards was appointed to the Board on 1 August 2003
- Mr Michael Parker was appointed to the Board on 29 September 2003.
- Mr George Verberg was appointed to the Board on 10 December 2003

Directors' Interests

The directors held no interests in the issued share capital of Urenco Limited either beneficially or otherwise at 31 December 2003 or at any other time during the year. No director had a material interest during the year in any contract which is significant in relation to the company's business.

Corporate Governance

The Company is committed to setting high standards of corporate governance and intends to further develop its corporate governance in accordance with best practice, taking account of the company's ownership structure. The Board recognises that it is accountable to the Company's shareholders for good governance.

Directors and the Board

The Board reviews the composition of the Board to take into account the skills and experience required in the context of the business and strategy of the Group. The Board recognises the need for a reasonable balance between Executive and Non-Executive directors in providing judgement and advice in the process of decision-making.

During 2003, the Board consisted of four Executive and nine Non-Executive directors. The roles of Chairman and Chief Executive are combined. All directors have access to advice from the Company Secretary and training is available for all directors of the Company.

The Board manages overall control of the Group's affairs and is responsible for Company policies and strategic direction. It meets on a regular basis to consider matters specifically reserved for its decision. These include the approval of financial statements, major acquisitions and disposals, authority levels for expenditure, treasury policies, risk management and major policies in respect of environment and health and safety issues.

The day-to-day operational management of the Group has been delegated by the Board to the Chief Executive acting in conjunction with the Executive Directors. They provide guidance and direction in addition to ensuring consistency with overall strategy and risk management. Their decisions are communicated throughout the Group on a regular basis.

Internal Control and Risk Management

The Board has overall responsibility for internal control, including risk management, and sets appropriate policies having regard to the objectives of the Group. The Chief Executive in conjunction with the Executive Directors has responsibility for the identification, evaluation and management of both financial and non-financial risk and the implementation and maintenance of control systems in accordance with Board policies.

The Group operates an objective-driven approach aimed at satisfying its core purpose set out in a rolling 10 year business plan. The business plan is refined into an annual budget which is approved by the board. Management reports for the Group are prepared on a quarterly basis and reviewed by the board. The plans and reports cover both revenue and capital expenditure and form the basis of business plans for all the Group's business entities.

The Board has reviewed the effectiveness of the system of internal control for the financial year and the period to the date of approval of the financial statements. It should be understood that such systems are designed to provide reasonable management of and not absolute assurance against risk of failure of business objectives.

At the end of 2003 the Board appointed BDO Stoy Hayward as internal auditors to the Group.

A programme of communication exists and continues to be developed, to ensure that all staff are aware of the parameters constituting acceptable business performance and expectations of the Board in managing risk.

Audit Committee

The Board has an Audit Committee, chaired by Mr Williams and consisting entirely of Non-Executive Directors, which meets a minimum of three times a year. The other committee members are Mr Goodrich and Mr Vos. The Chief Executive and the Finance Director are invited to attend committee meetings. The Committee's primary responsibilities include monitoring the system of internal control of the Group, and providing a forum for reporting by the Group's external and internal auditors.

The Audit Committee also reviews annually the performance of the Company's auditors to ensure an objective, professional and cost-effective relationship is maintained.

Remuneration Committee and Report

The committee met twice in 2003. It is composed entirely of Non-Executive Directors. The members of the Remunerationcommittee in 2003 were:

Mr de Leur (Chairman)	1 January 2003 – 10 December 2003
Mr Verberg (Chairman)	from 10 December 2003
Mr Adew	1 January 2003 – 1 August 2003
Mr Edwards	from 1 August 2003
Dr Jaeger	full year 2003

The Chief Executive is invited to attend Committee meetings. The Committee determines the remuneration packages, including contract periods of the Executive Directors. The Committee is governed by terms of reference agreed by the Board and the Committee intends that the remuneration of all Executive Directors will continue to be determined, subject to review on these principles, by the Committee.

The policy of the Company is designed to attract, motivate and retain Executive Directors by providing appropriate remuneration to achieve this purpose.

Total Remuneration

In line with the principles referred to above, the total remuneration levels of the Executive Directors are reviewed annually by the Remuneration Committee having regard to remuneration levels of directors of comparable companies.

The total remuneration package of Executive Directors comprise the following components:

- Base salary – This is determined for each director by the Remuneration Committee taking into account the performance of the individual and information from independent sources on the rates of salary for similar jobs in a selected group of comparable companies.
- Bonus – Performance related bonuses for Executive Directors are at the discretion of the Remuneration Committee.
- Contracts of service – The directors' service agreements provide for discretionary reviews of salary and for termination on twelve months' notice by either party.
- Pensions – The Executive Directors are members of the Group pension scheme which provides a pension of up to two thirds base salary on retirement, normally between the ages of 60 and 65 and dependent on length of service. The scheme also provides for dependants' pensions and lump sums on death in service. The scheme is a defined benefit pension scheme, which is approved by the Inland Revenue.

Other benefits for each Executive Director include:

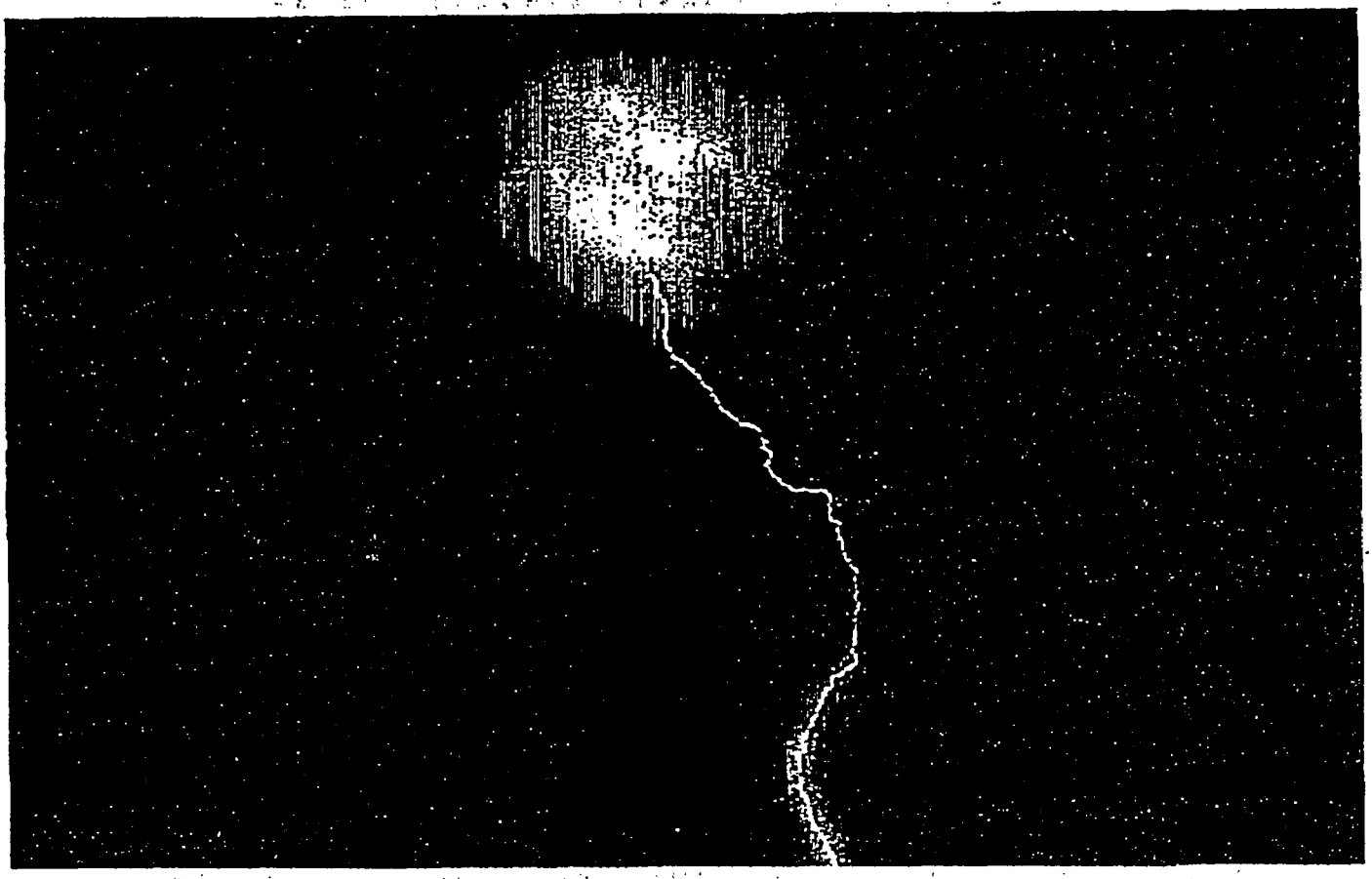
- Private Medical Insurance.
- The provision of a company car including petrol for private mileage or equivalent salary allowance.

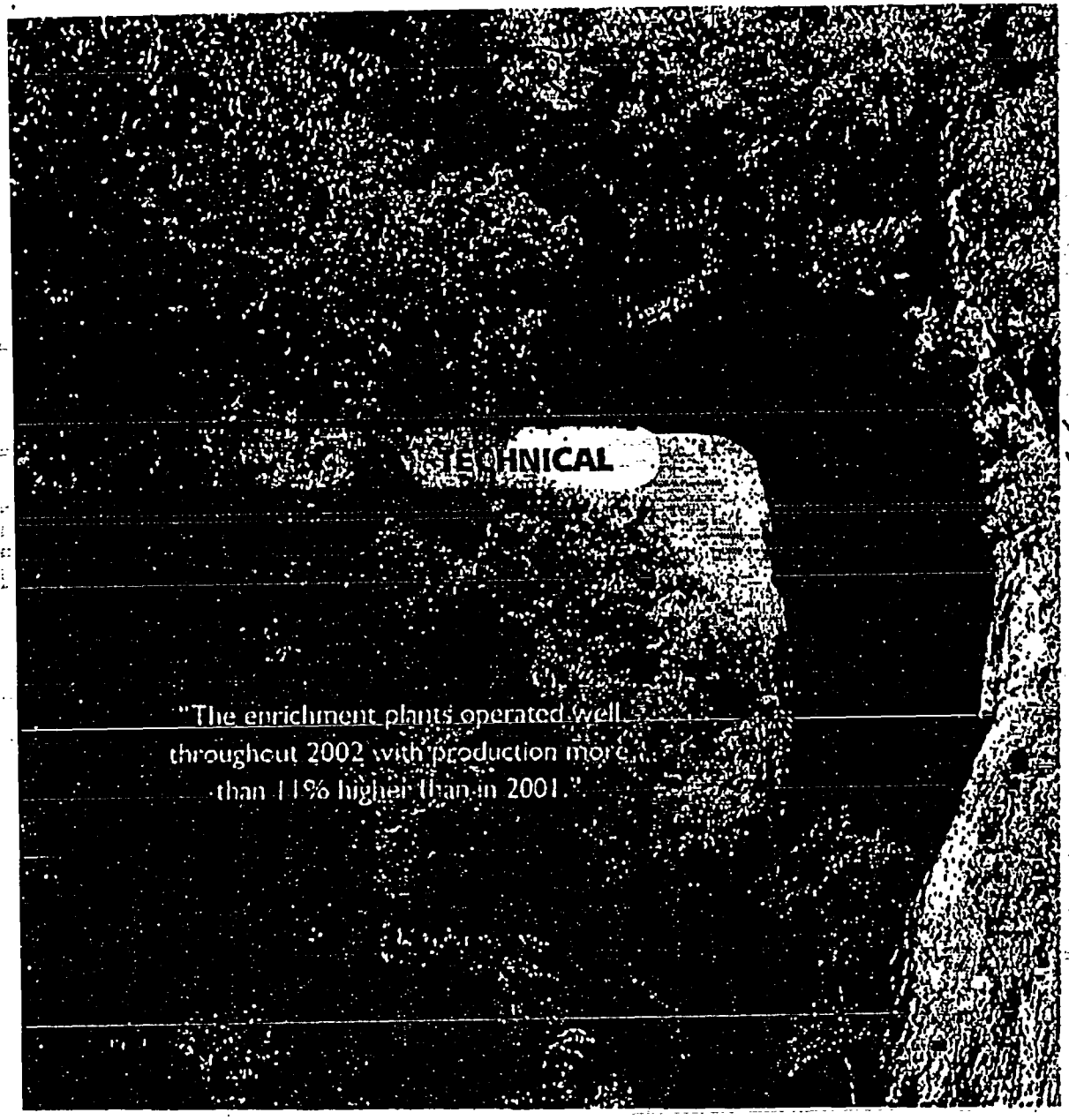
4

4100

Urenco Limited Annual Report and Accounts

Year to 31 December 2002





"The enrichment plants operated well throughout 2002 with production more than 11% higher than in 2001."

New Plant Construction

The expansion of Urenco's enrichment plant capacity to meet the demands of the Group's future order book continues at all three sites. Commissioning of cascades in the third assay hall of the E33 enrichment plant in Capenhurst, UK, and in the first tranche in the first cascade hall of the SP5 enrichment plant in Almelo were both completed ahead of schedule in September of the year. A further three cascades were also commissioned in one of the two new cascade halls of the UO₂-1 enrichment plant in Gronau. With centrifuge failure rates remaining low and no major tranche of capacity being decommissioned, Group enrichment plant capacity consequently increased by around 11% over the year to a nominal 3,630 tSWU, a third in Almelo, a quarter in Gronau and the remainder at Capenhurst.

A licence for a third hall in the SP5 enrichment plant in Almelo was received and an application submitted for a licence to increase enrichment capacity at that site to 2,800 tSWU. The licencing procedure for the second enrichment plant at Gronau has continued though the public hearing has been delayed into the spring of 2003 with a consequent delay of some months in the possible date for a decision to the year end.

Manufacture of the TC12 centrifuge for the plant expansion programme has had another record year with component production centred at Almelo, rotor production undertaken at Almelo and Jarfalla, and centrifuge final assembly at the enrichment plants at the sites all performing well, within budget and with low reject rates. Investment in manufacturing facilities has increased capacity by 25 per cent in the year and further investment coming on line in the next year to remove bottlenecks will raise the capacity by a further 25 per cent. Production rates an order of magnitude higher than those of a decade ago will thus become practical. The Group remains committed to quality, retaining accreditation under the ISO 9000 series scheme.

Preparations are in hand to move the cascade pipework manufacturing from the Jarfalla site to a purpose designed facility at Gronau.

Research and Development

Operation of the base generation of centrifuge, the TC21, in a half shed test cascade in the enrichment plant at Gronau continued successfully throughout the year. This section of the cascade has now been operating nearly three years. Testing of the first centrifuges assembled for the completion of the cascade, however, identified problems in the series production route of one of the centrifuge stationary components. A revised design was developed and qualified and first assembly of centrifuges restarted late in the year. It is now expected that the full cascade will be commissioned by the middle of 2003.

Value engineering and production cost reduction for both the TC12 and TC21 centrifuge designs continues to form the basis for the ongoing R&D programme with more cost effective replacement designs for high cost components under active development and qualification.

7

4067

16015

(8)

Fossil, Hydro and Renewables

Nuclear

Braidwood Generating Station

Byron Generating Station

Clinton Power Station

Dresden Generating Station

LaSalle County Generating Station

Limerick Generating Station

Oyster Creek Generating Station

Peach Bottom Atomic Power Station

Quad Cities Generating Station

Three Mile Island Unit - 1

Zion Generating Station

Power Marketing

Power Generation

Nuclear

Search

Careers

Diversity

Contact U

Links

Sitemap

Exelon Nuclear operates the largest nuclear fleet in the nation, the third largest fleet in the world. Exelon's ten stations - with 17 reactors - represent approximately 20 percent of the U.S. nuclear industry's power capacity. More than 18,000 megawatts of capacity. But size is not as important as performance. We are on track to become the world's premier nuclear plant operator.

By all of the industry's measures of performance and safety, Exelon Nuclear is a leader. Size and scale provide great advantages for industry leadership, process improvement, and innovation. By applying the group's extensive experience, sharing best practices, and leveraging economies of scale, Exelon Nuclear will continue to move much further. And much faster.

© 2002 Exelon Corporation. All rigl

(9)

UNITED STATES
SECURITIES AND EXCHANGE COMMISSION
Washington, D.C. 20549

FORM 10-Q

[X] QUARTERLY REPORT PURSUANT TO SECTION 13 OR 15 (d) OF THE SECURITIES EXCHANGE ACT OF 1934

For the quarter ended September 30, 2004

OR

[ ] TRANSITION REPORT PURSUANT TO SECTION 13 OR 15 (d) OF THE SECURITIES EXCHANGE ACT OF 1934

Commission file number 1-14287

USEC Inc.

(Exact name of registrant as specified in its charter)

Delaware *(State of incorporation)*

52-2107911 *(I.R.S. Employer Identification No.)*

2 Democracy Center
6903 Rockledge Drive,
Bethesda, Maryland 20817
(301) 564-3200

Indicate by check mark whether the registrant (1) has filed all reports required to be filed by Section 13 or 15(d) of the Securities Exchange Act of 1934 during the preceding 12 months (or for such shorter period that the registrant was required to file such reports), and (2) has been subject to such filing requirements for the past 90 days. Yes X No ____

Indicate by check mark whether the registrant is an accelerated filer (as defined by Rule 12b-2 of the Securities Exchange Act of 1934.) Yes X No ____

As of September 30, 2004, there were 84,685,000 shares of Common Stock issued and outstanding.

(9)

USEC Inc.
CONSOLIDATED CONDENSED STATEMENTS OF INCOME (LOSS) (Unaudited)
(millions, except per share data)

	Three Months Ended September 30,		Nine Months Ended September 30,	
	2004	2003 As restated	2004	2003 As restated
Revenue:				
Separative work units	$194.6	$ 265.6	$ 518.2	$ 798.0
Uranium	16.8	28.0	111.8	104.2
U.S. Government contracts	40.8	47.5	120.8	128.6
Total revenue	252.2	341.1	750.8	1,030.8
Cost of sales:				
Separative work units and uranium	180.1	263.7	533.3	797.0
U.S. Government contracts	36.5	36.4	110.9	116.1
Total cost of sales	216.6	300.1	644.2	913.1
Gross profit	35.6	41.0	106.6	117.7
Centrifuge demonstration costs	16.4	12.1	36.4	32.7
Selling, general and administrative	15.3	15.1	47.2	44.3
Operating income	3.9	13.8	23.0	40.7
Interest expense	10.0	9.8	29.8	28.7
Interest (income)	(1.2)	(1.5)	(2.7)	(4.6)
Income (loss) before income taxes	(4.9)	5.5	(4.1)	16.6
Provision (credit) for income taxes	(1.5)	2.1	(1.2)	6.8
Net income (loss)	$ (3.4)	$3.4	$(2.9)	$9.8
Net income (loss) per share – basic and diluted	$(.04)	$.04	$(.03)	$.12
Dividends per share	$.1375	$.1375	$.4125	$.4125
Average number of shares outstanding	84.4	82.3	83.8	82.1

See notes to consolidated condensed financial statements.

and is secured by certain assets of the subsidiary and, subject to certain conditions, certain assets of USEC. Borrowings under the facility are subject to limitations based on percentages of eligible accounts receivable and inventory. Obligations under the facility are fully and unconditionally guaranteed by USEC.

Outstanding borrowings under the facility bear interest at a variable rate equal to, based on the borrower's election, either (i) the sum of (x) the greater of the JPMorgan Chase Bank prime rate or the federal funds rate plus ½ of 1% plus (y) a margin ranging from .75% to 1.25% based upon collateral availability or (ii) the sum of LIBOR plus a margin ranging from 2.5% to 3% based on collateral availability. The revolving credit facility includes various operating and financial covenants that are customary for transactions of this type, including, without limitation, restrictions on the incurrence and prepayment of other indebtedness, granting of liens, sales of assets, making of investments, maintenance of a minimum amount of inventory, and payment of dividends or other distributions. The new facility does not restrict USEC's payment of common stock dividends at the current level, subject to the maintenance of a specified minimum level of collateral. Failure to satisfy the covenants would constitute an event of default. At September 30, 2004, USEC was in compliance with covenants under the revolving credit facility.

The total debt-to-capitalization ratio was 37% at September 30, 2004, and 36% at December 31, 2003. In October 2004, Standard & Poor's lowered its ratings on USEC as follows: corporate credit rating to BB- with negative outlook from BB with stable outlook, senior notes ($500 million) to B from BB-, and revolving credit facility to BB+ from BBB-. In July 2004, Moody's affirmed its negative outlook on USEC, lowered the rating on USEC's senior notes ($500 million) to Ba3 from Ba2, lowered the senior implied rating to Ba2 from Ba1, and placed the ratings under review for possible further downgrade.

USEC expects that its cash, internally generated funds from operations, and available financing under the revolving credit facility will be sufficient over the next 12 months to meet its obligations as they become due and to fund operating requirements and capital expenditures, purchases of SWU under the Russian Contract, interest expense, American Centrifuge demonstration costs, and quarterly dividends. USEC expects to renegotiate the revolving credit facility that provides $150 million in revolving credit commitments prior to expiration of the facility in September 2005, and to identify alternatives to retire or refinance the first installment of senior notes amounting to $350 million that is scheduled to mature in January 2006.

Quantitative and Qualitative Disclosures about Market Risk

At September 30, 2004, the balance sheet carrying amounts for cash and cash equivalents, accounts receivable, accounts payable and accrued liabilities, and payables under the Russian Contract approximate fair value because of the short-term nature of the instruments.

USEC does not enter into financial instruments for trading purposes. The fair value of long-term debt is calculated based on a credit-adjusted spread over U.S. Treasury securities with similar maturities. The scheduled maturity dates of long-term debt, the balance sheet carrying amounts and related fair values at September 30, 2004, are as follows (in millions):

See 1333

(10)

Uranium Conversion/Enrichment - Current Issues (USA)

(last updated 26 Oct 2004)

Contents:

- General
- Honeywell uranium conversion plant, Metropolis, Illinois
- LES Eunice uranium enrichment plant project (New Mexico) (extra page)
- LES Hartsville uranium enrichment plant project (Tennessee) (extra page)
- LES Claiborne enrichment plant project (Louisiana) (extra page)
- USEC Paducah (Kentucky) and Portsmouth (Ohio) enrichment plants (extra page)

> See also Current Issues for

- Nuclear Fuel Fabrication (USA)
- Uranium Enrichment/Fuel Fabrication - Decommissioning (USA)
- Uranium Hexafluoride Transport
- Waste Management - Depleted Uranium

General

> See also Regulatory Issues - USA

US DOC dumping case against Eurodif and Urenco

On Sep. 29, 2004, DOC amended the final results of the first antidumping duty administrative review of LEU from France, decreasing COGEMA/Eurodif's weighted-average margin from 5.43 percent to 4.56 percent.
Federal Register: September 29, 2004 (Volume 69, Number 188) p. 58128-58129 (download fullt text)

On July 26, 2004, DOC finally determined that a weighted-average dumping margin of 5.43% (rather than 5.34% in the preliminary determination) exists for COGEMA/Eurodif for the period of July 13, 2001, through January 31, 2003.
Federal Register: August 3, 2004 (Volume 69, Number 148) p. 46501-46508 (download full text)

On June 30, 2004, DOC finally determined ad valorem subsidy rates for Eurodif/COGEMA of 3.63 percent ad valorem for 2001, and 0.71 percent ad valorem for 2002.
Federal Register: July 7, 2004 (Volume 69, Number 129) p. 40871-40873 (download full text)

On June 30, 2004, DOC finally determined ad valorem subsidy rates for Urenco Group of 1.57 percent

ad valorem for 2001, and 1.47 percent ad valorem for 2002.
Federal Register: July 7, 2004 (Volume 69, Number 129) p. 40869-40871 (download full text)

On January 29, 2004, DOC preliminarily determined that the total estimated net countervailable subsidy rate for Eurodif is 6.54 percent ad valorem for 2001 and 3.03 percent ad valorem for 2002.
Federal Register: February 5, 2004 (Volume 69, Number 24) p. 5502-5505 (download full text)

On January 29, 2004, DOC preliminarily determined that the total estimated net countervailable subsidy rate for Urenco Group Ltd. is 1.66 percent ad valorem for 2001 and 1.40 percent ad valorem for 2002.
Federal Register: February 5, 2004 (Volume 69, Number 24) p. 5498-5502 (download full text)

On January 20, 2004, Department of Commerce issued a Notice of Preliminary Results of Antidumping Duty Administrative Review, indicating a Weighted-Average Margin for COGEMA/Eurodif of 5.34%.
Federal Register: January 27, 2004 (Volume 69, Number 17) p. 3883-3887 (download full text)

On September 16, 2003, the U.S. Court of International Trade (CIT) found that DOC's Final Remand Determination of June 23, 2003, is unlawful and reversed it.
> Download United States Court of International Trade Slip Opinion 03-121, USEC Inc. v. United States, 09/16/2003 (PDF)

On Mar. 25, 2003, the U.S. Court of International Trade (CIT) overturned Department of Commerce (DOC) decisions that the enrichers had violated U.S. trade laws in their sales of enrichment services in the U.S. The court vacated DOC's final determinations to slap duties on Urenco and Cogema SWU sales in the U.S. (Platts, Mar. 25, 2003)
> Download United States Court of International Trade Slip Opinion 03-34, USEC Inc. v. United States, 03/25/2003 (PDF)

On Jan. 22, 2002, the US International Trade Commission approved 32.10 percent duties on enriched uranium imports from France while it approved 2.23 percent tariffs on enriched uranium from Germany, the UK, and the Netherlands. (AFX Jan. 22, 2002)
> View US ITC vote (Jan. 22, 2002)

On Dec. 14, 2001, the US Commerce Department found that French uranium enrichment company Eurodif, had sold its services in the US at almost 20 per cent below fair market price, but virtually cleared UK-based Urenco Group of dumping in the US market. (Financial Times Dec. 15, 2001)

Federal Register: December 21, 2001 (Volume 66, Number 246):

- Notice of Final Determination of Sales at Less Than Fair Value: Low Enriched Uranium From France (p. 65877-65886) · United Kingdom, Germany and the Netherlands (p. 65886-65889)
- Notice of Final Affirmative Countervailing Duty Determination: Low Enriched Uranium From France (p. 65901-65902) · Germany, the Netherlands, and the United Kingdom (p. 65903-65905)

Federal Register: January 3, 2002 (Vol.67, No.2), p.344-345:

- Termination of investigations: Germany, the Netherlands, and the United Kingdom

> Import Administration, International Trade Administration, U.S. Department of Commerce

Honeywell uranium conversion plant, Metropolis, Illinois

NRC License No. SUB-526, Docket No. 04003392

Honeywell Metropolis conversion plant shut down after UF6 leak

NRC cites Honeywell Metropolis uranium conversion plant for violations

After a thorough review, the Nuclear Regulatory Commission staff has determined that two violations of NRC requirements occurred as a result of the uranium hexafluoride release at the Honeywell plant in Metropolis, Illinois, in late December 2003.
NRC inspectors found that Honeywell employees reconfigured the fluorination system without detailed instructions which allowed the leak to occur. During the event, the company also failed to implement some parts of its emergency response plan and did not provide sufficient information to local emergency responders.
> View NRC release May 11, 2004

NRC approves restart of Honeywell Metropolis uranium conversion plant (Illinois)

> View NRC releases: Mar. 27, 2004 · Apr. 14, 2004 · Apr. 17, 2004

Converdyn uranium conversion plant to resume operation after 3-month outage due to leakage

The Metropolis conversion facility is scheduled to restart operations during the week of 22 March 2004, according to ConverDyn. In a phased restart, front-end uranium hexafluoride (UF6) operations will begin first, followed by the restart of the remaining stages of the process, to be completed during the week of 29 March. The first full cylinders of UF6 are expected to become available during the week of 5 April. (WNA News Briefing 04:11, March 16, 2004)

UF6 leak at Honeywell Metropolis conversion plant entails another plant shutdown

"At approximately 2:24 a.m. (CST) there was a uranium hexafluoride (UF6) leak from a valve in their chemical process. The release was confirmed to have been terminated at approximately 3:20 a.m. (CST). Uranium hexafluoride is a hazardous chemical with low level radioactivity associated with the uranium component of the chemical.
Honeywell declared a site area emergency at 3:00 a.m. (CST). Fence line monitors indicated the possibility of a material release offsite. Local authorities evacuated approximately 25 people near the plant and approximately 75 people remained sheltered in their homes. Three individuals were taken to the hospital. Two of these individuals have been released. There were no injuries onsite. [...]" (NRC PNO-II-03-022, Dec. 22, 2003)
The NRC dispatched inspectors to the plant. In a Confirmatory Action Letter, NRC ordered Honeywell to shutdown the plant and perform an own investigation into the event. (NRC Release II-03-052, Dec. 23, 2003)
In its Inspection Report dated March 16, 2004, NRC identified two apparent license violations: the failure to have a procedure for the evolution of bringing two fluorinators online for dual operation, and the failures to properly maintain and implement aspects of the Radiological Contingency Plan.

> Download NRC Inspection Report (March 16, 2004) (PDF)

Converdyn uranium conversion plant shut down for incidents

Converdyn uranium conversion plant resumes operation

ConverDyn's Metropolis conversion facility resumed the production of uranium hexafluoride (UF6) on 18 November 2003, the company announced. Production will gradually increase and normal output rates are expected by mid-December. The facility has undergone significant repairs, retraining and a recertification programme due to recent incidents at the plant. (WNA News Briefing 03.47, Nov. 25, 2003)

Converdyn uranium conversion plant shut down for incidents

ConverDyn's Metropolis conversion facility experienced two unrelated plant incidents on 20 September, 2003, that have led to the temporary shutdown of uranium hexafluoride (UF_6) production at the site. The plant is expected to restart in early October. (WNA News Briefing 03.38, Sep. 24, 2003)
The incidents included: a hydrofluoric acid (HF) spill on Sep. 9, 2003, an antimony pentafloride (SbF_5) release on Sep. 12, 2003, and an uranium hexafluoride (UF_6) release from a cylinder pigtail on Sep. 30, 2003. Those incidents were subject to an NRC Inspection Report and Notice of Violation dated Dec. 17, 2003.

NRC accepts blending of CaF_2 waste to meet release criteria

By letter dated Sep 14, 2001, the NRC accepted a proposal by Honeywell to blend its calcium fluoride settling pond waste with natural fluorspar (CaF_2) to meet the uranium concentration criterion of 212 pCi/g (7.84 Bq/g; 313 ppm) for the unrestricted release of the material. The blended material is to be trucked to Hastie Trucking & Mining Company in Cave-In-Rock, Illinois, where it is to be manufactured into a fluorspar briquette for use as a fluxing agent in the steel industry. This arrangement evades the necessity to dump the waste material in a Texas landfill.

Missing shipment of uranium hexafluoride conversion waste

"MISSING SHIPMENT OF CaF SETTLING POND CLEANUP WASTE
A shipment of CaF settling pond waste left the site on July 25, 2001 and apparently did not arrive on July 27, 2001 at the Andrews County WCS in Texas. The shipment, one of several, consisted of 44,480 pounds [20.2 metric tonnes] of 80% CaF and 20% lime with less than 500 ppm natural uranium contained in it. The natural uranium is calculated at about 19 pounds [8.6 kg] total contained in the shipment. The driver reported that the shipment was delivered, but there is no paperwork to support the delivery. [...]

* * * UPDATE ON 8/23/01 @ 1425 BY ROBERTS TO GOULD * * *
Wills Trucking found the material intact on the ground on 8/22/01 north of Dallas, Tx. [...]."
(NRC Daily Event Report Aug. 24, 2001)

LES enrichment plant projects

> see extra page

USEC Paducah (Kentucky) and Portsmouth (Ohio) enrichment plants

> see extra page

compiled by:
WISE Uranium Project (home) · Current Issues - Uranium Enrichment - Other Countries

Public Citizen

Buyers Up • Congress Watch • Critical Mass • Global Trade Watch • Health Research Group • Litigation Group
Joan Claybrook, President

URENCO LIMITED

A CORPORATE PROFILE

April 2004

A Report by Public Citizen's Critical Mass Energy & Environment Program

215 Pennsylvania Ave SE • Washington, DC 20003 • (202) 546-4996 • www.citizen.org

URENCO LIMITED

A CORPORATE PROFILE

April 2004

Behind LES and its plan to build a controversial uranium enrichment plant in New Mexico is another company that is not well known in the United States. Urenco Limited is an unusual corporation controlled by government and private sector interests in Europe. It has been a lightning rod for anti-nuclear activism in three countries, and lax security at its operations has been cited as a factor in the illicit spread of nuclear technology to countries such as Pakistan, Iraq, Libya, and North Korea. The following is a background report on Urenco.

Urenco Limited Headquarters:
18 Oxford Road
Marlow
Buckinghamshire
SL7 2NL
United Kingdom
Tel. 44 (0) 1628 486 941
www.urenco.com

2002 Financial Results (latest available):

Revenues: 632.5 million euros (about $663 million)
After-tax profit: 87.3 million euros (about $ 92 million)

Employees: about 1,800

Urenco is one of the world's leading producers of low-enriched uranium for nuclear power plants. The company, which claims a global market share of more than 13 percent, operates three enrichment plants, located in Almelo, Holland (operating under the auspices of Urenco Nederland B.V); Capenhurst, England (Urenco Capenhurst Limited); and Gronau, Germany (Urenco Deutschland GmbH). It also has a research and development facility in Jülich, Germany, and a marketing office in Washington, D.C. Along with nuclear fuel, Urenco provides related products such as medical and industrial isotopes.

Urenco was established as the Urenco Group in 1971 to carry out a plan by Britain, West Germany, and Holland to jointly develop a capacity for uranium enrichment. Although it was sanctioned at the governmental level through the Treaty of Almelo, Urenco was structured as a profit-making corporation owned by private interests as well as public agencies. Urenco was originally a marketing agent for the three separate enrichment facilities, but in 1993 they were united under Urenco Limited as a holding company. Today Urenco is controlled by British Nuclear Fuels, the Dutch government's Ultra-Centrifuge Nederland and the German joint venture URANIT, which is owned by the utility companies RWE and E.ON.

The creation of Urenco was a key part of the effort by European countries to break free of the enrichment monopoly held by the United States in the West since the advent of nuclear power. The Europeans were not, however, united in this effort. When France was excluded from Urenco, it set up a rival consortium called Eurodif along with Spain, Italy, Belgium and Iran. Eurodif focused on the established technology of diffusion, while Urenco promoted the untested but potentially more energy-efficient centrifuge process.

Urenco did not limit its customer base to Europe. In the mid-1970s, the company negotiated a multi-billion-dollar deal to sell large quantities of enriched uranium to Brazil, whose government was dominated by the military at the time. This raised concerns that the uranium could be converted to weapons use. Public opposition in Holland was so strong that Urenco had to delay the deal until Brazil agreed to safeguards imposed by the International Atomic Energy Agency.[i]

Even more troubling than the possibility that Brazil might divert its Urenco uranium were the reports that Pakistan was actively developing a nuclear weapons program with the assistance of a scientist, Dr. Abdul Quadeer Khan, who had worked for a Dutch subcontractor to Urenco and was thought to have had access to sensitive information. A 1980 report by the Dutch government found that Khan had at least attempted to obtain such information, though the report said it was unclear whether he had succeeded.[ii] Numerous journalistic accounts later reported that Khan did indeed obtain detailed information about Urenco's centrifuge process while working for the subcontractor, Fyssich Dynamisch Oderzoekslaboratorium (commonly known as FDO). Among these was an article in *Time* magazine that also stated that Khan had brought home to Pakistan the names of more than 100 Western firms that could provide the equipment needed for a centrifuge plant.[iii] In 1987 the offices of one such company—Leybold-Heraeus, a key contractor for Urenco--was raided by West German customs officials.[iv] In 1985, Khan was convicted in absentia on charges of stealing confidential papers and was sentenced to four years in prison, but the verdict was later overturned on a legal technicality. Nonetheless, he was expelled from Holland in 1989.[v]

Urenco's name also emerged in reports about the illicit transfer of nuclear weapons technology to the Saddam Hussein government in Iraq. In 1990, *Nuclear Fuel* magazine published an interview with Bruno Stemmler, a centrifuge expert who had worked for MAN Technologien, a German supplier for Urenco. Stemmler said that during a trip to Iraq in 1988 he was shown design blueprints that resembled Urenco's first-generation centrifuge. Stemmler was quoted as saying that he had no idea how the blueprints got there, but the magazine reported that German investigators believed that Stemmler and another former MAN employee, Walter Busse, may have illegally diverted centrifuge design know-how to the Iraqis.[vi]

Later press reports named Karl-Heinz Schaab, a former senior technician in the Urenco centrifuge development program, as also being investigated for selling secret information to the Iraqis.[vii] Referring to Urenco's role in these investigations, a U.S. Department of Energy official said: "We've seen a consistent pattern of data leaving that program, and that's an indication they have a major security problem...Urenco has a lot of explaining to do."[viii] In 1999, Schaab was convicted of treason in a German court.[ix]

Urenco also came under fire from the United Nations, which accused the company of obtaining uranium from Namibia without permission. The UN had asserted authority over Namibia in 1967, but the apartheid government of South African continued to exercise control of the territory and its mineral wealth. A Urenco spokesperson responded to the charge by saying "we don't know where the stuff comes from."[x] (The case was later dropped as Namibia moved toward independence in 1990.)

Urenco got a big boost in 1982, when the Uranium Enrichment Group of Australia consortium chose its technology in an international competition, a decision that was reported to be based on "economic superiority."[xi] In 1984 Urenco got its first contract in the United States, with Boston Edison, following a decision by the U.S. Department of Energy to allow American nuclear power plants to order fuel from abroad for the first time.[xii]

Soon Urenco began to explore the idea of not only selling but also producing in the United States. In 1987, it hired the engineering company Fluor Corp. to do a detailed cost study of building a U.S. centrifuge plant.[xiii] Urenco apparently liked the results of the study. In June 1989 it joined with four U.S. partners—including Fluor subsidiary Fluor Daniel Inc. and electric utilities Duke Power, Graystone Corp. (a subsidiary of Northern States Power Co.) and Louisiana Power & Light Company—to form a joint venture called Louisiana Energy Services (LES). The venture planned to spend $750 million to build the first privately owned enrichment plant in the United States. The three utilities involved operated a total of 11 nuclear power stations. Urenco was to have the largest equity interest in the venture—about 47 percent—followed by Duke Power with about 29 percent, Fluor Daniel with about 13 percent and shares below 10 percent each for Northern States Power and Louisiana Power & Light.[xiv]

According to press reports, the plant, which was to be located in the northern Louisiana town of Homer, was strongly supported behind the scenes by Senator J. Bennett Johnston (D-La.), Chairman of the Senate Energy & Natural Resources Committee.[xv] Once Johnston went public with his support, he did so with intensity. Speaking of the project, he told an interviewer: "I stake my political life on it, my integrity...This is not a subject on which reasonable minds can disagree."[xvi]

Some minds did disagree. A local group called Citizens Against Nuclear Trash (CANT) was formed to oppose the project, and it received permission from the Nuclear Regulatory Commission to intervene in the licensing process. CANT was joined by national environmental groups as well as by civil rights organizations such as the NAACP, which raised concerns over the fact that the site of the plant was very close to two predominantly African-American communities. LES rejected the environmental racism charge and asserted that the experience of Urenco facilities in Europe showed that centrifuge plants "can be constructed and operated without human health or environmental effects on any populations."[xvii]

The roadblocks put up by CANT and other opponents, including the Nuclear Information & Resource Service, stretched out the approval process. In 1997, eight years after the project was announced, the Atomic Safety & Licensing Board of the Nuclear Regulatory Commission rejected the LES application, questioning the need for the facility and agreeing with CANT that

the location raised issues of environmental racism. The following year Urenco and its partners abandoned the plan.

Urenco started facing other problems in North America when the United States Enrichment Corporation (USEC), which was privatized in 1998, accused Urenco (as well as Eurodif) of dumping fuel in the U.S. market. In May 2001, the U.S. Department of Commerce imposed a 3.72 percent countervailing duty on Urenco and 13.94 percent on Eurodif.[xviii] Two months later the Commerce Department added an anti-dumping duty, which in the case of Urenco was 3.35 percent—though only for fuel produced in Britain.[xix] The Urenco duties were each later reduced to about 2.2 percent. In September 2003, the U.S. Court of International Trade overturned the anti-dumping penalties but upheld the countervailing duties.

Urenco and USEC were also at odds when Urenco and a revised lineup of partners (including British Nuclear Fuels subsidiary Westinghouse Electric and affiliates of three U.S. utilities: Exelon, Entergy and Duke Energy) reconstituted LES and began planning a $1.1 billion enrichment plant to be located in Tennessee.[xx] USEC was not the only source of opposition. As in Louisiana, local residents in the area, about 40 miles northeast of Nashville, formed an organization—Citizens for Smart Choices—to fight the project. Public officials also had their doubts. The Trousdale County Commission approved a set of restrictions that were stricter than federal standards, a move that was prompted by concerns that the company was not being completely candid. "From the start they didn't tell the truth," Trousdale County Attorney Betty Lou Taylor told *The Tennessean* newspaper.[xxi]

In September 2003, LES announced that it was abandoning Tennessee and looking to yet another site for the enrichment plant, this time in Lea County, New Mexico. The plan received strong support from various public officials (including Senator Pete Domenici (R-N.M.)) and the state agreed to provide tax incentives, but community opposition emerged once again. A group called Citizens Nuclear Information Center was formed under the leadership of retired businessman Lee Cheney. The most serious concern about the plant, Cheney told the *Albuquerque Journal*, was that there was no plan for disposal of the radioactive waste generated by the facility.[xxii]

This time around, LES and its supporters tried to change the rules of the game in favor of the project, which now had a $1.2 billion price tag. An aide to Sen. Domenici reportedly arranged for a provision to be inserted in a key energy bill that would require the U.S. Nuclear Regulatory Commission (NRC) to reach a licensing decision on new enrichment plants within two years, far less than the five years the NRC spent weighing an earlier LES application. The aide, Alex Flint, previously worked as a lobbyist for Exelon Corp., one of the LES partners.[xxiii] The energy bill, including the provision, is still pending in Congress.

Urenco also continues to be embroiled in controversy regarding nuclear proliferation. Beginning in late 2003, a series of press reports alleged that Pakistan was involved in transferring nuclear technology to Iran and that this technology ultimately came from Urenco, allegedly via the same 1970s theft of materials by Abdul Qadeer Khan discussed below.[xxiv] Khan later confessed publicly that he transferred nuclear secrets to Libya and North Korea. He was fired from his position as a science advisor to the Pakistani government, yet he was shielded from prosecution thanks to a pardon granted by Pakistani President Musharraf.

These matters became an issue in New Mexico for LES, now 70.5 percent owned by Urenco. One newspaper in the state wrote that "Urenco has also long been suspected as the unwitting source of nuclear technology that put Pakistan on the map as a nuclear power."[xxv]

Back in Europe, Urenco has been undergoing some structural changes. In October 2003, the company was divided into two parts: Urenco Enrichment Co. and Enrichment Technology Co. (ETC). The following month, the French government-owned nuclear group Areva agreed to purchase a 50 percent equity interest in ETC, which consists of Urenco's centrifuge equipment business. The move was seen as part of a plan by Areva to expand its enrichment business—it already controls Urenco's rival Eurodif—in preparation for an expected privatization of the group. At the same time, Areva announced that it would be adopting centrifuge technology at Eurodif's enrichment plant in France.

URENCO'S ENVIRONMENTAL RECORD

In September 2002 staff members of the NRC met with representatives of LES and were given a presentation on the operating experience of the Urenco facilities in Europe. The NRC staffers were told that there had been two releases to the environment at the Almelo facility in 1998 and 1999, but the significance of the events was downplayed. There had been a total of 13 releases of small quantities of uranium hexafluoride in the history of Urenco, mostly in the earlier history of the company. The LES representatives claimed that "in over 30 years of operation URENCO has had no incidents of significant consequence."[xxvi]

Here are some additional details about the three Urenco enrichment plants from publicly available sources:

Capenhurst, UK. In August 2001, fire crews were called to the plant after a leak of uranium hexafluoride. Urenco declared it a "building emergency" and evacuated the immediate areas, but the company and local authorities insisted there was no risk to the public.[xxvii] In March 2004, a truck carrying radioactive material from the plant was in an accident in Capenhurst and overturned, causing one of the containers it was carrying to crack. Decontamination units were brought to the scene.[xxviii] A 2002 report by the British Geological Survey found elevated levels of uranium in stream sediment near the Capenhurst facility.[xxix]

Almelo, Holland. Urenco's Dutch plant has been the target of protests since the late 1970s. In April 1983, for example, several thousand protestors, many of them carrying flaming torches, marched to the plant.[xxx] A protest at Almelo was held as recently as January 2004.[xxxi] In 1994, the group WISE-Amsterdam reported that radiation levels at the Almelo plant were well in excess of the limits stated in the facility's license.[xxxii] WISE has also criticized Urenco for sending its tails (depleted uranium) to Russia for re-enrichment, resulting in waste that is kept under conditions that are much less stringent than in Holland.[xxxiii]

Gronau, Germany. The Gronau plant has also been the scene of numerous protests, especially in 2002 after Urenco announced plans for increasing the capacity of the facility.[xxxiv] In March 2004

rainwater caused a short circuit in an air pressure sensor at the plant, causing the ventilation system to fail. The problem was reportedly corrected in 70 minutes.[xxxv]

Urenco has been surrounding by controversy for just about its entire history. As hard as the company tries to proclaim the safety of its operations, there continues to be serious opposition to its uranium enrichment activities both in Europe and North America. The environmental issues, along with the questions about Urenco's contribution (albeit unwitting) to nuclear proliferation, will make the LES deal as hard a sell in New Mexico as it was in Louisiana and Tennessee.

NOTES

---

[i]. "Nuclear Fuel Deal Set," *Chemical Week*, January 25, 1978, p.37.

[ii]. "Pakistani May Have Obtained Classified Nuclear Data," Associated Press, February 29, 1980.

[iii]. George Russell, "Who Has the Bomb," *Time*, June 3, 1985, p.36.

[iv]. Simon Henderson, "Cologne Company Raided Over Supply of Nuclear Equipment Plans to Pakistan," *Financial Times*, April 30, 1987, p.2.

[v]. "Pakistani Nuclear Physicist Expelled from Netherland," Associated Press, January 3, 1989.

[vi]. Mark Hibbs, "Iraq has Early Urenco Centrifuge Design, But Mass Production Years Away, Expert Says," *Nuclear Fuel*, December 24, 1990, p.1

[vii]. See, for example: Mark Hibbs, "Hunted German Expert May Be Hiding in Iran," *Nucleonics Week*, February 8, 1996, p.12.

[viii]. Quoted in Mark Hibbs, "Stemmler, Too, Sold Baghdad Urenco Centrifuge Blueprints," *Nuclear Fuel*, February 12, 1996, p.1.

[ix]. "German Sentenced for Providing Iraq Nuclear Secrets," Associated Press, June 29, 1999.

[x]. Quoted in "U.N.'s Namibia Council Plans Suit on Mining," *New York Times*, May 26, 1985, p.6.

[xi]. David Fishlock, "Why Urenco Came Out on Top," *Financial Times*, November 3, 1982, p.15.

[xii]. Paul Lewis, "Europeans Push Sales of Reactor Fuel in U.S.," *New York Times*, November 23, 1984, p.D1.

[xiii]. Eric Lindeman, "Urenco Hires Fluor to do Cost Study of Proposed U.S. Centrifuge Plant," *Nuclear Fuel*, June 1, 1987, p.9.

[xiv]. "LES Partnership Agreement Signed," *Nuclear Fuel*, April 3, 1990, p.4.

[xv]. Eric Lindeman and Michael Knapik, "Urenco, U.S. Partners to Build Centrifuge Plant in Louisiana," *Nuclear Fuel*, June 12, 1989, p.1.

[xvi]. Quoted in Thomas W. Lippman, "Uranium Plant Poses Test for Industry, Senator," *Washington Post*, March 5, 1990, p.A4.

[xvii]. Quoted in Wilson Dizard III, "LES Denies Environmental Racism Charge," *Nuclear Fuel*, April 25, 1994, p.6.

[xviii]. Daniel Horner, "DOC Preliminary Determination Awards Countervailing Duties in USEC Case," *Nuclear Fuel*, May 14, 2001, p.1.

[xix]. "Urenco Response to U.S. Department of Commerce's Preliminary Anti-Dumping Determination," Business Wire, July 6, 2001.

[xx]. Michael Knapik, "USEC Boldly Tells NRC that LES Plant May Not Be Needed and Could Hurt HEU Deal," *Nuclear Fuel*, July 8, 2002, p.1.

[xxi]. Quoted in Kelli Samantha Hewett, "Lack of Trust Soured LES Deal, Some Say," *The Tennessean*, August 31, 2003, p.1B.

[xxii]. John Fleck, "New Group Fights Nuke Factory Plan," *Albuquerque Journal*, November 4, 2003, p.D3.

[xxiii]. John J. Fialka, "Energy Bills Helps Firm with NRC—Lobbyist Turned Aide Shepherds a Provision Assisting Former Employer," *Wall Street Journal*, December 4, 2003, p.A4.

[xxiv]. See, for example: Douglas Frantz, "Iran-Pakistan Atomic Link Seen," *Los Angeles Times*, November 28, 2003, p.A1 and William J. Broad, David Rohde and David E. Sanger, "Inquiry Suggests Pakistanis Sold Nuclear Secrets," *New York Times*, December 22, 2003, p.A1.

[xxv]. Ben Neary, "Issues With LES Parent Company Might Be Red Flags," *Santa Fe New Mexican*, December 9, 2003, p.A-4.

[xxvi]. A summary of the meeting between NRC staff members and LES representatives held on September 5, 2002 can be found online at <http://www.nrc.gov/materials/fuel-cycle-fac/ml022660310.pdf>. The reference to the two releases at Almelo can be found on the third page of the memo. The other information and the quote can be found in the slide presentation appended to the memo.

[xxvii]. "Chemical Leak at Factory," *Liverpool Daily Post*, August 11, 2001, p.9.

[xxviii]. Jessica Shaughnessy, "Decontamination Units Called to Tanker Crash," *Chester Chronicle*, March 26, 2004.

[xxix]. British Geological Survey, *Uranium Anomalies Identified Using G-BASE Data*, Internal Report IUR/02/001, 2002; available online at <http://www.antenna.nl/wise/uranium/pdf/ir02_001.pdf>.

[xxx]. United Press International, April 3, 1983.

[xxxi]. See <http://www.uwg-ahaus.de/aktuelljan04_urencoalmelo.htm>.

[xxxii]. See <http://www.antenna.nl/wise/407/4028.html>.

[xxxiii]. See <http://www.indymedia.nl/nl/2002/11/7420.shtml>.

[xxxiv]. See <http://www.antenna.nl/wise/uranium/epeur.html#UREGRONAU>.

[xxxv]. *Gronauer Nachrichten*, March 25, 2004; cited at <http://www.antenna.nl/wise/uranium/epeur.html#UREGRONAU>.