Appendix A
Panel Organization

1. Panel on Structural Geology & Geoengineering

Chair:	Dr. Clarence R. Allen	Staff:	Mr. R.K. McFarland
Member:	Dr. Don U. Deere		Dr. Leon Reiter
Ad Hoc:	Dr. Patrick A. Domenico		

2. Panel on Hydrogeology & Geochemistry

Co-Chair:	Dr. Patrick A. Domenico	Staff:	Dr. Robert W. Luce
Co-Chair:	Dr. Donald Langmuir		
Ad Hoc:	Dr. Clarence R. Allen		
Ex Officio:	Dr. Don U. Deere		

3. Panel on the Engineered Barrier System

Chair:	Dr. Ellis D. Verink	Staff:	Dr. Carlos A.W. Di Bella
Members:	Dr. Dennis L. Price		
	Dr. Donald Langmuir		
Ex Officio:	Dr. Don U. Deere		

4. Panel on Transportation & Systems

Chair:	Dr. Dennis L. Price	Staff:	Dr. Sherwood C. Chu
Member:	Dr. Ellis D. Verink		
Ex Officio:	Dr. Don U. Deere		

5. Panel on the Environment & Public Health

Chair:	Dr. John E. Cantlon	Staff:	Dr. Sidney J.S. Parry
Ad Hoc:	Dr. D. Warner North		
Ex Officio:	Dr. Don U. Deere		

6. Panel on Risk & Performance Analysis

Chair:	Dr. D. Warner North	Staff:	Dr. Leon Reiter
Ad Hoc:	Dr. John E. Cantlon		
	Dr. Patrick A. Domenico		
	Dr. Dennis L. Price		
	Dr. Ellis D. Verink		
Ex Officio:	Dr. Don U. Deere		

7. Panel on Quality Assurance

Chair:	Dr. John E. Cantlon	Staff:	Dr. Sherwood C. Chu
Member:	Dr. Clarence R. Allen		
Ad Hoc:	Dr. Donald Langmuir		
Ex Officio:	Dr. Don U. Deere		

Appendix B
Nuclear Waste Technical Review Board Members: Curricula Vitae

Dr. Don U. Deere

Chairman

President Reagan appointed Dr. Deere to serve as Chairman of the Nuclear Waste Technical Review Board on January 18, 1989.

Dr. Deere has more than 45 years' experience as an international consultant in the planning, designing, and construction of shafts, tunnels, dams, underground mines, and storage projects, primarily in the fields of engineering geology and rock mechanics. With more than 35 years of university teaching experience and approximately 50 professional papers, he is presently an adjunct full professor in the Department of Civil Engineering and the Department of Geology at the University of Florida.

Dr. Deere consults extensively, both in the United States and overseas, primarily concerning dams, tunnels, and landslides associated with hydroelectric projects. Formerly he worked on the foundation design of numerous nuclear power plants. Currently, Dr. Deere advises the U.S. Bureau of Reclamation on aspects of the New Waddel Dam near Phoenix, Arizona, and serves as consultant on the design and construction of the Washington, D.C., metro system, a position he has occupied for the past 26 years.

He also has consulted on various aspects of several dozen hydroelectric engineering projects in many foreign countries, including Argentina, Brazil, Canada, Chile, Colombia, Costa Rica, the Dominican Republic, Ecuador, Egypt, Greece, the British Colony of Hong Kong, Israel, Mexico, Panama, Peru, Rhodesia, Turkey, Venezuela, and New Zealand. He currently consults on the English Channel undersea tunnels project for the chief executive of TRANS-MANCHE LINK, the consortium of five British and five French contractors who are constructing the tunnels.

Dr. Deere received the BEAVER Award in January 1990 and the MOLES Award in 1983 for Outstanding Achievement in Construction. In March 1990, he received the Rock Mechanics Award of the Society of Mining Engineers. In 1987, he participated in a National Academy of Sciences committee, which evaluated and proposed the final list of possible locations for the Superconducting Super Collider. He was elected to the National Academy of Engineering (1966), the National Academy of Sciences (1971), the National Academy of Sciences of Argentina (1987), and is a member of numerous professional societies.

He received a B.S. in mining engineering from Iowa State College (1943), an M.S. in geology from the University of Colorado (1949), and a Ph.D. in civil engineering from the University of Illinois (1955).

He resides in Gainesville, Florida.

Dr. Clarence R. Allen

President Reagan appointed Dr. Allen to serve on the Nuclear Waste Technical Review Board on January 18, 1989.

Dr. Allen is professor emeritus in geology and geophysics at the California Institute of Technology, where he has served as director of the Seismological Laboratory, chairman of the Division of Geological Sciences, and chairman of the faculty. He has more than 40 years' teaching experience and is the author of more than 120 professional publications.

Over the last 25 years, Dr. Allen has served in a variety of capacities on almost 30 advisory committees and professional boards, including the National Academy of Sciences' Board on Radioactive Waste Management, Panel on Earthquake Prediction, Geology Section, and Commission on Physical Sciences, Mathematics, and Resources; as chairman of the National Earthquake Prediction Evaluation Council; chairman of the National Science Foundation's Earth Science Advisory Panel; and chairman of the California State Mining and Geology Board.

He also has been a consultant on major dams and nuclear power plants located throughout the world, including Argentina, Brazil, Canada, Chile, Costa Rica, Egypt, Haiti, Iran, Iraq, Pakistan, Paraguay, Peru, the Philippines, Tunisia, the United States, and Venezuela. Dr. Allen has conducted field research in Chile, China, Indonesia, Japan, Mexico, New Zealand, the Philippines, Taiwan, Tibet, Turkey, the United States, and Venezuela.

Dr. Allen received the first G.K. Gilbert Award in Seismic Geology from the Carnegie Institution of Washington. He has served as president of both the Geological Society of America and the Seismological Society of America and was elected to the American Academy of Arts and Sciences (1974), the National Academy of Engineering (1976), and the National Academy of Sciences (1976).

He is a fellow of the Geological Society of America, the American Geophysical Union, and the American Association for the Advancement of Science and a member of five other professional societies. His wide-ranging research interests include seismicity, tectonics of fault systems, geologic hazards, earthquake prediction, siting of critical facilities, and geophysical studies of glaciers.

Dr. Allen is a Phi Beta Kappa graduate from Reed College (1949), where he received a B.A. in physics. He subsequently received an M.S. in geophysics (1951) and a Ph.D. in structural geology and geophysics (1954) from the California Institute of Technology.

Dr. Allen divides his time between Pasadena, California, and Copalis Beach, Washington.

Dr. John E. Cantlon

President Reagan appointed Dr. Cantlon to serve on the Nuclear Waste Technical Review Board on January 18, 1989.

As vice president emeritus for research and graduate studies and former dean of the graduate school at Michigan State University, Dr. Cantlon brings to the Board more than 20 years of academic and administrative experience at Michigan State University. After serving six years as academic vice president and provost, he was appointed to the research and graduate studies position. He retired from Michigan State University on September 1, 1990. Dr. Cantlon also has served as director of the Environmental Biology Program at the National Science Foundation.

Over the last 30 years, Dr. Cantlon has served on almost two dozen advisory committees with various academic, government, and private organizations, including the White House, Department of Energy, National Academy of Sciences, Environmental Protection Agency, National Science Foundation, Oak Ridge National Laboratory, World Resources Institute, Woods Hole Research Center, and the Boyce Thompson Institute. Recently he participated in a National Academy of Sciences' committee, which evaluated and proposed the final list of possible locations for the Superconducting Super Collider.

Dr. Cantlon is a member of more than a dozen professional organizations and societies. In particular, he has served as president of the Ecological Society of America; president of the Michigan Academy of Science, Arts, and Letters; and chairman of the board of the Michigan Energy and Resources Research Association.

With more than 40 years' teaching and research experience at four universities and the publication of three dozen professional publications, Dr. Cantlon also is a professor emeritus of botany at Michigan State University. His diverse research interests include physiological ecology, micro-environments, Alaskan tundra vegetation, and academic administration and research related to economic development.

Throughout his career, Dr. Cantlon has received numerous awards including the Distinguished Faculty Award and Centennial Review Distinguished Lecturer at Michigan State University. In 1986, he was awarded the Distinguished Faculty Award by the Michigan Council of Governing Boards.

He received a B.S. in biology and chemistry from the University of Nevada (1947) and a Ph.D. in plant ecology from Rutgers University (1950).

Dr. Cantlon resides in East Lansing, Michigan.

Dr. Patrick A. Domenico

President Bush appointed Dr. Domenico to a four-year term on the Nuclear Waste Technical Review Board on May 31, 1990.

Dr. Domenico is currently the David B. Harris Professor of Geology at Texas A&M University's College Station campus, where he teaches and conducts research in his area of expertise, ground-water hydrology. He has more than 25 years' teaching experience and has authored more than 40 professional publications, including a textbook on ground-water hydrology. Over the past 10 years, Dr. Domenico's research and consulting activities have focused on hazardous and nuclear waste transport in the subsurface.

In the area of nuclear waste disposal, Dr. Domenico has served the Department of Energy as an adviser to the scientific program at the Basalt Waste Isolation Project and acted as a consultant to Argonne National Laboratory on the Deaf Smith and Nevada Test Site projects. Additionally, he served on the Performance Assessment Board for the Waste Isolation Pilot Plant as consultant to the Sandia National Laboratories.

Dr. Domenico has acted as a consultant for many private and governmental organizations, including the International Bank for Reconstruction and Development, DuPont Chemical Company, and the Edison Electric Institute. In these positions, he has worked on projects dealing with hydrologic, ground-water supply, geothermal, and environmental issues.

Dr. Domenico has served on several expert panels, including the Panel on Groundwater Modeling of the Scientific Community on Problems of the Environment and the National Science Foundation Uranium Mill Tailings Study Panel. He also was a participant in the planning workshops for the *Hydrogeology* volume of the *Geology of North America.* He is a registered engineer with the state of Nevada.

Through the course of his career, Dr. Domenico has received many prestigious awards, including the Birdsall Distinguished Lecturer in Hydrogeology (1981-1982), the Distinguished Teaching Award from the College of Geoscience (1986), and the Distinguished Teaching Award from Texas A&M University (1989).

Dr. Domenico is a cum laude graduate from Syracuse University (1959), where he received a B.S. in geology. He later received an M.S. in engineering geology from Syracuse (1963) and a Ph.D. in hydrology from the University of Nevada (1967).

He presently resides in College Station, Texas.

Dr. Donald Langmuir

President Reagan appointed Dr. Langmuir to serve on the Nuclear Waste Technical Review Board in January 1989.

Dr. Langmuir brings to the Board an extensive background in ground-water geochemistry. He is presently a professor of geochemistry at the Colorado School of Mines, Golden, Colorado. During his career, Dr. Langmuir has accumulated more than 25 years' teaching experience at Rutgers University, Pennsylvania State University, the University of Nevada, the University of Sydney in Australia, and the Colorado School of Mines. He also has worked in the Water Resources Division of the U.S. Geological Survey.

His research interests include uranium, thorium, and radium geochemistry as it relates to radioactive waste disposal; ground-water prospecting for and in-situ leaching of ore deposits; mechanisms and modeling of metal and ligand sorption and solution-mineral equilibria in the saturated and unsaturated zones; thermodynamic and kinetic properties of water-rock systems; acid-rain weathering of building materials; and ground-water pollution.

Over the last 10 years, Dr. Langmuir has served on or chaired almost a dozen expert panels on various research programs sponsored by the Department of Energy, Nuclear Regulatory Commission, Environmental Protection Agency, and Lawrence Berkeley Laboratory. He was state president of the 7,500-member Colorado Mountain Club in 1990.

With memberships in nearly a dozen professional societies, Dr. Langmuir has served as chair of numerous society committees and sessions of national meetings related to hydrology and geochemistry and prepared several symposia and short courses. He is a fellow of the Mineralogical Society of America and the American Association for the Advancement of Science. Dr. Langmuir also has been associate editor of *Geochimica et Cosmochimica Acta,* the journal of the Geochemical Society, and served on the editorial board of *Interface*, the journal of the Society of Environmental Geochemistry and Health.

Over the last 25 years, Dr. Langmuir has published nearly 85 professional papers and articles and been awarded 23 grants and contracts supporting $1.8 million worth of research. He has consulted for clients in 16 states, as well as in Australia, Canada, France, and Sweden.

He is a cum laude graduate of Harvard University (1956), where he received an A.B. in geological sciences. After serving as a naval officer, he subsequently received an M.A. (1961) and a Ph.D. (1965) in geology from Harvard University.

Dr. Langmuir resides in Golden, Colorado.

Dr. John J. McKetta, Jr.

President Bush appointed Dr. McKetta to serve a four-year term on the Nuclear Waste Technical Review Board in February 1992.

Dr. McKetta is the Joe C. Walter Professor of Chemical Engineering emeritus at the University of Texas, Austin, and brings to the Board some 55 years' experience in practicing and teaching chemical engineering. He is a recipient of the Herbert Hoover Award for "unselfish service to society" (1989), a former president of the American Institute of Chemical Engineers (1962), and an honorary fellow of the Society of Technical Communicators. He serves on the boards of directors of Howell Corporation, Kinark Corporation, and Tesoro Petroleum Corporation.

Dr. McKetta has special expertise in two areas of research: solubility of hydrocarbon systems at high pressure and vapor-liquid-liquid equilibrium in hydrocarbon-water systems.

Among his numerous awards for professional achievement are: the F.J. Van Atwerpen Award for Outstanding Contributions to the Field of Chemical Engineering (1985) from the American Institute of Chemical Engineers, the Fuels and Petrochemical Division Award (1983), and the Warren K. Lewis Award for Excellence in Chemical Engineering (1969). Dr. McKetta also received the Boris Pregel Award in Science and Technology from the New York Academy of Sciences (1978) and the Charles M. Schwab Memorial Award from the American Iron and Steel Institute (1973). He is a member of the National Academy of Engineering, the American Chemical Society, the American Gas Association, and the American Institute of Mining, Metallurgical, and Petroleum Engineers.

In 1946, Dr. McKetta began his distinguished teaching career as a professor of chemical engineering at the University of Texas, Austin. Dr. McKetta also has been the University's E.P. Schoch Professor of Chemical Engineering (1970-1982), dean of the College of Engineering (1963-1969), and chairman of the Department of Chemical Engineering (1950-1952). He received his B.S. in Chemical Engineering from Tri State University in 1937 and also has three degrees from the University of Michigan: a B.S.E. (1943), an M.S. (1944), and a Ph.D. (1946). He has published 495 referred articles and books.

Dr. McKetta resides in Austin, Texas.

Dr. D. Warner North

President Reagan appointed Dr. North to serve on the Nuclear Waste Technical Review Board on January 18, 1989. Although his term expired on April 19, 1990, President Bush reappointed Dr. North to a second term on August 7, 1990.

Dr. North is a consulting professor in the Department of Engineering-Economic Systems at Stanford University, and a principal with Decision Focus, Inc., Los Altos, California. In his work for that firm, Dr. North has performed risk assessments and other related activities for the Electric Power Research Institute and numerous electric utilities, energy companies, chemical companies, industry associations, the Department of Energy, the Environmental Protection Agency, the National Science Foundation, and the government of Mexico. Prior to his employment with Decision Focus, he spent 10 years with SRI International in Menlo Park, California.

Dr. North's areas of expertise are risk analysis and decision analysis. He has worked on a wide variety of public policy issues, including weather modification, wildland fire protection, biological quarantine for the U.S. space program, disposal of chemical munitions and agents, planning of energy systems and energy research and development, and risk assessment and management of toxic chemicals. Dr. North serves on the editorial boards for *Risk Analysis*, *Risk Abstracts*, and *Management Science.* He is president of the Society for Risk Analysis.

Dr. North served as a consultant on decision analysis to the National Academy of Sciences (NAS) for its review in 1986 of the DOE methodology used to select prospective sites for the nation's first geologic repository for high-level radioactive waste. Dr. North has participated in six other NAS studies on environmental risk issues, including those resulting in the reports *Risk Assessment in the Federal Government: Managing the Process* (1983) and *Improving Risk Communication* (1989). Dr. North currently serves on the NAS Committee on Air Pollution Risk Assessment.

Dr. North has served on EPA Science Advisory Board (SAB) committees since 1978. From 1982 to 1990, he was a member of the Environmental Health Committee, and he currently serves as a consultant to this committee. During 1988-89, he was the chair of the Global Climate Change Subcommittee for the SAB review of two EPA reports to Congress on climate alteration from carbon dioxide and other radiatively active gases in the atmosphere. Dr. North also has been a reviewer of the carcinogen risk assessment guidelines, chair of the subcommittee that reviewed EPA's risk assessment research, and vice chair of the subcommittee that advised EPA on the congressionally mandated revision of the Hazard Ranking System used to select Superfund sites. From March 1987 to June 1989, Dr. North was a member of the California Governor's Scientific Advisory Panel for the Proposition 65 Toxics Initiative, passed in 1986.

Dr. North received a B.S. in physics from Yale University (1962); an M.S. in physics (1963), an M.S. in mathematics (1966), and a Ph.D. in operations research (1970) from Stanford University.

He resides in Woodside, California.

Dr. Dennis L. Price

President Reagan appointed Dr. Price to serve on the Nuclear Waste Technical Review Board in January 1989. Although his term expired in April 1990, President Bush reappointed Dr. Price to a four-year term on July 23, 1990.

Dr. Price is now professor of industrial and systems engineering, director of the Safety Projects Office, and coordinator of the Human Factors Engineering Center at Virginia Polytechnic Institute and State University. With more than 20 years' teaching experience at three institutions and eight years of industrial experience with two corporations, his present interests include transportation of hazardous materials, human factors research, engineering psychology, industrial hazard control, design and evaluation of person-machine systems, and system safety analysis.

Since 1977, Dr. Price has been a human factors / safety engineering consultant for a variety of clients including Florida Power and Light, U.S. Navy, IBM, Union Camp, Mountain West Research in Nevada, Aetna Life and Casualty, Liberty Mutual, Sears, and product liability attorneys in 10 states. He also is certified as a hazard control manager and a product safety manager.

As a member of the National Academy of Sciences' (NAS) Transportation Research Board, Dr. Price has served as chairman or been a member of six committees or subcommittees, including the chairman of the A3C10 Committee on the Transportation of Hazardous Materials. In addition, he was chairman of NAS' Task Force on Pipeline Safety and a member of its Committee on Demilitarization of Chemical Weapons. For his NAS service, Dr. Price received the Distinguished Service Award (1987) and the Outstanding Service Commendation (1981).

Dr. Price's publications include more than 30 papers in the open literature, 1 book, 7 chapters in various books, and more than 160 technical reports for private industry, clients, or government agencies. Some of these studies were the subjects of public hearings and radio and television programs with nationwide coverage. He is also on the editorial board of *Human Factors*, the journal of the Human Factors Society, and serves as a professional reviewer for seven organizations. Dr. Price is a member of six professional organizations and has served on numerous university committees.

Dr. Price has a very diverse educational background with a B.A. from Bob Jones University (1952), an M.A. in psychology from California State University at Long Beach (1967), and a Ph.D. in industrial engineering from Texas A&M University (1974). He also received an M.A. and B.D. from the American Baptist Seminary of the West (1955).

He resides in Blacksburg, Virginia.

Dr. Ellis D. Verink, Jr.

President Reagan appointed Dr. Verink to serve on the Nuclear Waste Technical Review Board in January 1989. On October 30, 1990, President Bush appointed Dr. Verink to a second term.

Dr. Verink brings to the Board nearly 50 years' experience in materials selection and corrosion. He is a Distinguished Service Professor of Metallurgical Engineering Emeritus, former chair of the Materials Science and Engineering Department at the University of Florida, and president of Materials Consultants, Inc. He was elected a fellow of the Metallurgical Society (1988) and the American Society for Metals (1978).

In addition to his election to president of the Metallurgical Society, Dr. Verink has served on the executive committee, board of directors, and board of trustees of the American Institute of Mining, Metallurgical and Petroleum Engineers. He was a three-term national director of the National Association of Corrosion Engineers and served on five National Academy of Sciences committees, including two that reviewed the conceptual geologic repository designed by Swedish engineers. Dr. Verink also has been chair or a member of more than 20 other national committees or advisory groups.

With more than 25 years of academic experience, Dr. Verink has served as chair of nine committees, including the Search Committee for the President of the University of Florida, and has been a member of eight other university committees. For his contributions to materials science and university teaching, Dr. Verink was elected a fellow of the Metallurgical Society and has received nearly a dozen other awards, including the Willis Rodney Whitney Award, Florida Blue Key Distinguished Faculty Award, Educator Award of the Metallurgical Society, and University of Florida Teacher-Scholar of the Year Award.

As a registered professional engineer with special accreditation in corrosion engineering, Dr. Verink has been a consultant on numerous projects for such private clients as the Aluminum Association, Copper Development Association, Sandia Corporation, and the Lockheed-Georgia Company. He has been a member of American delegations to both China and the former Soviet Union and has lectured in five foreign countries.

Dr. Verink has written more than 75 technical papers, edited 2 books and 9 chapters in other books, and served as a corrosion editor for the *Journal of the Electrochemical Society* and on the editorial board of *Surface Technology Magazine* and *Journal of Materials Education*.

Dr. Verink has three educational degrees in metallurgical engineering: a B.S. from Purdue University (1941) and an M.S. (1963) and a Ph.D. (1965) from Ohio State University.

He resides in Gainesville, Florida, where he is a past president of both the Kiwanis Club and the YMCA.

Appendix C
Meeting List for 1991–92

January 15, 1991

Board Business Meeting
Arlington, Virginia
Topic: Board activities
Minutes available

January 16, 1991

Board Meeting
Arlington, Virginia
Topic: Briefings by environmental groups, industry groups, public policy groups, and state organizations
Transcript available

January 17, 1991

Board Meeting (morning session)
Arlington, Virginia
Topic: Overview of OCRWM program, systems integration, and future interactions with the Board
Transcript available

January 17, 1991

Board Business Meeting (afternoon session)
Arlington, Virginia
Topic: Board activities
Minutes available

February 1991

No meetings

March 1, 1991

Meeting
Panel on Structural Geology & Geoengineering
Tucson, Arizona
Topic: Potential and past volcanic activity within the Yucca Mountain vicinity
Transcript available

March 6-7, 1991

Joint Meeting
Panel on Structural Geology & Geoengineering
Panel on Hydrogeology & Geochemistry
Denver, Colorado
Topic: Site-suitability review, Calico Hills/ESF alternatives analysis study, and test prioritization
Transcript available

March 14-15, 1991

Meeting
Panel on Transportation & Systems
Albuquerque, New Mexico
Topic: Nature and scope of Waste Isolation Pilot Plant transportation program
Transcript available

March 26-27, 1991

Joint Meeting
Panel on Quality Assurance
Panel on Structural Geology & Geoengineering
Dallas, Texas
Topic: Quality assurance on ESF preliminary design; follow-up on DOE quality assurance program
Transcript available

April 16, 1991

Board Meeting
Natural and Anthropogenic Analogues
Reno, Nevada
Topic: Field studies, possible natural analogue sites, and the potential for using archaeological studies as analogues
Transcript available

April 17, 1991

Board Business Meeting
Natural and Anthropogenic Analogues (cont.)
(afternoon session)
Reno, Nevada
Minutes available

April 18, 1991

Board Business Meeting
Reno, Nevada
Topic: Board activities
Minutes available

May 20-21, 1991

Meeting
Panel on Risk & Performance Analysis
Arlington, Virginia
Topic: Performance assessment
Transcript available

May 1991

Release of Board's *Third Report*

June 9-15, 1991

Board trip to Canada
See Board's *Fourth Report*

June 25-27, 1991

Joint Meeting
Panel on Hydrogeology & Geochemistry
Panel on Structural Geology & Geoengineering
Denver, Colorado
Topic: Hydrologic, hydrochemical, and rock mechanics field testing
Transcript available

July 15, 1991

Meeting
Panel on Structural Geology & Geoengineering
Arlington, Virginia
Topic: Management Systems Improvement Strategy; and ESF design review update
Transcript available

July 16-17, 1991

Board Business Meeting
Arlington, Virginia
Topic: OCRWM research priorities and budget; international waste management programs; EPA standards, NRC regulations, and the DOE's 10 CFR 960
Transcript available

July 18, 1991

Board Business Meeting
Arlington, Virginia
Topic: Board activities
Minutes available

August 12-14, 1991

Board Trip to the Waste Isolation Pilot Plant
Carlsbad, New Mexico
See Board's *Fourth Report*

August 15, 1991

Public Hearing
Panel on Transportation & Systems
Denver, Colorado
Topic: Transportation issues
Transcript available

September 18-19, 1991

Meeting
Panel on Structural Geology & Geoengineering
Las Vegas, Nevada
Topic: ESF design review
Transcript available

September 25-26, 1991

Meeting
Panel on Transportation & Systems
Arlington, Virginia
Topic: DOE update on transportation issues
Transcript available

October 8-10, 1991

Board Business Meeting
Las Vegas, Nevada
Topic: Thermal loading / repository design
Transcript available

October 11, 1991

Board Business Meeting
Las Vegas, Nevada
Topic: Board activities
Minutes available

November 12-13, 1991

Meeting
Panel on Structural Geology & Geoengineering
Seattle, Washington
Topic: Technologies for sealing openings, tour The Robbins Company
Transcript available

December 1991

No meetings scheduled

Release of Board's *Fourth Report*

January 7–8, 1992

Board Business Meeting
Arlington, Virginia
Topic: Overview of OCRWM program priorities and budget allocations
Transcript available

January 8, 1992

Board Business Meeting
Arlington, Virginia
Topic: Board activities
Minutes available

January 8-10, 1992

Board Tour of Surry Nuclear Power Station
Williamsburg, Virginia

January 22–23, 1992

Meeting
Panel on Structural Geology & Geoengineering
Irvine, California
Topic: Seismic vulnerabilities
Transcript available

February 10, 1992

Meeting
Panel on the Engineered Barrier System
Augusta, Georgia
Topic: Overview of defense management activities
Transcript available

February 11-12, 1992

Board Tour of Savannah River Site
Augusta, Georgia

February 12, 1992

Board Tour of Chem-Nuclear Systems, Inc.
Barnwell, South Carolina

March 10-11, 1992

Meeting
Panel on Transportation & Systems
Arlington, Virginia
Topic: Transportation system safety issues and monitored retrievable storage concept design
Transcript available

April 6, 1992

Board Business Meeting
Dallas, Texas
Topic: Board activities
Minutes available

April 7-8, 1992

Board Business Meeting
Dallas, Texas
Topic: Early site-suitability evaluation, total system performance assessment
Transcript available

April 9, 1992

Board Business Meeting
Dallas, Texas
Topic: Board activities
Minutes available

May 11-14, 1992

Meeting
Panel on the Engineered Barrier System
Hanford Plant, Richland, Washington
Idaho National Engineering Laboratory, Idaho Falls, Idaho
Topic: Overview of defense high-level waste management activities

June 9-17, 1992

Board International Trip
Finland, Switzerland

July 7-10, 1992

Board Business Meeting
Denver, Colorado
Topic: To be determined

August 1992

No meetings scheduled

September 1992

No meetings scheduled

October 13-14, 1992

Board Business Meeting
Las Vegas, Nevada
Topic: To be determined

October 15-16, 1992	**Meeting** **Panel on Structural Geology & Geoengineering** *Las Vegas, Nevada* Topic: Volcanism
November 1992	**No meetings scheduled**
December 1992	**No meetings scheduled**

Appendix D
Presenters List

The following people made presentations during Board or panel meetings held from August 1, 1991, through January 31, 1992. This list is arranged alphabetically by organization. The Board also wishes to thank those who made presentations to the Board or panel members during various trips and tours we have taken during recent months.

Analysas Corporation
300 South Tulane Avenue
Oak Ridge, TN 37830
(615) 576-9120

Lydia Ellis

Applied Decision Analysis, Inc.
3000 Sand Hill Road, Bldg. Four
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Menlo Park, CA 94025
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Lee Merkhofer

Arizona State University
Mathematics Department
Tempe, AZ 85287
(602) 965-3718

Jon Helton

Association of American Railroads Transportation Test Center
P.O. Box 11130
Pueblo, CO 81001
(719) 584-0554

Peter Conlon
Jack B. Stauffer

Atomic Energy of Canada, Ltd.
Whiteshell Laboratories
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(204) 753-2311

Gary Simmons

Bechtel
50 Beale Street
P.O. Box 193965
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(415) 986-4166

Kenneth M.S. Mark

Center for Nuclear Waste Regulatory Analysis
6220 Culebra Road
San Antonio, TX 78228
(512) 522-5209

Simon Hsiung

Colorado School of Mines
P.O. Box 28176
Lakewood, CO 80228
(303) 989-0170

James E. Friant

Disposal Safety, Inc.
1660 L Street, NW
Washington, DC 20036
(202) 293-3993

Benjamin Ross
Spoke on behalf of EPRI

Edison Electric Institute U Waste
12988 Angosto Way
San Diego, CA 92128
(619) 487-7510

Jay Smith

EG&G Measurements, Inc.
2621 North Losee Road, NW
P.O. Box 1912
North Las Vegas, NV 89030
(702) 794-7474

Kent Ostler

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304
(415) 855-2000

Robert Shaw

Environmental Defense Fund
1515 Arapahoe
Tower 3
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Denver, CO 80202
(303) 820-4497

Adam Babich

Environmental Evaluation Group
7007 Wyoming Boulevard, NE
Suite F2
Albuquerque, NM 87109
(505) 828-1003

James Channell

Environmental Research/Institute for Underground Storage
Theodor-Heuss-Strabe 4
W-3300 Braunschweig
Federal Republic of Germany
531 8012-231

Klaus Kühn

E.R. Johnson Associates, Inc.
10461 White Granite Drive
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Oakton, VA 22124
(703) 359-9355

N. Barrie McLeod

Fluor Daniel, Inc.
3333 Michelson Drive
Irvine, CA 92730
(714) 975-5835

Phillip J. Richter

Geomatrix
100 Pine Street
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San Francisco, CA 94111
(415) 434-9400

Kevin Coppersmith
Frank H. Swan

Georgia Technologies
620 Cherry Street, NW
Atlanta, GA 30332
(404) 894-3717

Daniel B. Bullen
Spoke on behalf of EPRI

Golder Associates, Inc.
4104-148th Avenue. NE
Redmond, WA 98052
(206) 883-0777

Charles Voss
Ian Miller

Intera Consultant Group, Inc.
1313 5th Street, SE
Minneapolis, MN 55428
(612) 623-9599

Terji Brandshaug

Intera Information Technologies
3609 South Wadsworth Boulevard
Denver, CO 80235
(303) 985-0005

Mick Apted
Spoke on behalf of EPRI

International Technology Corporation
5301 Central Avenue, NE
Suite 700
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Appendix E
Department of Energy Responses to the Recommendations Made in the Board's *Fourth Report* (December 1991)

As part of its effort to keep the Nuclear Waste Technical Review Board informed of its progress, the Department of Energy submitted to the Board on April 1, 1992, a summary of initial responses to recommendations the Board made in its *Fourth Report*. The Board has included those responses along with the transmittal letter in this report. Inclusion of these responses does not necessarily imply Board concurrence.

Department of Energy
Washington, DC 20585

March 31, 1992

Dr. Don U. Deere
Chairman, Nuclear Waste Technical
Review Board
1100 Wilson Boulevard
Arlington, Virginia 22209

Dear Dr. Deere:

This letter transmits the Department of Energy's (DOE) responses to the Nuclear Waste Technical Review Board's recommendations made in its Fourth Report to the U.S. Congress and the U.S. Secretary of Energy that was issued on December 10, 1991. Our responses to the Board's 10 recommendations may be found in the enclosure.

I am pleased to note that the program has made significant progress since your previous report that was dated May 1991. As noted during our meetings, we are conducting surface-disturbing activities at the Yucca Mountain site for the first time since 1986. This work not only gathers data that is essential in resolving the site suitability issues, but it also permits us to demonstrate program progress. This progress is essential in maintaining the support of program stakeholders and Congress. As I explained during our recent meeting with the Board, I have chosen to advance the Exploratory Studies Facility design effort as much as practical, while still maintaining the surface-based testing program needed to sustain program progress. As evidenced by our responses to the Board's report, I believe that our strategies, activities, and plans are largely consistent with the Board's recommendations.

In the coming months, we hope to accomplish several programmatic milestones. We intend to issue the baseline site suitability evaluation report and the preliminary repository system performance assessment report for public comment. We welcome the Board's comments on these important technical documents. These efforts, along with the expansion of the site characterization activities, and the siting activities for the MRS facility provide the strategic focus for the program in the coming year.

With the synthesis of site characterization data, we also hope to resolve several of the basic suitability questions concerning the Yucca Mountain site. I hope to get the Board's input on approaches for dealing with the residual uncertainty associated with data collection and a consensus on how to balance data, peer

review, and expert judgment in order to produce a defensible performance assessment. The resolution of these issues is essential to the basic determination of site suitability.

We appreciate the Board's reviews, insightful comments, and recommendations on the content and performance of our program. The Board's independent oversight is essential in affirming the soundness and quality of the Civilian Radioactive Waste Management program. We look forward to working with you and the Board in the future.

Sincerely,

John W. Bartlett

John W. Bartlett, Director
Office of Civilian Radioactive
Waste Management

Enclosure

DOE Response to the Recommendations of the Nuclear Waste Technical Review Board in Its *Fourth Report to the U.S. Congress and the U.S. Secretary of Energy* December 1991

INTRODUCTION

The Nuclear Waste Policy Amendments Act of 1987 established the Nuclear Waste Technical Review Board to evaluate the technical and scientific validity of activities undertaken by the Department of Energy (DOE) in the Office of Civilian Radioactive Waste Management (OCRWM).

The Board is required to report, not less than two times per year, to the Congress and the Secretary of Energy, its findings, conclusions, and recommendations. The Board has issued four reports to date. The fourth report, issued on December 10, 1991, includes 10 recommendations in 5 broad areas: (1) structural geology and geoengineering; (2) hydrogeology and geochemistry; (3) the engineered barrier system; (4) the environment and public health; and (5) risk and performance analysis.

These recommendations and DOE's responses are presented in this report. Each recommendation is quoted verbatim from the Board's report of December 10, 1991, and is followed by the response.

STRUCTURAL GEOLOGY AND GEOENGINEERING

These recommendations from the Board concern the Site Characterization Plan, ongoing Exploratory Studies Facility (ESF), and conceptual repository design.

Recommendation 1:

The Board recommends that the DOE revise its program to include earlier underground excavation. Surface-based drilling alone will not reveal all the important hydrogeologic characteristics of the many important structural geologic features. Underground access across key geologic features to visually examine and evaluate those features is critical to determining site suitability and should be made an early goal regardless of budgetary constraints.

Response:

DOE recognizes the importance of conducting both surface-based and subsurface investigations to support the evaluation of suitability of the Yucca Mountain site. The schedule for such investigation and evaluation is constrained by various factors, including program funding. As discussed in the January 7-8, 1992, meeting with the Board, program planning and allocation of available funds are based on the goal of meeting the two primary programmatic milestones: to begin receipt of waste in 1998 and to begin disposal of waste in 2010. These two milestones are of equal importance in fulfilling the mission of OCRWM.

Under the fiscal year 1992 budgetary constraints, DOE chose to advance the ESF design effort as much as possible while still maintaining the surface-based testing activities. Surface-based testing is essential to obtain needed data, address early site suitability issues, and sustain scientific progress. The design and construction of the ESF is a major program effort that will require a multiyear commitment of significant resources in order to achieve any useful results in the near term. Current budget restrictions will not allow OCRWM to fund the ESF-related activities required to move this element of the program forward in a coherent manner, and at the same time fund ongoing site characterization activities that must be maintained to ensure program continuity and regulatory compliance (e.g., seismic, hydrologic, and environmental monitoring).

DOE agrees that underground access is essential to site characterization. DOE expects that a large portion of the projected future increases in program funding will be allocated to ESF design and construction in order to gain underground access to Yucca Mountain as quickly and as efficiently as practical.

Recommendation 2:

The Board recommends that 16- to 20-ft tunnel diameters be considered for the ramps and exploratory tunnels. Smaller tunnels would be more in line with the requirements of an exploratory facility and offer additional benefits, such as reduced excavation volumes, lower ventilation requirements, and smaller surface facilities. Smaller tunnel-boring machines, which are not only less expensive but also more available in the marketplace, could be used. Finally, the increase in tunneling advance rates due to smaller tunnels would provide additional schedule savings.

Response:

DOE recognizes that potential near-term cost and schedule savings can be realized through the use of smaller diameter tunnels for the ESF. Other factors, however, must be considered in the context of overall program requirements. These factors include: testing strategies, the potential for test-to-test interference; sealing strategies; operational safety; and the potential impacts of underground exploration on repository design and on the ability of the natural barrier to isolate waste. In order to minimize the adverse impacts of exploration and characterization activities, the ESF design and layout must be integrated with the potential repository design. If smaller diameter tunnels are used for the ESF, and later have to be reamed to a diameter sufficient for the repository operational requirements should the site be found suitable, a range of safety, technical, and cost and schedule issues may be introduced. For example, removal of ESF ground support prior to reaming may increase risk of injury. Also, enlargement of the ESF openings, and eventual procurement of larger tunnel boring machines, includes increased costs that are likely to more than offset the near-term cost savings.

Ramp and drift diameters were analyzed during the revisions to the ESF Title I designs, and they will continue to be evaluated while the requirements are refined in Title II design. The repository Advanced Conceptual Design will be developed in parallel with the ESF Title II design. Multiple alternative concepts will be evaluated in this process with interfaces being coordinated with the ESF designs.

Recommendation 3:

In light of budgetary uncertainty, the DOE should consider the development of contingency plans for fiscal year 1993 and beyond for reaching the major milestones of the site-characterization program. Such plans should include early underground access from at least one portal (e.g., the south portal) and its access ramp. Key geologic features should be crossed at various locations above and below the repository horizon. In this way, **both** *subsurface and surface-based site characterization can proceed to some extent, even in times of budgetary uncertainty.*

Response:

As discussed in the January 1992 meeting on budget considerations, the design and construction of the ESF is a major program effort that will require a multiyear commitment of significant resources. DOE has chosen to fund the ESF design activities as much as possible while still maintaining an active surface-based testing program.

At the same time, DOE is exploring different options for obtaining the earliest possible access to key underground units and features in a way that is consistent with achieving overall program goals. Several of these options and concepts, including an early exploratory pilot program for limited underground exploration, the phased development of the ESF as currently conceived, and specific suggestions from the Board were discussed at the January 1992 meeting. Within budgetary constraints, DOE will continue to evaluate these and other options in terms of program goals, and Nuclear Regulatory Commission (NRC) and environmental requirements.

Recommendation 4:

The Board encourages the use of a structured probabilistic approach that not only can serve to provide useful estimates of volcanic hazard at Yucca Mountain, but also can help discriminate between those differences in input assumptions that have a significant impact on volcanic hazard and those that do not.

Response:

DOE's volcanism studies are based on a structured probabilistic approach that is consistent with the Board's recommendation. A technical paper describing this approach is presently undergoing internal review prior to publication. This paper reviews recurrence models of volcanic events and attempts to constrain the estimate of the recurrence rate for the Yucca Mountain region using a simple Poisson model, and also by analogy to the recurrence rate of volcanic events for active volcanic fields in southern Nevada and adjacent California areas. This paper is being published as part of an effort to obtain a consensus on the elements of a probabilistic approach to volcanism studies.

The strategy for implementing a probabilistic approach to the volcanism issue for the Yucca Mountain site is described in study plan 8.3.1.8.1.1, "Probability of Magmatic Disruption of the Repository." A second report on the structural controls of volcanic activity will also be completed this fiscal year.

Recommendation 5:

The Board urges the DOE to place added emphasis on the evaluation of volcanic vulnerabilities and consequences. As with other natural hazards, the likelihood and magnitude of adverse consequences, options for their avoidance through engineering design, and not just the occurrence of natural phenomena alone, should be considered.

Response:

DOE agrees that volcanic vulnerabilities and consequences need to be evaluated; this is a part of the planned site characterization program. The likelihood and magnitude of adverse consequences and options for their avoidance will also be considered.

Initial work on the consequences of magmatic disruption of a repository was completed in the early 1980's. DOE reviewed possible volcanic scenarios for magmatic disruption of a repository (Crowe et al., 1983) and provided preliminary assessments of radiological releases associated with a disruptive event (Link et al., 1982). Revised consequence analyses were re-initiated in 1991 and are continuing this year. The level of effort for this work will increase in 1993 as the data required to resolve the issues is further refined and constrained.

The plans for assessing the effects of magmatism on a repository at the candidate Yucca Mountain site are to be detailed in study plan 8.3.1.8.1.2, "Effects of a Volcanic Eruption Penetrating the Repository." The first of the three classes of consequences to be considered are those consequences associated with small-volume basaltic eruptions penetrating the repository. The thrust of this work is to determine if the volume of waste that could be erupted on to the surface by a magmatic event can be constrained. This approach relies on data collected from analogue volcanic centers in the southwestern United States. The perspective is probabilistic. The study attempts to establish the likelihood of surface radionuclide releases according to the depth of burial of radioactive waste associated with the magmatic disruption of a repository. These values will be coupled with the calculations of the probability of a future magmatic event intersecting the potential repository and the recurrence rate of volcanic events. The second class of consequences considered is those associated with the subsurface effects of magmatic activity within the repository block, regardless of whether such activity produces a surface eruption. The emphasis of this examination will be determining whether subsurface activity could accelerate the release of waste through coupled processes to the accessible environment. The third class of consequences being evaluated is those associated with the physical processes of magmatism in the Yucca Mountain region, including melt generation, storage, ascent, and eruption. The goal of this work is to provide a mechanistic foundation for predictions of future volcanic activity. This work may be used to assess calculations of the radiological releases of radionuclides if the first class of studies is insufficient to resolve the volcanism issue.

While it appears technically feasible to mitigate the effects of future volcanism through engineering design, DOE believes such action is not warranted by the current estimates of the likelihood of magmatism impacting the waste isolation capabilities of the repository. If the studies described above indicate that the probability and consequences of magmatic disruption of the repository are significant enough to warrant consideration of avoidance by engineering design, DOE will conduct such engineering trade studies.

HYDROGEOLOGY AND GEOCHEMISTRY

The following recommendation pertains to the hydrogeology and geochemistry studies of the proposed repository site and the test programs to verify the expected behavior.

Recommendation 6:

The Board recommends that the DOE carry out sensitivity studies to determine how limitations in instrument accuracy could affect estimates of water flux and performance in the unsaturated zone. This information should be used to refine testing strategies, determine the need for new instrumentation, and provide a realistic estimate of the DOE's ability to adequately characterize the unsaturated zone.

Response:

Sensitivity analyses related to limitations in instrumentation and testing methods are an integral part of each unsaturated zone study and are a major part of the overall interpretive study of the unsaturated zone that will be described in study plan 8.3.1.2.2.9, "Site Unsaturated Zone Modelling and Synthesis." The general approach used by the stochastic modeling activity recognizes that the accuracy of a model representation depends on the adequacy and completeness of the underlying conceptual model as well as on the presence of computational and data-related error. The adequacy and completeness of the conceptual model will be established prior to construction of a final hydrogeologic model for the site. Approximate quantitative bounds of uncertainty for the site moisture-flow model will be estimated through a combination of classical statistical and geostatistical data analyses, sensitivity analysis studies, and stochastic modeling. Limitations and uncertainties associated with testing methods will be considered in this process.

ENGINEERED BARRIER SYSTEM

The following Board recommendations to DOE pertain to the design of the Engineered Barrier System (EBS) and its contribution to the overall system waste isolation performance.

Recommendation 7:

Engineered barriers must be viewed as an integral part of the repository system. Studies of the potential contribution of engineered barriers, such as multi-purpose canisters, should not be deferred until a later date. EBS development and testing should be funded continuously and at a level sufficient to evaluate its contribution to long-term predictions of repository behavior.

Response:

DOE understands the Board's concerns that continued reductions in funding in the EBS program may affect the proposed timetable for site evaluation and repository development if the site is found suitable. The need to evaluate the potential contribution of the EBS to long-term predictions of reposi-

tory performance is fully recognized. DOE also recognizes that the development of the waste package requires long-term corrosion testing of candidate materials and that there is no work currently being done in this area.

DOE is fully cognizant of the need for additional effort in waste package materials and design, and in the design and testing of other parts of the EBS. However, current budgetary constraints have curtailed much of the development effort for now. As discussed in the January 7-8, 1992, meeting with the Board, higher program priorities associated with surface-based testing in support of site suitability evaluation, and the monitored retrievable storage and transportation activities in support of waste acceptance in 1998 have prevented allocating additional funds to the EBS development effort. DOE intends to begin the Advanced Conceptual Design phase of EBS and repository design studies in October 1992. A major increase in funding for EBS design is being planned for future years to meet program milestones.

Recommendation 8:

The Board recommends that the DOE consider organizing a follow-up meeting of EBS workshop experts plus other selected participants as early as possible in 1992. The purpose of this follow-up meeting would be to review and consolidate the recommendations and comments about EBS concepts gathered at the DOE's June 1991 workshop.

Response:

DOE concurs with the Board that the EBS Concepts Workshop held in Denver, CO, in June 1991 was useful. The concepts and evaluations derived from that workshop have influenced the thinking of the personnel involved in the pre-advanced conceptual design development of the EBS. As stated in the DOE's "Extended Summary Report on Engineered Barrier System Concepts Workshop," another workshop is planned for fiscal year 1993. This workshop would concentrate on those concepts selected by DOE for the ACD in order to provide a more focused and thorough evaluation of the candidate ACD concepts.

ENVIRONMENT AND PUBLIC HEALTH

This Board recommendation pertains to the manner by which DOE will demonstrate compliance with NRC regulations with respect to system performance.

Recommendation 9:

The Board recommends that the DOE seek clarification from the NRC of the procedures by which alternative levels of subsystem performance could be authorized.

Response:

DOE recognizes the potential need for developing procedures by which alternative levels of subsystem performance may be introduced into a potential licensing strategy. Under 10 CFR Part 60.113(b), "... the Commission may approve or specify some other radionuclide release rate, designed containment period, or pre-waste emplacement ground water travel time, provided that the overall system performance objective, as it relates to anticipated processes and events, is satisfied." The burden is on DOE, based on its evaluation of the site and engineered components of the repository system, to present data and analyses that would support approval by the Commission of alternatives to the existing subsystem performance objectives. As site characterization data are obtained and analyzed, and the iterative performance assessments become more refined, DOE will be able to identify potential alternatives to the existing subsystem performance objectives if necessary. Discussions of such alternatives and the supporting evidence will be undertaken with the NRC at that time as part of the pre-licensing interactions.

RISK AND PERFORMANCE ANALYSIS

The following Board recommendation pertains to the methodology for utilizing expert opinion in conducting the performance assessment of the potential repository.

Recommendation 10:

The DOE needs to refine further its methods for assessing expert judgment, and the DOE and the NRC need to attain agreement on the potential use of experts prior to beginning the licensing process. The Board suggests that a workshop be held in 1992 to examine the use of expert judgment in the DOE's current performance assessment and in the performance assessment exercises carried out by other organizations (NRC, Electric Power Research Institute, and Golder Associates), and to propose specific recommendations for the improvement of this part of the performance assessment process in subsequent iterations.

Response:

DOE agrees that it would be useful to reach a common understanding with NRC regarding the use of experts and the role of expert judgment prior to beginning the licensing process. The results from the working group on the use of expert judgment that was convened by NRC's Advisory Committee on Nuclear Waste should also provide useful input to achieving this understanding. DOE is planning a workshop on expert judgment, as recommended by the Board, to be held in the fall 1992 timeframe.

DOE intends to preserve the flexibility to define the level of expert judgment or peer review to be applied during site characterization for specific cases when the use of subjective methods may become necessary. With respect to recent activities noted by the Board, DOE has relied on consultants who are specialists in the use of expert judgment in the various tasks where expert judgment has played a key role. These include the Exploratory Studies Facility Alternatives Study, the Test Prioritization Task, the Calico Hills Risk Benefit Analysis, and the Early Site Suitability Evaluation. In each case, expert judgment was a key component of the evaluation, although the tasks varied in the degree to which formal elicitation was used. Lessons that have been learned from these tasks are being incorporated in plans for similar activities in the future.

The Total System Performance Assessment models constructed by both Sandia National Laboratories and Golder Associates for DOE benefited from the work of staff members specializing in the elicitation of expert judgment. In addition, both performance assessment teams have demonstrated how judgments can be merged with existing data to further constrain modeling. With respect to selection of models and to determination of probability distributions of model parameters, the elicitation has substantially enhanced the comprehensiveness of performance assessments of the Yucca Mountain site.

Appendix F
Questions from the Senate Committee on Energy and Natural Resources

On March 31, 1992, Dr. Deere testified before the Senate Committee on Energy and Natural Resources. Following the hearing, the Board was asked to respond in writing to 12 follow-up questions. The answers, which are provided below, were submitted to the Committee on April 22, 1992.

1. The Board has been a strong advocate of getting underground at Yucca Mountain as quickly as possible. What is your opinion of the decisions made to date with respect to the priorities in this program? In your opinion, has the Department developed the appropriate priorities for getting the job done?

The Department of Energy (DOE) in its allocation of funds has given higher priority in the past to surface-based drilling and trenching than to developing the underground exploratory studies facility (ESF). The Board has been an advocate of going underground as quickly as possible, primarily so that data will be available to make *early judgments* about the suitability of the site. Excavating the tunnel declines (ramps) down to the potential repository level will provide greater exposure to the critical geologic features and will provide a better understanding of the Yucca Mountain block than can be achieved through surface-based drilling alone. Once underground, extensive data can be gathered on geochemistry, geohydrology, and geoengineering, which will be crucial for carrying out performance assessments for determining site suitability.

There are other benefits as well. The information gained underground would help the DOE to reevaluate the *scope* of the exploration and testing and to update *cost and schedule estimates* for completing site characterization.

The Board believes that both underground work and surface-based testing should proceed in parallel. The scope of such work and the rate at which it can be accomplished will, of necessity, be determined by the funds available and the established milestone dates.

The Board would like higher priority placed on other aspects of the program, for example, on issues relating to repository design, such as the *thermal-loading strategy* and the provision for *long-lived engineered barriers.* Although the DOE recognizes the importance of these two program elements, they have not been adequately funded. The Board believes that the DOE should refocus its efforts on these areas *now*, so that both the thermal-loading strategy and the potential contribution of long-lived engineered barriers can be included in overall system-performance studies.

2. The Technical Review Board was very involved in the decision to change plans for construction of the underground facility at Yucca Mountain. Could you explain to the Committee your perspective on the decision to change from shafts to ramps? What can be accomplished otherwise? Does this shift mean that we have wasted all of the money that went into planning for the exploratory shafts?

After evaluating the DOE's original design for the ESF, the Board recommended using ramps excavated by tunnel boring machines (TBM) instead of vertical shafts excavated by the drill-and-blast method. Also, the Board considered the number of exploratory drifts in the DOE's original plans to be insufficient to answer questions relating to site suitability and the potential presence of disqualifying features. Therefore, we recommended the excavation of additional exploratory drifts (tunnels) at the repository level and within the underlying Calico Hills unit.

Although the overall costs for ramps are greater than for shafts, the use of ramps would provide several advantages in the Board's view. Using TBMs, ramps can be excavated at rates of 50-100 feet per day, versus the 10-15 feet per day for shaft excavation. As a result, the cost of excavation per foot is several times less for ramps than for shafts. In addition, the damage to the tunnel walls using TBM technology is minimal when compared to conventional drill-and-blast methods. The ramps would be longer than the shafts resulting in a greatly enhanced exposure of rock, which would provide scientists a better opportunity to observe the faults, the rock characteristics, the ground-water conditions, and the geologic stratigraphy and structure of the Yucca Mountain block. The Board favors early underground access, which would allow these critical features to be observed and tested in a timely fashion.

Over an 18-month period, the DOE evaluated the alternative ESF ramp proposal. The conclusion was to change to a ramp alternative. The change from shafts to ramps means that some of the funds allocated to the preliminary design work for the two vertical shafts in the original site-characterization plan could have been better spent. However, in the Board's view, the potential benefits of ramp access and additional exploratory drifts (e.g., early determination of site suitability and an enhanced appreciation of the overall characteristics of the site) will far surpass the lost time and costs of the previous design.

3. A significant amount of money is spent in the waste program on so-called prelicensing activities and interaction with NRC. In your opinion, is this interaction necessary at this juncture? Why couldn't this be delayed until after the hole is dug?

The Board believes that participating in prelicensing activities and interacting with the Nuclear Regulatory Commission (NRC) are the most efficient and cost-effective ways for the DOE to seek clarification of the NRC licensing requirements for a first-of-a-kind geologic repository. Because a facility of this kind has not previously been licensed anywhere in the world, details related to regulatory requirements and their implementation may have to evolve over time. The rationale for this process is strengthened when questions arise about the intent of the NRC's requirements and about the scope of the proposed studies. The Board staff and some Board members have occasionally attended and interacted at meetings between the NRC and the DOE and believe these meetings to be helpful in determining the necessary direction and scope of the DOE site-characterization and licensing studies.

It should be understood, however, that an NRC staff position on a given question does not necessarily imply concurrence of the independent NRC repository licensing board,

which, during the licensing process, will examine all licensing materials and consider the testimony of outside experts and intervenors.

4. In your opinion, is there undue emphasis on the regulatory activities at this point, or is it the appropriate amount of emphasis?

Based on the Board's review of the technical and scientific aspects of the DOE program, the current emphasis on regulatory activities is appropriate because collected data, computations, and conclusions about site characterization and repository development must eventually be presented to the NRC during formal licensing proceedings. This material must be defensible against the emerging EPA standard, the NRC regulations, and any technical and procedural objections raised by outside experts and intervenors. These regulatory activities are especially important since no organization or entity, including the DOE, has ever before applied for a license to construct a geologic repository for high-level radioactive waste.

5. The Department's current schedules envision a decision on the suitability of the Yucca Mountain site and submission of a license application to NRC in 2001. Does this mean that we will not know until 2001 even if the site is unsuitable? How can this program be structured better to ensure that disqualifying factors are discovered as early as possible?

Given the DOE's current schedule for completing the ESF, the determination of site suitability may not come much before 2001, the DOE's target date for license application. The Board believes that one of the DOE's primary objectives should be to determine as soon as possible, through early underground excavation and testing, if obvious disqualifying features are present at the site. Consequently, the Board has advocated that underground excavation should proceed in parallel with surface-based testing. Surface-based testing alone will not provide all the important information on fault zones in the geologic block and on the hydrogeologic characteristics of the site.

The DOE's schedule for site characterization and licensing assumes that the probability of finding any disqualifying conditions at the Yucca Mountain site is very low. The Board is somewhat less confident of such a finding and believes that substantial underground excavation and testing will be required to make this determination. The Board is concerned that delays in the initiation of underground excavation and testing could lead to delays in the identification of potentially disqualifying conditions. The Board therefore believes that a higher priority should be placed on getting underground as soon as possible to explore the site and perform important testing.

6. In your opinion, what could be done to speed up the process of completing site characterization at Yucca Mountain and making an ultimate decision on the suitability of the site?

From a conceptual standpoint, the process of characterizing any potential repository site consists of two interrelated elements, both of which should proceed concurrently. The first of these elements involves the search for obvious disqualifying features that can be readily identified through the early exploration and testing described previously. If no such obvious disqualifying features are found, however, there may be other characteristics of a potential site that may have a bearing on its suitability for repository development. The second element is the systematic gathering of data related to such characteristics. These data

will be required to make the ultimate decision with respect to a site's suitability or unsuitability, and they also will be needed for proceeding with a license application.

The combined process referred to above can proceed at Yucca Mountain with the maximum speed if two conditions are fulfilled. The first is the availability *to the program* of sufficient and predictable short- and long-term funding, and the second is ongoing prioritization of studies *by the program managers* to assure that, whenever possible, those studies that have the greatest impact on the early determination of site suitability are conducted first.

7. Current regulations will require a judgment on the suitability of the site to isolate radionuclides for 10,000 years. How will it be possible to prove the performance of Yucca Mountain for 10,000 years? Is it possible to prove anything for that long?

The regulatory framework has evolved during the past two decades through the efforts of the EPA and the NRC and defines the requirements for repository licensing. The assessment of long-term repository performance will be based on the analysis of scientific data and informed judgment.

Although predicting the performance of a repository at Yucca Mountain over the next 10,000 years will be a significant challenge, the Board is optimistic that adequate and reasonable technical and scientific judgments about the geologic barriers to radionuclide migration can be made to support conclusions on repository performance for 10,000 years within the current regulatory framework. Such scientific judgments could be based on (1) the recent geologic history of the Yucca Mountain region, (2) a review of the 13-million-year history of the repository block, and (3) comparisons of the Yucca Mountain site with natural geologic analogues elsewhere in the world where radionuclides have been isolated for periods far greater than 10,000 years.

Because 100 percent assurance is not possible on even short-term predictions of natural geologic processes, the Board has repeatedly emphasized that *added* confidence in long-term waste isolation can be gained by incorporating robust engineered barriers. Engineered barriers are those components of the repository system that are subject to human control (i.e., the thermal load of the repository, the waste form, emplacement mode, containers and canisters, and backfill). The Board believes, for example, that a long-lived container could be manufactured with materials whose long-term performance might be more confidently predicted over thousands of years than can the performance of rock formations and hydrogeologic processes. The Board believes it should be possible to reduce overall uncertainty about a repository's long-term performance by relying on natural geologic barriers *in combination with* a robust engineered barrier system designed to isolate radioactive waste for thousands of years.

8. Have we designed regulatory requirements for storage and disposal of nuclear waste that are so stringent that we are destined to fail? Have we designed requirements that cannot be proved? Is the existing regulatory framework too stringent? Would it be desirable to reevaluate what standards need to be met to assure protection of the public health and safety?

At this point, the Board is not aware of any technical problems such that the proposed repository or other elements of the storage, transport, and disposal system are "destined to fail" in obtaining regulatory approval. However, the regulatory framework is complex, and

the data and analyses needed to ensure compliance with regulatory requirements have not yet been clearly established. Very substantial uncertainties remain to be resolved through further data gathering during the site-characterization process. The Board believes that ambiguities and potential inconsistencies in the regulatory framework need technical clarification. The appropriate level of regulatory stringency is a matter to be determined by the EPA and the NRC.

As further information and analyses are obtained, it could become clear that some proposed regulatory requirements will not be met at the unsaturated site at Yucca Mountain with the current repository design. For example, potential gaseous emissions of carbon-14 might violate the proposed EPA limit in 40 CFR 191. The consequences of this violation could be an extremely small but finite increase (a fraction of a microrem per capita per year) in radiation exposure from the atmosphere over that from carbon-14 levels naturally present from cosmic rays. Design changes in the waste-management system could allow the proposed regulatory requirement to be met, but perhaps at increased cost.

The siting of nuclear waste storage and disposal facilities remains a highly contentious issue among the federal government, state governments, and local interests. Even if compliance with regulatory requirements is achieved, determined public opposition to nuclear waste facilities is likely to persist. In such a climate, it would be difficult to make safety standards less stringent unless a large majority of the public believes that such a change does not compromise their health and safety or that of future generations.

9. Given the existing regulatory framework, do you believe we can resolve sufficiently the uncertainties about the suitability of any site? Does any particular type of site, or type of medium, give us better chances for success in resolving uncertainties, or does each bring with it some uncertainties?

There will always be uncertainties about the long-term conditions and behavior of various rock types and formations, and different sites have their own advantages and disadvantages. This is why site characterization is so crucial to determining site suitability and for gathering data for repository design and licensing. Logically, sites with a more complex geology will likely require more extensive characterization before uncertainties about site suitability can be brought to acceptably low levels.

In addition to these initial uncertainties about the geology of a given site, and even after site characterization has been completed, there will be residual uncertainties that may never be resolved with absolute certainty. For example, we will never be 100 percent certain about the nature of future climatic changes, when they might take place, and how such climatic changes could affect the movement of water through a given geologic area. As with other large-scale construction projects (dams, subway tunnels, etc.), the mere existence of uncertainties does not necessarily mean that a site will be found unsuitable.

Existing and emerging regulatory standards and criteria will have to be met before any repository can be licensed, no matter where or in what medium it is located. To determine if a given site is suitable and to predict a potential repository's long-term performance, extensive site characterization will have to be conducted. The Board believes that with thorough site characterization, including surface-based *and* underground excavation and testing, questions about a site's suitability can be sufficiently resolved.

10. You talk in your statement about the need for greater emphasis on engineered barriers. Could you explain this a little bit more? In your opinion, why has the Department not put a greater emphasis on this? In your opinion, will greater emphasis on engineered barriers improve the chances for successful licensing of a repository at Yucca Mountain?

The Board has repeatedly expressed its concern about the continuing reductions in allocations to the DOE's research program on engineered barriers. Board members believe that engineered barriers have a potentially very important role to play in providing redundancy within the entire waste management system in general, and within the repository system in particular. And a robust, long-lived container, which would be a major component in an engineered barrier system, could actually reduce the uncertainty related to the containment of radionuclides and thus could facilitate the licensing of a repository.

In the past, the DOE has listed a number of reasons for its diminishing emphasis on engineered barriers, including (1) its understanding of the NRC regulations, which were originally interpreted as not allowing credit for waste package life beyond 1,000 years, (2) budgetary constraints, and (3) the priority given to other aspects of the program (e.g., site characterization because of the Secretary's dual goals of receipt of spent fuel by 1998 and disposal by 2010).

The Board believes, however, that a redundant, multibarrier, defense-in-depth approach will be necessary to establish acceptably low levels of uncertainty for successful licensing of, and full public confidence in, a geologic repository. Investigating the potential of engineered barriers should proceed as part of the total design of the repository and waste-management system. Postponement of such investigations could mean that the technology and engineering design will not be available when needed.

11. At the hearing, you made the recommendation that a policy decision be made to delay the final closure of the repository and to provide for a 100-year period for monitoring its performance prior to any decision on closure. Please explain what the benefits of such an approach would be. How would such a policy shift change the regulatory framework and requirements for determining the suitability of the Yucca Mountain site? How would such a policy shift change the costs of this program?

The Board has not taken a position on the Canadian plan, which I referenced at the Committee hearing. This plan would allow monitoring of an open repository for 100 years leaving decisions relating to spent fuel retrieval or repository closure until the end of that period. The DOE might investigate the potential advantages of such an approach, the most obvious of which is its potential for a technically more sound and better-informed decision about closure. Future generations will have the experience gained from 100 years of monitoring as well as new technologies to factor into the decision-making process.

There could be other advantages. The requirement for backfilling as the waste is emplaced could be eliminated, resulting in cost savings. Ventilating the repository for 100 years or more could allow scientists to achieve the most desirable temperature range in the repository. Design flexibility and savings in the engineering costs associated with final closure could be additional potential benefits. It also is conceivable that at some time in the future it will become economical to reprocess spent fuel for the recovery of uranium and other valuable isotopes.

Although delaying final closure would give a repository additional flexibility, such a facility would still fall within the existing regulatory framework and would be required to meet the same site-suitability and licensing criteria.

12. At the hearing, the suggestion was made that if it costs $6 billion to study the suitability of the Yucca Mountain site and only $2 billion to build a repository at the site, then why not go ahead and build a test facility and see if it works. Should we be looking more seriously at an approach to nuclear waste disposal that focuses more on resolving the uncertainties as we go along rather than requiring that all uncertainties be resolved up front? Would such an approach be more rational given the first-of-a-kind nature of geologic disposal and given the difficulty in predicting the performance of anything thousands of years into the future?

The DOE's current repository development program calls for a comprehensive, $6.3-billion characterization of the Yucca Mountain site, including extensive underground exploration and testing. Based on information collected during site characterization, the DOE would then attempt to predict the repository's performance over the next 10,000 years (long-term performance predictions are required for licensing). The predictions would form the basis both for determining the site's suitability and for a license application to the NRC. If the site's predicted performance meets existing regulatory requirements, the NRC would then issue a license for repository construction and waste emplacement.

As an alternative approach, it has been suggested that waste could be more quickly and more cheaply emplaced in an *unlicensed* "demonstration facility," and its performance monitored. (Under current regulations, without performance predictions the facility could not be licensed.) Although this approach at first appears attractive, it has numerous and significant disadvantages. First, without the extensive site-characterization data normally required to design such a disposal facility, chances increase that the integrity of the disposal site could be compromised by poor design decisions. Second, the same lack of data would preclude at the outset any kind of long-term predictions on the behavior of the "demonstration facility." As a result, the only way to verify the performance of the facility would be to monitor its performance for thousands of years, thus leaving the responsibility for safe waste management in the hands of future generations. If, at some point, the facility's performance were found to be unacceptable (due to site limitations or an inappropriate repository design, for example) the facility would have to be modified, or all of the waste would have to be removed and a new site found. Both solutions could be costly and require extensive rehandling of the waste. Finally, and even more important, it is not at all clear that the public would accept the development of an unlicensed "demonstration facility" for the disposal of commercial spent fuel and high-level waste.

In summary, developing an unlicensed "demonstration facility" for the disposal of spent fuel — were it to be accepted by the public — would be a risky undertaking, especially for such a first-of-a-kind facility that is supposed to safely isolate radioactive waste for 10,000 years.