# Appendix A
# Panel Organization

## 1. Panel on Structural Geology & Geoengineering

| | | | |
|---|---|---|---|
| Chair: | Dr. Clarence R. Allen | Staff: | Mr. R.K. McFarland |
| Members: | Dr. Edward J. Cording | | Dr. Leon Reiter |
| | Dr. D. Warner North | | |
| | Dr. Dennis L. Price | | |

## 2. Panel on Hydrogeology & Geochemistry

| | | | |
|---|---|---|---|
| Co-Chair: | Dr. Patrick A. Domenico | Staff: | Dr. Robert W. Luce |
| Co-Chair: | Dr. Donald Langmuir | | |
| Members: | Dr. Edward J. Cording | | |
| | Dr. John J. McKetta, Jr. | | |

## 3. Panel on the Engineered Barrier System

| | | | |
|---|---|---|---|
| Chair: | Dr. Ellis D. Verink, Jr. | Staff: | Dr. Carlos A.W. Di Bella |
| Members: | Dr. Donald Langmuir | | |
| | Dr. John J. McKetta, Jr. | | |
| | Dr. Dennis L. Price | | |

## 4. Panel on Transportation & Systems

| | | | |
|---|---|---|---|
| Chair: | Dr. Dennis L. Price | Staff: | Dr. Sherwood C. Chu |
| Members: | Dr. Garry D. Brewer | | |
| | Dr. D. Warner North | | |
| | Dr. Ellis D. Verink, Jr. | | |

## 5. Panel on the Environment & Public Health

| | | | |
|---|---|---|---|
| Chair: | Dr. Garry D. Brewer | Staff: | Dr. Sidney J.S. Parry |
| Members: | Dr. John E. Cantlon | | |
| | Dr. D. Warner North | | |
| | Dr. John J. McKetta, Jr. | | |

## 6. Panel on Risk & Performance Analysis

| | | | |
|---|---|---|---|
| Chair: | Dr. D. Warner North | Staff: | Dr. Leon Reiter |
| Members: | Dr. Garry D. Brewer | | |
| | Dr. Patrick A. Domenico | | |
| | Dr. Dennis L. Price | | |
| | Dr. Ellis D. Verink, Jr. | | |

## 7. Panel on Quality Assurance

| | | | |
|---|---|---|---|
| Chair: | Dr. John E. Cantlon | Staff: | Dr. Sherwood C. Chu |
| Members: | Dr. Clarence R. Allen | | |
| | Dr. Donald Langmuir | | |

# Appendix B
# Nuclear Waste Technical Review Board Members: Curricula Vitae

## Dr. John E. Cantlon

### Chair

President George Bush appointed Dr. Cantlon to chair the Nuclear Waste Technical Review Board on May 27, 1992. His term of office will expire April 19, 1996. President Ronald Reagan first appointed Dr. Cantlon to the 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.

During the past 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. Clarence R. Allen

President George Bush appointed Dr. Allen to a second term on the Nuclear Waste Technical Review Board for a four-year term expiring on April 19, 1996. President Ronald Reagan first appointed Dr. Allen to the 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. Garry D. Brewer

President George Bush appointed Dr. Brewer to serve on the Nuclear Waste Technical Review Board for a four-year term that will expire April 19, 1996.

Dr. Brewer is professor of resource policy and management and dean of the School of Natural Resources and Environment at the University of Michigan. He has more than 18 years' teaching experience and is author, coauthor, or editor of nine books and more than 175 professional publications. He edited *Policy Sciences* (1974-76, 1990-91) and *Simulation & Games* (1977-79) and served or serves on the editorial boards of seven other professional journals, including the *Journal of Conflict Resolution* and *Public Administration Review*.

From 1970 to 1974, Dr. Brewer was on the senior staff of the RAND Corporation in Santa Monica, California, dividing his efforts between strategic studies and evaluations of large-scale social service systems for people who are disabled. In 1974, Dr. Brewer joined the founding faculty of Yale's School of Organization & Management. He then took a year's leave to become a fellow at the Center for Advanced Study in the Behavioral Sciences, Palo Alto, California, returning to the Yale faculty in 1975. From 1975 until 1991, Dr. Brewer was a member of the Yale faculty, holding the Frederick K. Weyerhaeuser Chair (1984-90) and the Edwin W. Davis Chair (1990-91). He served in leadership roles in Yale's Center for International and Area Studies and the Institution for Social and Policy Studies, the latter of which he directed in 1991.

Dr. Brewer's professional activities include membership on the boards or executive committees of the Woods Hole Oceanographic Institution (1987-92), the Organization for Tropical Studies (1989-93), and the Yosemite National Institutes (1990-95). He also serves the National Academy of Sciences as a member of the Board on Environmental Studies and Toxicology, the Polar Research Board, the Committee on the Outer Continental Shelf, and the Committee on Environmental Research. Since 1981, he has served on the faculty of the International Executive Forum of the Western Behavioral Sciences Institute in La Jolla, California, and taught courses on environmental management at INSEAD, the European Institute of Business Administration in Fontainebleau, France. He continues to consult with the Rockefeller Brothers Fund for the International Management Center in Budapest, Hungary.

Professional awards include Yale School of Forestry & Environmental Studies Distinguished Teacher of the Year (1988 and 1990); the American Fisheries Society's silver medal (1988); election to the Connecticut Academy of Arts and Sciences (1990); life membership in the Oceanographic Society (1990); the *Fusion de Dos Culturas* silver medal from the government of Mexico (1991); and the Karl Bosworth Award from the American Society for Public Administration (1991).

Dr. Brewer earned an A.B. in mathematical economics from the University of California, Berkeley (1963) and an M.S. in public administration (development) at San Diego State University (1966). He earned an M.S. in public administration (1966), an M.A. (1968) and Ph.D. (with distinction in 1970) in political science from Yale University. He was a Kent Fellow from 1966 to 1970, after which he was invited to join the fellowship of the Society for Values in Higher Education.

Dr. Brewer resides in Ann Arbor, Michigan.

## Dr. Edward J. Cording

On June 15, 1992, President George Bush appointed Dr. Cording to serve on the Nuclear Waste Technical Review Board for a four-year term that will expire April 19, 1996.

Dr. Cording is professor of civil engineering at the University of Illinois at Urbana-Champaign. He has more than 25 years' teaching experience and is author, coauthor, or editor of more than 60 professional publications. Dr. Cording was the recipient of the 1976 American Society for Testing and Materials Hogentogler Award and the American Society of Civil Engineers Thomas A. Middlebrooks Award for 1985. He was elected to the National Academy of Engineering in 1988 and is a member of Chi Epsilon, the civil engineering honor society.

Dr. Cording brings to the Board special expertise in tunneling and tunnel supports and linings, as well as his knowledge of soil movement, ground stability, large chamber design. He is particularly interested in tunnel behavior and movement in various soil and rock conditions.

Dr. Cording is a member of the American Society of Civil Engineers and a Fellow of the Geological Society of America. He served as President of the Commission on Teaching of Rock Mechanics (International Society for Rock Mechanics) from 1974 to 1981. He is also a member of the Association of Engineering Geologists, the International Association of Engineering Geologists, and the International Society for Soil Mechanics and Foundation Engineering. He served the U.S. National Committee on Tunneling Technology as chairperson of the Commission on Education and Training (1977-1980), vice-chairperson of the Committee (1980-1981), and chairperson (1981-1982).

As a consultant, Dr. Cording has provided geotechnical engineering and applied rock and soil mechanics advice to governments and organizations around the world. He has been a part of the Washington, D.C. Metro system, the Baltimore Subway, New York's Holland Tunnel, and numerous other projects in the United States. Abroad he has worked with groups in Argentina, Bolivia, Colombia, Rhodesia, South Africa, Zaire, Nepal and Taiwan.

In 1960, Dr. Cording earned a B.S. in geology from Wheaton College in Illinois, where he was elected to the Wheaton College Scholastic Honor Society. He earned his M.S. (1963) and his Ph.D. (1967) in civil engineering from the University of Illinois. From 1960 until 1967, he also served variously as a research assistant at the University of Illinois, as a soils engineer in Chicago and Seattle, as a mining engineer at the Nevada Test Site, and as a captain (soils engineer) in the U.S. Army Corps of Engineers. In 1967, he began his distinguished teaching career as a professor of civil engineering at the University of Illinois, Urbana-Champaign.

Dr. Cording resides in Urbana, Illinois.

# Dr. Patrick A. Domenico

President George 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 ten 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 consulted 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 of 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 George Bush appointed Dr. Langmuir to a four-year term on the Nuclear Waste Technical Review Board on June 23, 1992. President Ronald Reagan appointed Dr. Langmuir to his first term on January 18, 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.

During the last ten years, Dr. Langmuir has served on or chaired almost a dozen expert panels assessing the various research programs of the Department of Energy, Nuclear Regulatory Commission, Environmental Protection Agency, and Lawrence Berkeley Laboratory. He was state president of the 8,000-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.

During the last 28 years, Dr. Langmuir has published more than 140 professional papers and articles and been awarded 23 grants and contracts supporting the research of more than 30 students pursuing their masters or doctorate degrees. 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 George Bush appointed Dr. McKetta to serve a four-year term on the Nuclear Waste Technical Review Board on February 18, 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 articles and books.

Dr. McKetta resides in Austin, Texas.

## Dr. D. Warner North

President Ronald 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 George Bush reappointed Dr. North to a four-year 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., Mountain View, 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 (DOE), the Environmental Protection Agency (EPA), the National Science Foundation, and the government of Mexico. Prior to his employment with Decision Focus, he spent ten 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 Risk Assessment of Hazardous Air Pollutants.

Dr. North has served on committees of the Science Advisory Board (SAB) of the EPA 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 chaired 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 reviewed the carcinogen risk assessment guidelines, chaired the subcommittee that reviewed EPA's risk assessment research, and served as 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 Ronald Reagan appointed Dr. Price to serve on the Nuclear Waste Technical Review Board on January 18, 1989. Although his term expired April 19, 1990, President George 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 ten 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 Ronald Reagan appointed Dr. Verink to serve on the Nuclear Waste Technical Review Board from January 18, 1989, to April 19, 1990. On October 30, 1990, President George Bush appointed Dr. Verink to a second, four-year 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 has chaired or served as 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 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 1992–1993

**January 7–8, 1992**

**Full Board 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 9–10, 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**

**Full Board 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
Transcript available

**June 10–18, 1992**

**Board International Trip**
*Finland, Switzerland*

**July 6, 1992**

**Board Business Meeting (afternoon session)**
*Denver, Colorado*
Topic: Board activities
Minutes available

**July 7–8, 1992**

**Full Board Meeting**
*Denver, Colorado*
Topic: DOE update on site suitability; update on the role of the M&O contractor
Transcript available

**July 9–10, 1992**

**Board Business Meeting**
*Keystone, Colorado*
Topic: Board activities
Minutes available

**August 1992**

**No meetings scheduled**

**September 14–16, 1992**

**Meeting**
**Panel on Structural Geology & Geoengineering**
**Field Trip to Crater Flat/Lathrop Wells (areas of recent geologic investigations)**
*Las Vegas, Nevada*
Topic: Volcanism; update on characterization, probability, and volcanic effects studies
Transcript available

**September 16-21, 1992**

**Trip to Japan**
**Panel on the Engineered Barrier System**
Topic: Met with experts in Japan's engineered barrier research program

**October 12–13, 1992**

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

**October 14–16, 1992**

**Full Board Meeting**
**Tour of Yucca Mountain**
*Las Vegas, Nevada*
Topic: Source term, YMPO budget
Transcript available

**November 4–5, 1992**

**Workshop**
**Panel on Structural Geology & Geoengineering**
*Las Vegas, Nevada*
Topic: ESF and repository design

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|---|---|
| **December 1992** | **No meetings scheduled** |
| **January 5, 1993** | **Board Business Meeting**<br>*Arlington, Virginia*<br>Topic: Board activities |
| **January 6-7, 1993** | **Full Board Meeting**<br>*Arlington, Virginia*<br>Topic: M&O systems update; ESF and repository design follow-up |
| **January 8, 1993** | **Board Business Meeting**<br>*Arlington, Virginia*<br>Topic: Board activities |
| **February 1993** | **No meetings scheduled** |
| **March 1993** | **No meetings scheduled** |
| **April 20–23, 1993** | **Full Board Meeting**<br>*Reno, Nevada*<br>Topic: To be determined |
| **May 1993** | **No meetings scheduled** |
| **June 1–12, 1993** | **Board International Trip**<br>*United Kingdom, France, Belgium (tentative)* |
| **July 12–15, 1993** | **Full Board Meeting**<br>*Denver, Colorado*<br>Topic: To be determined |
| **August 1993** | **No meetings scheduled** |
| **September 1993** | **No meetings scheduled** |

| | |
|---|---|
| **October 19–22, 1993** | **Full Board Meeting**<br>*Las Vegas, Nevada*<br>Topic: To be determined |
| **November 1993** | **No meetings scheduled** |
| **December 1993** | **No meetings scheduled** |

# Appendix D
# List of Presenters

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

**B&W Fuel Company**
101 Convention Center Drive
Las Vegas, NV 89109
(702) 794-1800

Hugh A. Benton
David Stahl

**Duke Engineering & Services, Inc.**
526 South Church Street
P.O. Box 1004
Charlotte, NC 28201-1004
(704) 373-2473

Alden M. Segrest

**Duke Engineering & Services, Inc.**
101 Convention Center Drive
Las Vegas, NV 89109
(702) 794-1800

Robert Sandifer

**INTERA Inc.**
101 Convention Center Drive
Las Vegas, NV 89109
(702) 794-1800

Suresh Pahwa
Abraham E. Van Luik

**Nevada Agency for Nuclear Projects**
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# Appendix E
# Department of Energy Responses to the Recommendations Made in the Board's *Fifth Report* (June 1992)

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 September 30, 1992, a summary of initial responses to recommendations the Board made in its fifth report. The Board has included those responses along with the transmittal letter in this report. Inclusion of these responses does not imply Board concurrence.

Department of Energy
Washington, DC 20585

September 30, 1992

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Dr. John E. Cantlon
Chairman, Nuclear Waste Technical
Review Board
1100 Wilson Boulevard
Arlington, Virginia 22209

Dear Dr. Cantlon:

This letter transmits the Department of Energy's responses to the Nuclear Waste Technical Review Board's recommendations made in its Fifth Report to the U.S. Congress and the U.S. Secretary of Energy that was issued on June 3, 1992. Our responses to the Board's 15 recommendations may be found in the enclosure.

I am pleased to note that the program has continued to make significant progress since your previous report. As noted during our recent meetings, we are presently conducting expanded site evaluation work including the dry drilling of deep test holes with the LM-300 drill rig. During the coming fiscal year, we expect to start the site preparation work for the construction of the Exploratory Studies Facility with the goal of beginning first ramp construction in October 1993.

It is my hope that with the synthesis of data obtained during site characterization we can begin to resolve some of the basic site suitability questions surrounding the Yucca Mountain site. The resolution of these issues is paramount to an efficient and cost-effective program and the successful completion of the mission of the Office of Civilian Radioactive Waste Management.

I appreciate the Board's constructive review of our work and recommendations concerning the critical technical issues facing the program. I believe that the Board, as an independent body of renowned scientists and engineers, can help assure the soundness and quality of the program. I would like to thank you and the Board for your effort, and I look forward to continuing our mutually beneficial interactions 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
*Fifth Report to the U.S. Congress and the U.S. Secretary of Energy*
**June 1992**

## 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 five reports to date. The fifth report, issued on June 3, 1992, includes 15 recommendations in 5 broad areas: (1) the systems implications of thermal-loading; (2) geoengineering; (3) tectonic features and processes; (4) the engineered barrier system; and (5) transportation and systems.

These recommendations and DOE's responses are presented in this report. Each recommendation is quoted verbatim from the Board's report of June 3, 1992, and is followed by the response.

## SYSTEMS IMPLICATIONS OF THERMAL-LOADING

The following recommendations concern DOE's selection of a thermal-loading strategy for the potential repository at Yucca Mountain and the implications of such strategy for the other elements of the waste management system.

### Recommendation 1:

*The Board recommends that the DOE thoroughly investigate alternative thermal-loading strategies that are not overly constrained by a desire to rapidly dispose of spent fuel. This investigation should involve a systematic analysis of the technical advantages and disadvantages associated with the different thermal-loading strategies. An assessment of each strategy's implications for other elements of the waste management system also should be undertaken.*

#### Response:

Although DOE has not selected a final thermal-loading strategy for the potential repository at the candidate Yucca Mountain site, it has a reference strategy outlined in the Site Characterization Plan. DOE is currently investigating a range of alternatives including both "cold" (below the boiling point of water) and long-duration "hot" (above the boiling point of water) strategies. A team led by the Management and Operating contractor (M&O), and including principal investigators from Sandia National Laboratories (SNL) and Lawrence Livermore National Laboratory, is conducting a study to ensure that the impacts of each strategy on all components of the system, from the acceptance of waste at the reactor sites to the emplacement and subsequent monitoring in a repository, are thoroughly analyzed.

The study will also determine for each thermal-loading alternative the effects on the utilities, on the design and operation of the Monitored Retrievable Storage (MRS) facility, and on the transportation system. For example, impacts being assessed include to what extent spent fuel selection at the reactor sites would be required both with and without an MRS, and the duration of aboveground storage required for each potential thermal-loading strategy. The results of the study will be reviewed by scientists and engineers who are knowledgeable of, and responsible for, the design of the engineered barrier system and the repository.

The ability to efficiently dispose of spent fuel is but one of several major considerations in the analysis of any of the strategies. The major considerations in the selection of a thermal strategy include:

1. Duration of time before aqueous corrosion of the waste packages could allow a potential release of radionuclides.

2. Avoidance of additional uncertainties in the performance assessment of the engineered barrier system and hence in the licensing process.

3. System implications of cooling spent nuclear fuel for long periods before disposal in a repository.

## Recommendation 2:

*In assessing the different thermal-loading strategies, it is critical that special attention be paid to evaluating the uncertainties and, in particular, the critical hypotheses associated with each strategy. The Board strongly encourages the DOE to review its research plans to ensure that this evaluation be carried out through a balanced combination of modeling, field-mapping, laboratory testing, long-term, large-scale underground testing, and, if appropriate, the study of natural analogues. This information could then allow the timely selection of a prudent thermal-loading strategy.*

### Response:

DOE has reviewed in the past and will continue to review its research plans to ensure that a defensible licensing basis can be achieved for the selected thermal-loading. The site characterization program will be modified as appropriate to support maturation of design and performance assessment activities related to the development of thermal-loading strategies. Areas of site characterization that will address the impact of thermal-loading on various elements of the repository system include geomechanics, geohydrology, geochemistry, and mineralogy. Evaluations of the impact of thermal-loading on the waste forms, the engineered barrier system, and the natural barrier system are also planned.

The strategy is to develop models and perform laboratory studies and long-term, full-scale underground tests such that these activities will provide data over a range of thermal conditions, leading to a decision on the general range of repository thermal loading for more detailed evaluation. Underground testing plans will be revised where necessary to primarily address the selected thermal-loading range. Data necessary to evaluate system response at different thermal loadings within the selected range will be monitored and evaluated as the studies and tests progress. Final selection of the specific repository thermal loading will involve iteration of the site characterization program with design and performance assessment activities, and long-term, full-scale underground tests.

## Recommendation 3:

*Since thermal loads lower than those proposed by the DOE's reference repository design could require the use of expansion areas adjacent to the proposed 1,520-acre repository site, any exploratory work in these expansion areas should be conducted with deliberation to avoid disqualifying the areas for potential use later on.*

### Response:

Strictly speaking, the use of lower thermal loads would not require the use of expansion areas, but instead may result in the emplacement of less waste in the potential repository should the site be found suitable. In any case, DOE has adopted a conservative approach to all site characterization activities that occur inside the controlled area. This area includes the conceptual repository perimeter drift surrounded by a 5 kilometer boundary. In all likelihood, potential expansion areas would be within the current definition of this boundary. This conservative approach requires that evaluations be performed prior to initiation of exploratory work. These evaluations result in controls that are designed to limit potential impacts to the site.

The activities of concern include drilling of surface boreholes, excavation of trenches, excavation of the Exploratory Studies Facility (ESF), and possible excavation of other study facilities to support the test program. The DOE processes for authorizing site characterization activities consider the impacts of the activity on the physical, mechanical, chemical, and hydrologic characteristics of the geologic entity that act individually or collectively to inhibit, minimize, or preclude radionuclide transport. Appropriate controls are specified to ensure that the site characterization activities are accomplished in a manner that limits the impacts to the site to acceptable levels.

## Recommendation 4:

*Care should be taken in making critical decisions, especially irreversible decisions, that could have negative implications for other components of the waste management system. This is particularly important in light of the fact that important system-wide trade-off studies have not been completed.*

### Response:

DOE agrees that decisions, especially those of a critical or irreversible nature, should be taken only after careful consideration of all known and potential consequences for all components of the waste management system. As the designs of the individual elements of the waste management system mature, system design variables will be fixed. These design decisions will be based on the information available at that time, and supported by the results of the system studies.

DOE is conducting systemwide trade-off studies, as the Board has recommended, to provide a defensible, technical basis to support critical decisions. OCRWM system studies are structured to provide DOE with useful information for various possible system level decisions, addressing the resultant impacts on each system element. Evidence of this approach can be seen in the recent studies on the alternate cask and canister concepts and the system implications of thermal-loading.

Furthermore, DOE maintains close contact with the utility industry to stay abreast of their ongoing efforts. DOE plans to coordinate its efforts with those of the utility industry in areas such as the potential use of universal canisters, and the utilities' concerns and preferences regarding waste acceptance issues.

## GEOENGINEERING

These recommendations concern the Site Characterization Plan, ongoing ESF design, and conceptual repository design efforts.

## Recommendation 5:

*The Board recommends that the DOE avoid making design decisions for the exploratory studies facility that could preclude repository configurations shown by the proposed system studies to provide superior performance. In particular, as previously recommended by the Board, opening sizes should be as small as functionally required. The potential for using conventional rail transport should not be eliminated through the construction of tunnels with excessive grades, unless repository operational studies show the proposed design to be appropriate.*

### Response:

DOE agrees that the ESF configuration should not preclude otherwise advantageous repository design concepts should the site be found suitable. The evaluation of the impact of ESF design and construction activities on potential repository concepts is an ongoing process. The ESF construction work to be performed during the next year will be limited to no more than 200 feet of underground excavation at the North Portal. The locations selected for the North and South Portals are felt to be applicable to a wide range of potential ESF/repository configurations and, as such, will not present an unreasonable constraint. In any event, the location of the surface facilities is influenced more by topography, and such concerns as the extent of the flood plain, than by the exact arrangement of the underground workings.

Title II ESF design will proceed during the next 2 years based on the current Title I concept. However, close coordination will be maintained between the ESF and potential repository design. If changes in the ESF configuration that do not impact the site evaluation process are indicated by the evaluation of repository design concepts, they will be made during the normal course of ESF Title II design.

DOE is currently evaluating the ESF tunnel diameter. Evaluations to date indicate that the potential gains of smaller ramp sizes may not be justified in light of the drawbacks to the potential repository should the site be found suitable. While some savings in capital can be realized with smaller machines, advance rates are very similar for different sized machines because the larger machines are proportionally powered. Also, muck haulage by conveyor is fairly insensitive to Tunnel Boring Machine (TBM) size because even a relatively small conveyor system can easily transport the muck from the largest TBM. Overall, there may not be a compelling advantage to reducing the current ramp sizes. Procurement actions for TBM's consistent with the final DOE decision will commence during FY 1993.

The concept of using rail haulage was considered in the ESF Title I design effort (Design Analysis ST-MN-010, Rev. 3, Title I Design Summary Report). Two of the seven haulage options considered were rail haulage, with a third involving a monorail haulage system. The rail systems were discarded because of the grades involved in the ESF configuration. Even if the North ramp were to be reoriented to reduce its slope to rail grade, the ESF/repository block itself is inclined such (4+% slope in the main drift) that rail haulage would be difficult at best. Other features of underground rail haulage, such as long sweeping curves (resulting in large intersections with long tapering pillars), and operational inflexibility, make this concept less desirable than others.

Early in repository ACD a study will be undertaken to reassess the current potential repository horizon. A possible outcome of this activity could be the lessening of the gradient of the proposed repository block. If this were to occur, the viability of a rail haulage system would be enhanced, and subsequent repository transportation studies would then be conducted with these new data.

## Recommendation 6:

*The DOE should develop contingency plans for reduced funding levels that consider incremental approaches to excavating the Yucca Mountain block, possibly using one or two smaller tunnel boring machines, thus allowing early access across key underground geologic features.*

### Response:

The DOE is evaluating contingency plans and options to assure maximum efficiencies and cost effectiveness of site characterization activities that will yield the required data to make a site suitability decision with respect to disqualifiers at the earliest possible time. The DOE currently has a contingency plan similar to the one proposed by the Board. This plan would involve two tunnel boring machines, one with a diameter of 25 feet and the other of 18 feet. Underground excavation operations would start at the North Portal with the larger machine and proceed to the turnout for the North Calico Hills ramp. From this point, both machines would excavate the length of their respective levels. The two south ramps would be excavated from the bottom upward. A variant of this plan could include delaying the start of the Calico Hills ramp until the larger Topopah Spring (TS) ramp has been completed, and the TS Main Drift is excavated past the Core Test Area. This would allow excavation of the Core Test Area as early as possible.

The DOE has also developed a contingency plan to start the ESF North Ramp excavation as soon as possible. This plan would accomplish only that ESF design necessary to initiate the North Ramp excavation and utilize a leased or purchase a used TBM. Provided adequate funding is made available, the TBM can start operations by October 1993.

## Recommendation 7:

*The DOE should review and document the technology, practice, and experience developed by the Defense Nuclear Agency during the last 40 years for backfilling and sealing geologically contained nuclear explosions as part of its sealing program for a nuclear waste repository.*

## Response:

A review of the Defense Nuclear Agency's experience in backfilling and sealing underground openings has been initiated. The review is being performed by Sandia National Laboratories (SNL). This work is being performed as part of SNL's review of available technology to seal underground openings. The review will be documented in fiscal year 1993.

## Recommendation 8:

*Exploration work in expansion areas adjoining the proposed site should be conducted with the same requirements as those placed on the presently designated repository area, since the boundaries are not yet fixed.*

## Response:

DOE agrees that all site characterization activities, including both surface-based drilling and underground exploration, must be conducted under the same requirements. The current ESF Title I design does not preclude exploration outside the potential repository boundary as defined in the Site Characterization Plan-Conceptual Design Report (SCP-CDR). It simply describes a plan for characterizing the repository block as it existed at the time of preparation of the SCP-CDR.

# TECTONIC FEATURES AND PROCESSES

The following Board recommendations concern the investigations of the tectonic processes and geologic features at the candidate Yucca Mountain site.

## Recommendation 9:

*The Board recommends once again that the DOE give greater emphasis to seismic vulnerability studies. Discussions of site suitability, from the seismic point of view, should be based on the likelihood of adverse consequences and not on the occurrence of earthquake ground motion or fault displacement alone.*

## Response:

DOE recognizes the importance of seismic issues and has carried out seismic vulnerability studies in the past. For example, the Preliminary Design Cost-Benefit Assessment of the Tuff Repository Waste-Handling Facilities (SAND88-1600) examined the combined costs of design, licensing, construction and the consequences of failure as a function of different seismic design levels. In the coming fiscal year, at the direction of Dr. Bartlett, Director, OCRWM, seismic studies will receive a new emphasis through the initiation of a three-pronged action plan. As part of this plan, site characterization activities related to the assessment of adverse consequences of known seismic hazards will be accelerated, topical reports will be prepared addressing the concerns of the Nuclear Regulatory Commission, and a thorough study will be carried out examining the seismic vulnerability of a potential underground repository at Yucca Mountain. The seismic vulnerability study for an underground repository will be modelled after the cost/benefit analysis for the waste handling facilities, and will weigh the adverse consequences of failure of the underground facility as a function of different seismic design levels against the likelihood of those particular consequences occurring. It is anticipated that the seismic vulnerability component of the action plan will be completed in mid-1994.

## Recommendation 10:

*The Board also notes that important aspects of seismic risk assessment, particularly those associated with postclosure fault displacement within the repository block, cannot be carried out until exploratory underground excavation is well advanced and faults are exposed. The Board continues to recommend that underground excavation be given a high priority.*

### Response:

DOE agrees that underground access is important to assessing the potential for fault displacement within the repository block. The DOE also recognizes that a credible site characterization program must include both surface-based and underground testing. In FY 1992, DOE focused on surface-based testing 1) to address site suitability issues, 2) to support environmental prerequisites, and 3) to maintain program continuity and flexibility in responding to changes in funding allocations. In FY 1993, emphasis will be placed on initiating underground access through beginning excavation of the first ESF ramp.

## Recommendation 11:

*As with other areas of concern, the Board recommends the DOE greatly increase emphasis on systems engineering studies. It notes that seismic issues should not be considered independently of other factors in the overall system — such as thermal-loading, drift configuration, container emplacement, nature of engineered barriers, and transportation systems.*

### Response:

DOE agrees that seismic issues should not be considered independently of other factors in the overall system. As trade-off studies are carried out, impacts on the entire system will be evaluated. The selection of specific options will trigger reassessments of the need for and adequacy of site characterization activities. Modifications to the Site Characterization Program Baseline and to individual Study Plans will be made as warranted.

## THE ENGINEERED BARRIER SYSTEM

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

## Recommendation 12:

*Waste package containment goals should exceed, not just meet, minimum regulatory requirements. To achieve this, the Board again strongly recommends that engineered barriers be viewed as an integral part of the radioactive waste management program, and that development and testing of robust, long-lived waste packages be funded dependably and at a level sufficient to evaluate their contribution to long-term predictions of repository behavior, and to total system safety.*

### Response:

DOE considers the engineered barriers as an integral part of the overall program. DOE also concurs in the need to consider engineered barrier designs that exceed regulatory requirements. DOE intends to proceed with orderly development of engineered barriers at the pace permitted by the available funding, balancing the urgency of progress in other areas of the program, such as characterizing the site.

## Recommendation 13:

*The DOE should increase funding to the engineered barrier system program before repository-level geologic data become available for the Yucca Mountain site. Increased funding to the engineered barrier system program after site-specific geologic data start coming in may be viewed as an attempt to compensate for site deficiencies.*

### Response:

DOE understands the Board's concerns regarding the funding of the engineered barrier system. Under the current schedule, the development of the engineered barrier system will be during the License Application Design phase, which is before definitive geologic data become available from the ESF.

# TRANSPORTATION AND SYSTEMS

The following Board recommendations concern the interactions and interfaces between the various components of the overall waste management system.

## Recommendation 14:

*The Board recommends that the DOE initiate and pursue vigorously top-level system trade-off studies so as to provide a firm, systemwide rationale for making the various major decisions that will affect the safety, efficiency, and design of the total waste management system.*

### Response:

DOE agrees that top-level system trade-off studies are essential in providing a firm and defensible technical basis for making major decisions at the system level. The OCRWM Systems Analysis Program has been formulated to (1) support requirements definition, document development, and concept evaluation; (2) support design decisions and system planning; and, (3) provide inputs to other OCRWM organizations such as sensitivities to design, operational, and / or policy changes; or performance criteria for inclusion in specifications.

A number of system studies are being performed, including three that cut across all systems elements: (1) System Throughput Rate; (2) Study of the System Implications of Repository Thermal-Loading; and, (3) Assessment of Alternative Cask and Canister Concepts for Storage, Transportation, and / or Emplacement. In order to specify and prioritize future systems studies, a system study planning "roadmap" is being developed to structure system-level decisions, and identify information needs associated with decisions as well as studies needed to provide the information.

DOE will use the results of these and other system studies to help make major decisions in a timely manner. These decisions are essential in accomplishing OCRWM's mission of managing and disposing of the Nation's spent fuel and high-level radioactive waste in an efficient and cost effective manner that protects the health and safety of the public and the worker, and helps preserve the quality of the environment.

## Recommendation 15:

*The Board recommends that the DOE develop the necessary supporting documents for the implementation of systems safety and human factors programs, including program plan and design requirements for human factors, as well as overall system safety*.

### Response:

DOE recognizes the importance of systems safety and human factors programs in terms of their contribution to the success of the OCRWM mission. A System Safety Plan and a Human Factors Engineering Program Plan have been drafted and are currently being reviewed. These documents provide program-level guidance regarding the implementation of system safety and human factors engineering and they describe the interfaces and relationships between program-level and project-level (i.e. system element) activities. Each project will develop a Safety Engineering Plan and Human Factors Engineering Plan. Preliminary system safety and human factors engineering requirements have been identified at the overall system level in the draft *Civilian Radioactive Waste Management System Requirements* document.

# Appendix F
# Radioactive Waste Management Programs in Finland and Switzerland

## Finland

### Background and General Information

The information in this section was gathered from various sources — in some cases from foreign translations — and has not been verified with Finnish or Swiss experts.

Switzerland and Finland use the international standards to classify nuclear waste. High-level waste is the waste stream resulting from the first cycle of fuel reprocessing. It contains long-lived radionuclides found in spent fuel and requires both heavy shielding and cooling to be handled safely. Intermediate-level describes waste with significant beta/gamma activity but generally low alpha activity. It requires

**Scandinavia**

some radiation shielding, but no cooling. Low-level waste contains negligible amounts of long-lived radionuclides and can be handled without shielding. Decommissioning waste consists of parts of the nuclear reactor activated and/or contaminated during operation of the reactor. This system is slightly different from that used in the United States where waste generally is classified as high-level, low-level, or transuranic waste. Information on Finland's energy industry and the amount of spent fuel requiring disposal are presented in tables 1 and 2.

### The Finnish Nuclear Spent Fuel Management Strategy

#### Overall Spent Fuel Strategy

Nuclear energy plays an important role in the Finnish energy system, where in 1990, 35 percent of all electricity produced was generated by nuclear power. Four reactors, with a total capacity of 2,300 megawatts are currently in operation.

Two Soviet-built 445 megawatt pressurized water reactors (PWR) are operated by Imatran Voima Oy (IVO), the National Power Company, at Loviisa in southeastern Finland. IVO is government owned and operated. When the two reactors originally were purchased from the former Soviet Union, IVO made contractual arrangements for the entire fuel cycle service. This included both the receipt of fresh fuel and the return of spent fuel to the former Soviet Union. Whether these contracts will be continued is not

**Table 1 – The Energy Industry**

| | | |
|---|---|---|
| Population | 1988 | 5.0 million |
| Electric Power Plant Capacity | 1988 | 11.9 GWe (19% nuclear) |
| | 1990 | 12.6 GWe (18% nuclear) |
| | 1995 | 13.6 GWe (17% nuclear) |
| | 2000 | 15.1 GWe (15% nuclear) |
| Electric Power Production | 1988 | 53.8 TWh |
| | | **36% nuclear** |
| | | 25% hydro/geothermal |
| | | 19% coal |
| | | 12% solids |
| | | 5% gas |
| | | 3% oil |
| | 1990 | **35% nuclear** |
| | 1995 | **27% nuclear** |
| | 2000 | **25% nuclear** |
| Nuclear Power | | |
| Nuclear power plant capacity | 1990 | 2.3 GWe |
| | 1995 | 2.3 GWe |
| | 2000 | 2.3 GWe |
| Reactor mix | 1990 | PWR: 2 (1977/81)<br>BWR: 2 (1979/82) |

**Table 2 – Amount and type of spent fuel (MTU)**

| | Date | TVO | IVO |
|---|---|---|---|
| Cumulative Spent Fuel | 1980 | 22 | 46 |
| Light water reactors | 1985 | 228 | 140 |
| | 1990 | 450 | 270 |
| | 2000 | 888 | 500 |

known, but if they are not arrangements will be made to dispose of the spent fuel from IVO in Finland.

At a second site in southwestern Finland, two Swedish-built 710 megawatt boiling water reactors (BWR) are operated by Teollisuuden Voima Oy (TVO), the Industrial Power Company, at Olkiluoto in Eurajoki. TVO is 43 percent government owned and 57 percent privately owned, primarily by the electric utility companies. TVO has opted for a diversification of its fresh fuel supply services. The present strategy for spent fuel is to store it and, should foreign services for spent fuel management turn out to be unavailable or unattractive, to dispose of it in a deep geologic repository in Finland beginning in approximately 2020.

The utility has not signed any reprocessing contracts, and the reprocessing option is considered unreasonably expensive at this time. Furthermore, according to governmental agreements, consents for reprocessing would be required from those who are supplying the fuel.

Both of the nuclear power utilities depend on foreign supplies of uranium and its conversion, enrichment, and fabrication services (including from China and the former Soviet Union).

With such a relatively small nuclear industry, Finland would prefer to participate in some sort of international cooperative venture. Failing that, spent fuel from the reactors is being stored for 40 years, then placed in an underground repository. Reactor wastes are conditioned and stored at the nuclear power station sites.

### System Costs and Funding

Each year the utilities pay money into the State Nuclear Waste Management Fund. Cumulative fund contributions as of the end of 1990 have been confirmed as:

- TVO - 1903 million Finnish Markkaa (FIM)[1]
- IVO - 585 million FIM

According to current practice, to ensure that the financial liability is not underestimated, the utilities are required to present cost estimates each year for the future management of the nuclear waste. These costs are estimated assuming that nuclear power production will stop at the end of the year being considered. For 1990, the pertinent estimates for the cost of future nuclear waste management operations were about 4,000 million FIM for TVO, and about 1,000 million FIM for IVO consisting of the following breakdown:

**Table 3 – Cost in million FIM[1]**

| | TVO | IVO |
|---|---|---|
| 1. Spent Fuel Management | 1878 | 34 |
| 2. Reactor Waste Management[2] | 123 | 111 |
| 3. Decommissioning[2] | 806 | 820 |
| 4. Research and Administration | 1023 | 138 |
| Total | 3832 | 1103 |

[1] *In 1990 1 FIM = $0.25 U.S.*
[2] *See discussion of low- intermediate- and other wastes in Section VI.*

For the outstanding liability (i.e. the estimated future costs not yet covered by the contributions paid into the fund), the licensee must furnish securities as a precaution against insolvency. The administrative procedures are described in detail in the nuclear energy legislation.

## Nuclear Waste Legislation

The Nuclear Energy Act and Decree of 1988 gives the Finnish parliament the final say on building new major nuclear installations, including waste disposal facilities. The role of the parliament will be either to accept or reject a final proposal. The proposed host municipality for the nuclear installation also has a veto right. The government has the oversight of the early stages of nuclear projects and is also responsible for granting licenses for nuclear installations. The Finnish Centre for Radiation and Nuclear Safety is responsible for the technical and safety-related review of license applications.

The general safety requirements for nuclear power plants including the interim storage of spent fuel and reactor wastes were issued by the Finnish government in early 1991. The more detailed safety requirements applying to the issuing of licenses for the operating facilities are given in the decisions and guidelines of the Finnish Centre for Radiation and Nuclear Safety (STUK).

Finland follows closely the international efforts of the International Atomic Energy Agency (IAEA), the International Commission on Radiological Protection (ICRP), and the Organization for Economic Cooperation and Development / Nuclear Energy Agency (OECD / NEA). Furthermore, the Nordic nuclear safety authorities have developed joint recommendations, which have been published under the title *Disposal of high-level radioactive waste, consideration of some basic criteria - a consultative document.* An updated version of the Nordic criteria is in the process of being published.

## The Finish Repository for Spent Fuel

### The Repository Concept

TVO has been preparing for domestic spent fuel disposal in crystalline bedrock. According to current technical plans, the spent fuel will be stored in cooling pools at the reactors for about 40 years. After storage, the spent fuel will be encapsulated and transferred to an underground repository.

The repository for disposal of spent fuel from TVO is similar to the Swedish KBS-3 design, where encapsulated spent fuel will be emplaced in vertical holes in the floors of horizontal tunnels at a depth of 500 meters in the crystalline bedrock. In the boreholes the canisters are surrounded by bentonite clay forming a buffer of very low hydraulic conductivity between

1 *In 1990 1 FIM = US $0.25*

the canister and the rock. The tunnels will be backfilled with a mixture of sand and bentonite. The tunnels and shafts will be sealed at appropriate locations with specially designed plugs. Design principles of the repository are presented in Figures 1a, 1b, 1c.

**Major Milestones in the Spent Fuel Repository Program (TVO)**

The major milestones for the spent fuel waste management program derive from the Finnish government's policy decision of November 1983. IVO had contracted for the return of its spent fuel to the former USSR after an interim storage of 5 years. As a result, Finland would have to dispose only of spent fuel from TVO. Based on this original government policy design, TVO launched a program that aimed at carrying out the disposal of spent fuel in a deep geologic repository in Finland on the basis of the following milestones:

- By the end of 1985, about 100 feasible candidates for investigation sites for spent fuel disposal had been selected on the basis of geologic and other relevant scientific information. By the same date, the technical plans and safety assessments related to the disposal of spent fuel were updated.

- The spent fuel interim store (KPA-store) at Olkiluoto was commissioned in September 1987. Until disposal, the spent fuel from the TVO reactors will be stored in water pools at this storage facility.

- In 1987, five sites were nominated for preliminary site investigations for potential locations of a spent fuel repository. Investigations and deep drilling have been carried out at all sites since 1987.

- By the end of 1992, the preliminary site investigations and evaluations are to be performed to single out the two or three most appropriate sites for detailed investigations. By the same date, updated technical plans and safety assessments for spent fuel disposal will be reported.

- By 2000, detailed site investigations should have been carried out and one particular site selected and a technical disposal plan drawn up in such a way that the total disposal system fulfills the safety and environmental protection requirements.

- By 2010, TVO should be prepared to submit to the regulatory authorities the designs of the repository and the encapsulation facility. The construction licenses will be granted based on these designs.

- The construction of the repository and the encapsulation plant are to be completed by the year 2020, and after the approval of the final safety reports, the facilities would begin operation in 2050. The repository would be closed by the year 2060.

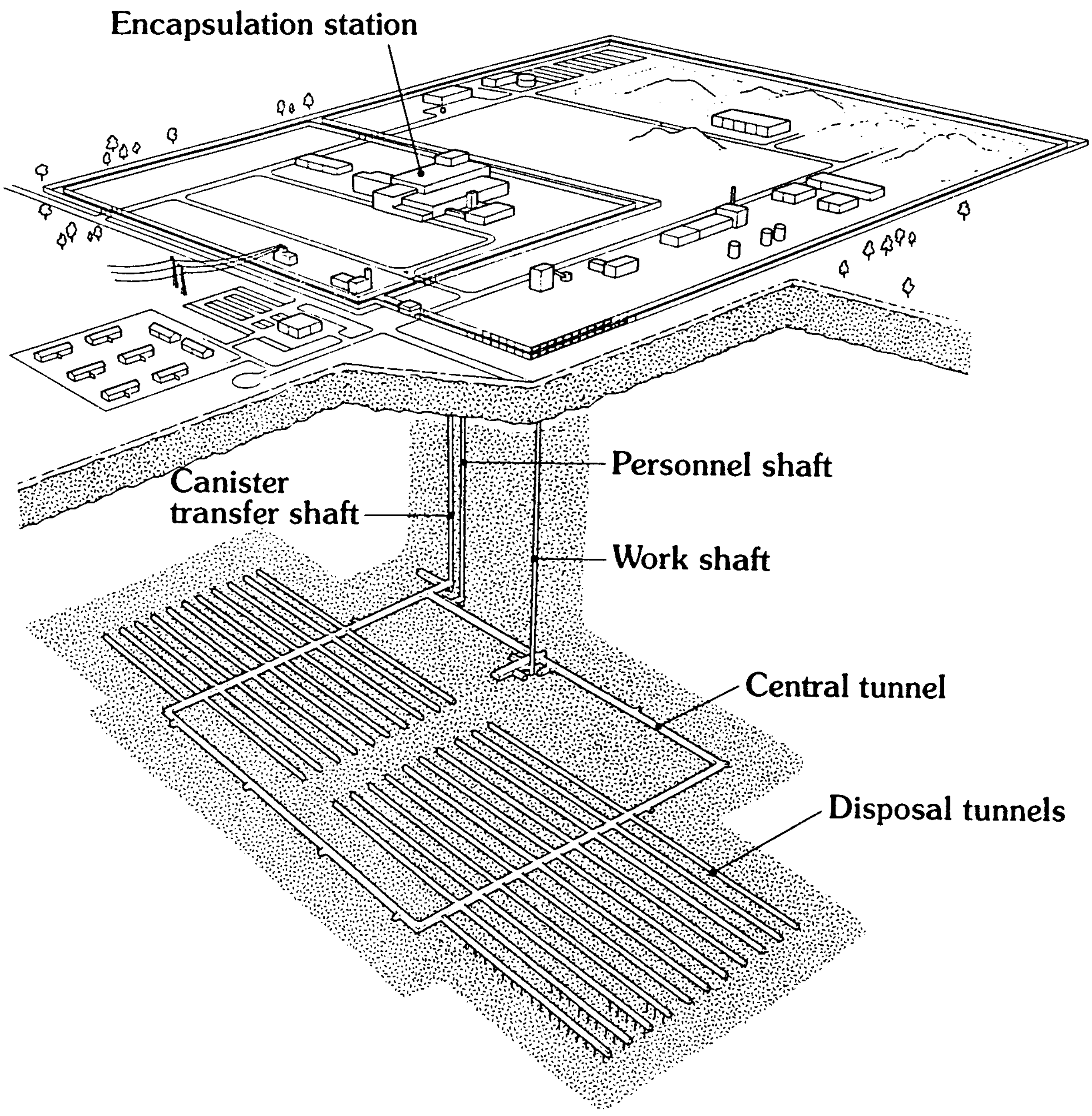
Agreements have been reached with the landowners about the investigations. The construction of the final repository will require approval from the local council. Issues affecting all parties are discussed by special groups set up to promote cooperation. TVO has also established local offices for the duration of the investigations.

## The Finnish Waste Package

**Canister Design**

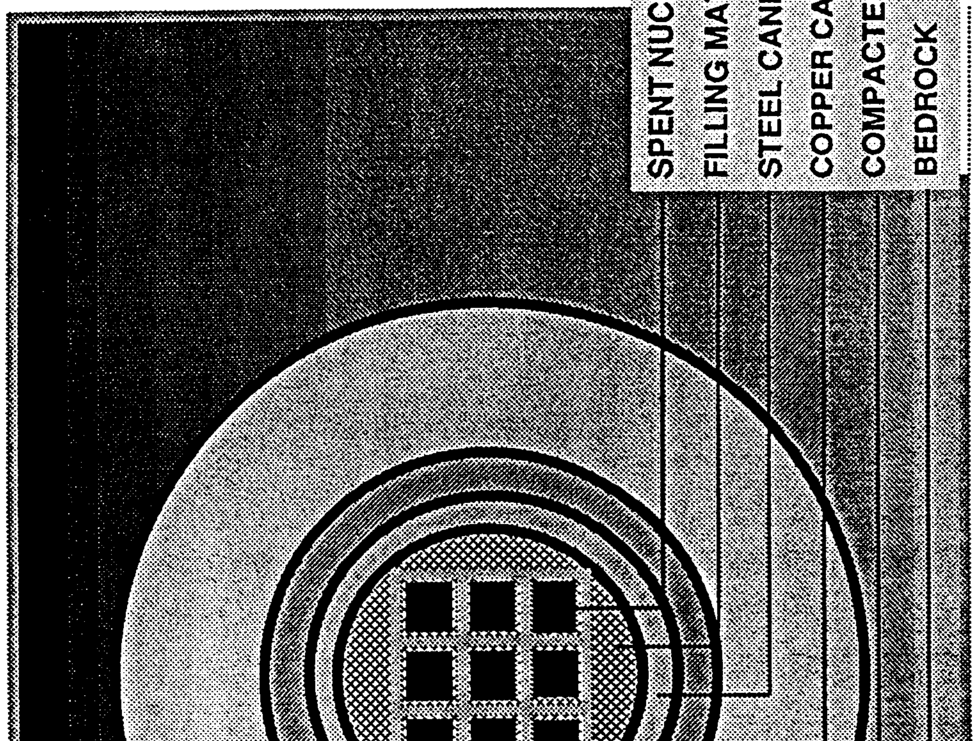
According to the current design spent fuel (or vitrified high-level waste, if Finland obtains foreign reprocessing) will be encapsulated in thick-walled copper canisters, each containing 8-9 BWR fuel assemblies. The spaces in the canisters are to be filled with either molten lead, lead shot, or other suitable material. Studies on other canister designs are underway. TVO is giving strong consideration to a waste package, developed in cooperation with Sweden, in which spent fuel would be encapsulated in thick steel containers covered with a thin layer of copper for corrosion protection. The spaces between the spent fuel rods are to be filled with either a lead-gravel, quartz-gravel, or glass-packing material. In either case, each canister has an inside diameter of 60 centimeters and an outside diameter of 80 centimeters.

# Figure 1a


Encapsulation station
Personnel shaft
Canister
transfer shaft
Work shaft
Central tunnel
Disposal tunnels

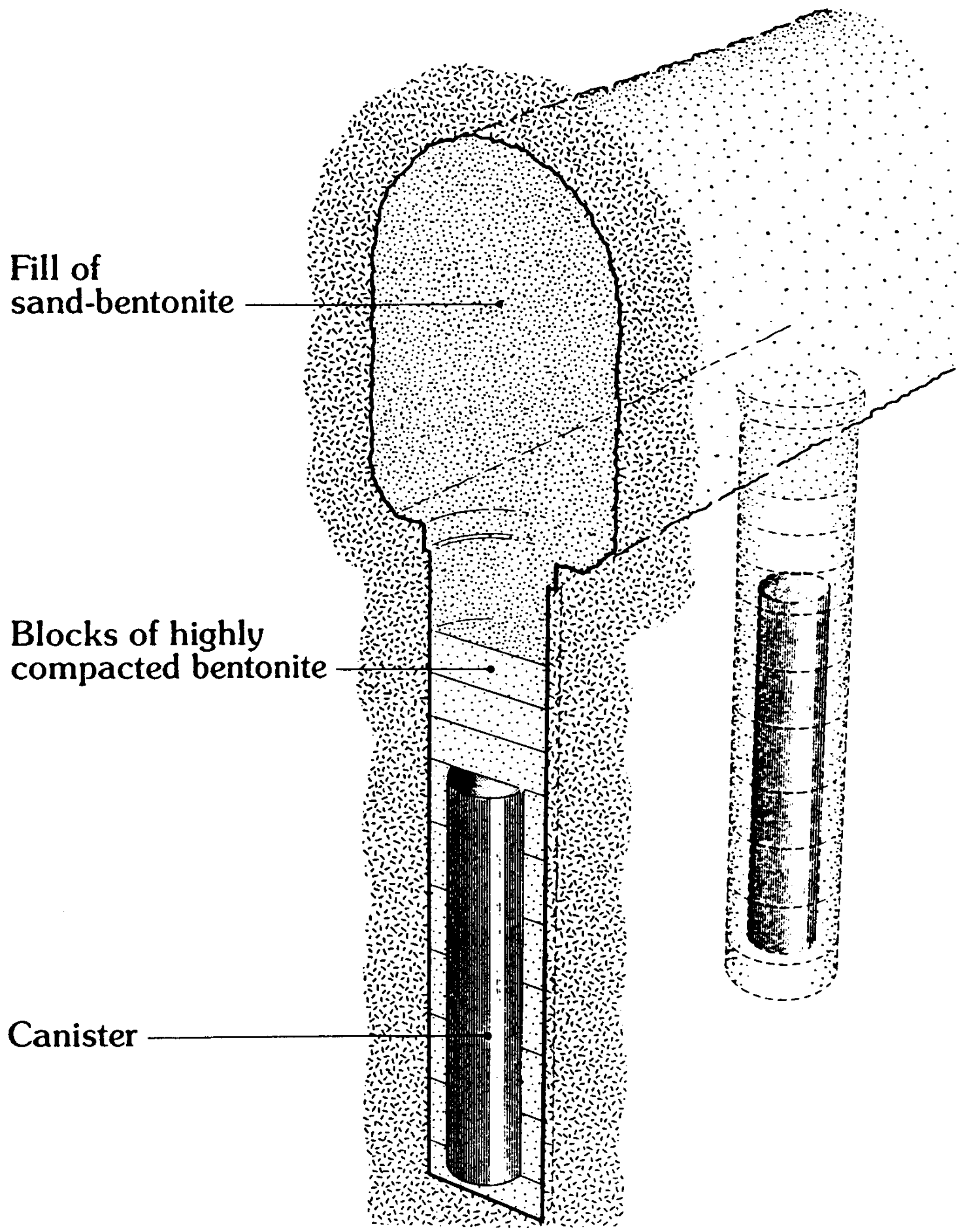
# Figure 1b

CIPLE




[redacted]

# Figure 1c
# Canister for Spent Fuel in Disposal Tunnel



The Advanced Cold Process Canister (ACPC) is presented in Figures 2 to 6. (The arrows, especially in Figure 4, are not precise.) The structure consists of a steel canister as a load-bearing element and an outer corrosion shield of copper.

Two alternative designs are presented. In CASE 1, the desired radiation levels are reached using thick walls. The wall thicknesses are 55 millimeters for steel and 60 millimeters for copper. In CASE 2, an extra lead liner is installed into the inner basket as a radiation shield. The reduced wall thickness is 50 millimeters for both steel and copper.

One canister can accommodate 9 BWR fuel assemblies (without fuel boxes). The total weight of a loaded and sealed canister is between 14,000 and 19,000 kilograms depending on the canister design and filling material to be used.

The mechanical design does not rely on the mechanical properties of the filling material. The main function of the filling material is simply to diminish the empty volume inside the canister. The particulates being considered are lead shot, quartz sand, and glass beads.

The outer copper lid is to be sealed using electron beam welding. At present, this method requires a vacuum atmosphere at welding. To draw a vacuum rapidly and to avoid the possible discharge of radioactive gases during welding, the internal steel shell containing the fuel assemblies must be made leak tight against the 1 bar internal net pressure caused by the outside vacuum. This leak-tightness can be achieved by a thread joint or by a bolted flange joint and a soft gasket in the steel lid (see Fig. 3). The bolted design is easier to install.

The maximum design temperature on the outer surface is limited to 100°C because of the chemical stability of the highly compacted bentonite in the deposition hole. The allowable heat load per canister is about 1,200 Watts. The highest temperature inside the canister is assumed to be less than 150°C.

The maximum dose rate on the surface of the canister is about 100 mSv/h. This requires that the maximum burn-up of the fuel assemblies is limited to 45 MWd/kgU when the shortest cooling time after removal from the reactor core is 15 years.

The mechanical design load for the canister is 15 MPa[2] external pressure. The maximum design pressure is distributed evenly and is acting on each face of the vessel. Thermal transient loads are not significant. Stationary temperature can vary between environmental temperature and the highest operation temperature (150°C). All mechanical pressure load is carried by the internal steel shell structure. The maximum tensile strain in the copper material is limited to 1 percent.

The outside shell is made of oxygen-free copper and is designed only for corrosion protection and leak-tightness purposes. The inside steel shell is designed to be leak tight only during the electron beam welding of the outer copper shell. To guarantee extra safety margins, the aim is that the canister design provide a *lifetime of 10,000 years or more* (emphasis added).

About 1,000 canisters will be required to accommodate the expected spent fuel, but that does not include the spent fuel that was supposed to have gone back to the former Soviet Union.

The R&D work being carried out includes measuring the solubility of unirradiated fuel in granitic ground water, characterization of high-level waste glass, canister corrosion, and the behavior of backfill materials.

*2 15 MPa equals approximately 2,175 pounds per square inch.*

# Figures 2–5

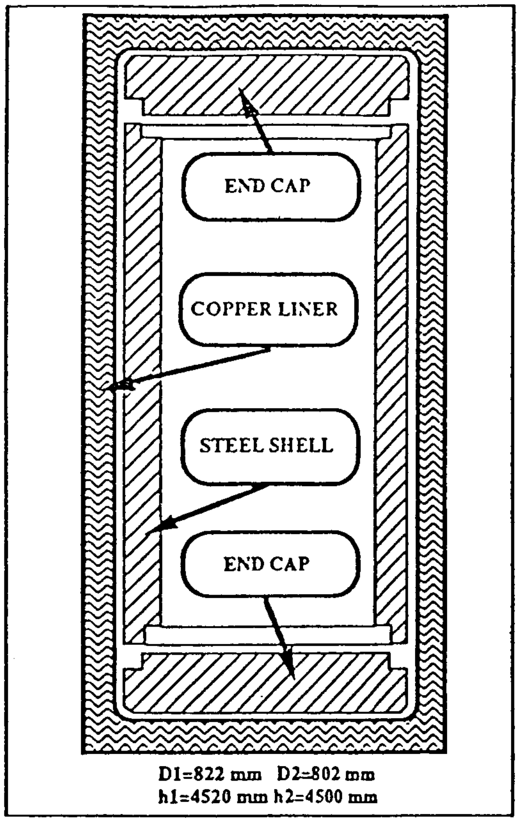



Figure 2. CASE 1 and CASE 2 design.

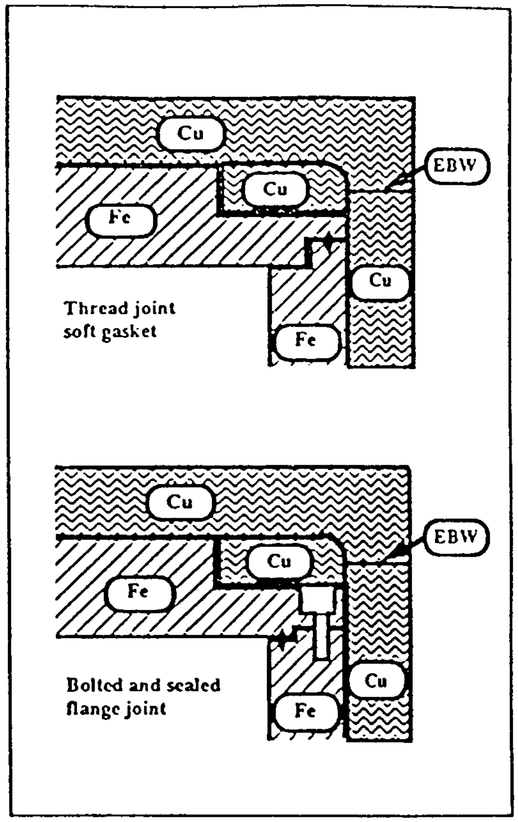



Figure 3. Proposed lid configurations.

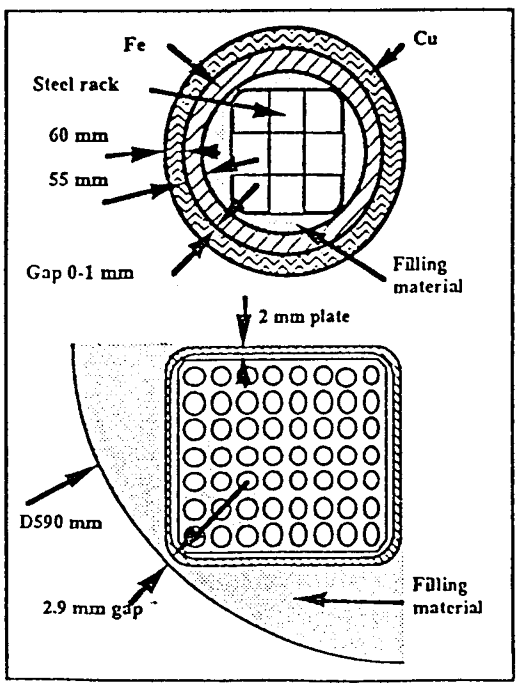



Figure 4. CASE 1 design details.

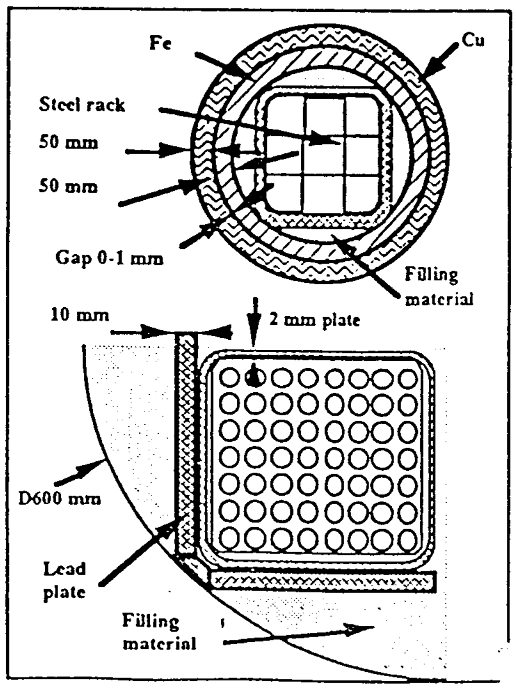
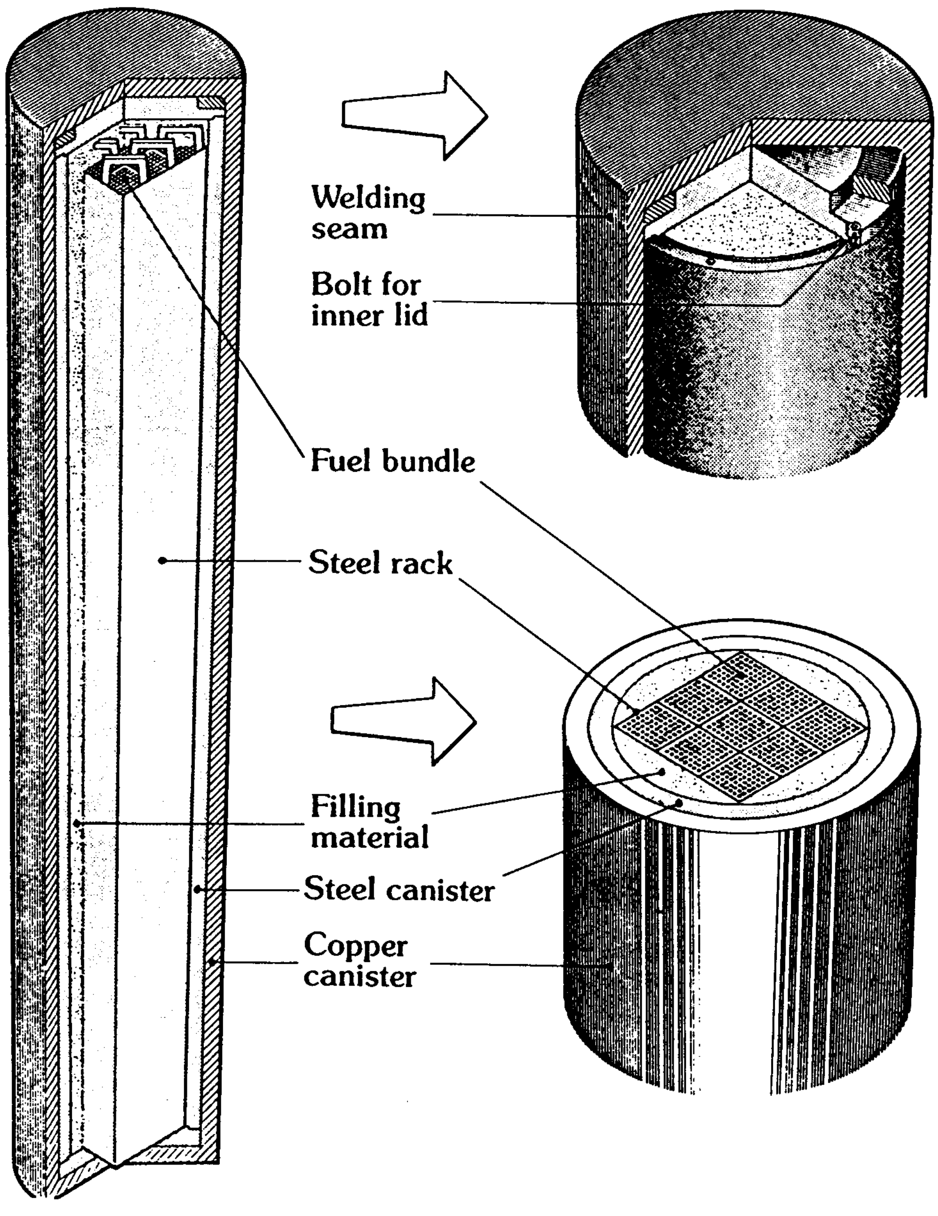



Figure 5. CASE 2 design details

# Figure 6 – Canister for Spent Nuclear Fuel



# Repository Program for Low-Level, Intermediate-Level, and Reactor Waste

### Repository Concept

Current plans call for the conditioning, storage, and final disposal of low- and intermediate-level wastes from reactor operation as well as waste from the decommissioning of nuclear facilities to take place in Finland. The disposal approach that has been adopted in Finland is to employ the reactor sites as locations for the low- and intermediate-level waste repositories. The two nuclear power companies are building their own repositories. The interim-stored wastes inside the power plants will be decommissioned at the same time as the plants themselves.

A repository at Olkiluoto was granted construction permits in 1988, and license application was made in 1991. The repository started operation this year. The wastes are disposed of in a repository at a depth of 50 to 130 meters in bedrock. The repository consists of two separate silos, 70-100 meters below ground surface, one for bituminized intermediate-level wastes, the other for dry maintenance waste. Both silos are 24 meters by 34 meters deep. The silo for maintenance waste is constructed of shotcreted rock. The silo for bituminized waste consists of a thick-walled concrete silo inside the rock silo. No backfilling will be used inside the concrete silo. Crushed rock may be used between the concrete silo and the rock. Waste will be emplaced within concrete boxes each containing 16 drums. The interim storage facility at Olkiluoto is planned to be decommissioned by the year 2055.

A repository plan for the Loviisa plant has been approved but construction postponed as there is still plenty of storage capacity for low- and intermediate-level waste at the plant. When built, it will be constructed about 110 meters below a gently dipping fracture zone in a zone of almost stagnant ground water. It will consist of a cavern for immobilized wet waste and tunnels for dry maintenance waste. For dry waste, microbial decomposition is being tested. Evaporator concentrates will be treated by separating cesium with selective ion exchanges. For the remaining wet paste, a plant based on a cementation process has been designed and licensed, but not built. Alternative methods for immobilizing spent ion exchange resins and the bottom slurry from evaporator concentrate tanks include drying, in-situ solidification in the repository and microbial decomposition of the resins. In the repository cavern for immobilized wet waste, the engineered barriers will consist of concrete containers, concrete walls, and a backfilling of crushed rock.

The designs of the Olkiluoto and Loviisa repositories are somewhat different mainly because of the local geologic conditions. At Olkiluoto the host rock massive favors vertical silo-type caverns, whereas at Loviisa horizontal tunnels are more suitable.

At the Olkiluoto site, the bedrock consists of an intact tonalite massive surrounded by micagneiss. Ground water at the site is of fresh or brackish type with no great variations in salinity.

The bedrock of the Loviisa site on the island of Hästholmen consists of rapakivi granite. The ground water on the island contains two zones of different salinity. The boundary between the upper, lens-like zone of fresh, flowing ground water and the lower zone of saline, stagnant ground water lies in a fracture zone varying between 60 and 140 meters. The repository will be constructed at the level of approximately 110 meters below the gently dipping fracture zone. Accordingly, the repository will be situated in a zone of almost stagnant ground water.

### Major Milestones in the Low- and Intermediate-Level Waste Management Program

- In accordance with the program, the preliminary safety analysis reports for the construction of repositories for low- and intermediate-level reactor wastes were submitted to the authorities at the end of 1986.
- The construction permit for the repository at the Olkiluoto plant was granted in 1988.
- The operating license application was submitted to the authorities in January 1991.

- The repository began operation in 1992.

## Storage

### Interim Storage of Spent Fuel

Wet storage for spent fuel has been chosen because of the extensive experience available. At the Loviisa plant, storage capacity in water pools is about 300 metric tons, adequate for about 10 years' accumulation of spent fuel. From 1981 to 1990, ten shipments of spent fuel were made to the USSR, about 200 metric tons. Presently, shipments to the former Soviet Union have been halted, and spent fuel is accumulating at the Loviisa plant. Other reactor wastes are stored in tanks or storage rooms at the plant.

At the Olkiluoto plant, spent fuel is temporarily stored in water pools, which have a capacity of about 370 metric tons. The pools are located in the reactor buildings. After a few years in temporary storage, the spent fuel is than transferred to a separate on-site facility (KPA-store) for long-term storage. It is designed modularly, allowing expansion as needed. Currently there are three pools (400 metric tons / pool with high-capacity fuel racks). The pools are 13.5 meters deep, have stainless-steel-clad walls of thick reinforced concrete, and stand on bedrock 7 meters below ground level. Dry reactor wastes are stored with bituminized wet waste, both inside the plant and in separate concrete buildings.

The total amount of spent fuel projected for the Olkiluoto plant is estimated to be about 1,800 metric tons (based on 40 years' operation). The interim store facilities at the same site will have an estimated operating life of 60 years, and the estimated maximum storage time for an individual fuel assembly is 40 years.

The interim storage facility for spent fuel at Olkiluoto was commissioned in 1987. The facility is planned to be in operation until 2050.

The estimated investment cost of interim storage for spent fuel at Olkiluoto is about $50 U.S. per kilogram of uranium.

At Loviisa, reactor wastes are stored in tanks (wet-wastes) and in storage rooms (solid wastes) at the plant. At Olkiluoto, dry waste and bituminized wet waste are stored both inside the plant and in separate concrete buildings.

To ensure the necessary capacity for 5 years of interim storage of spent fuel and the sufficient reserve capacity, an additional water pool facility was commissioned at the Loviisa site in 1984.

The total amount of spent fuel in the storage pools of the Loviisa plant is on an average 120 metric tons. At Olkiluoto the amount of spent fuel in the pools was 450 metric tons at the end of 1990.

## Transportation

From 1981 to 1990, ten shipments of spent fuel from Loviisa to the former USSR were undertaken. A total of about 200 metric tons of spent fuel have been shipped. Packages and a special train were leased (from the USSR) for the transportation of spent fuel. At Olkiluoto, 45 metric tons of spent fuel were transferred in 1990 from the storage pools inside the reactor units to a separate storage facility at the reactor site. The transfer cask being used is of CASTOR-type specially designed according to the specifications of TVO spent fuel. As the reactor and decommissioning wastes are stored and most likely also disposed of on-site, there is no need for very specialized transportation systems for these wastes.

## Quality Assurance Considerations

According to Finnish law, the objective in the design and implementation of disposal shall be a high level of quality which is commensurate to the safety significance of each object. For this purpose, the applicant shall in each case define the systems, components, structures and materials that are of essential importance to the operating period of the disposal or to long-term radiation safety and present their design bases for approval. To make sure that the design bases are fulfilled, the applicant shall introduce a quality assurance program, one part of which is the quality control program (OECD 1988).

Quality assurance measures are applied to nuclear waste management in a similar way as to nuclear power generation. These measures have been regulated and approved by the authorities, and they cover or will cover systematically all stages of nuclear waste management from waste production, handling, storage, conditioning and transportation to final disposal. The high quality of systems, equipment, structures, and materials is confirmed with a program of quality control typical of nuclear activities.

## Performance Assessment

Research and development of performance assessment concepts and procedures is carried out at the Technical Research Centre of Finland (the VTT Nuclear Engineering Laboratory in Helsinki, and the VTT Reactor Laboratory in Espoo).

Radionuclide release analyses performed in 1984 and 1985 were aimed at identifying pathways and evaluating the time scale of radionuclide releases to the biosphere in conditions characteristic of Finnish bedrock.

Comprehensive generic safety analyses, using the Olkiluoto area as the reference site, showed clear safety margins using conservative assumptions. Analyses were conducted for three types of scenarios: expected conditions, disturbances for each barrier, and disruptive events from natural and human-caused events.

### Safety considerations

In 1985, a safety assessment for the disposal of TVO's spent fuel was completed. The analyses were based on several scenarios to describe the anticipated conditions, defects in technical barriers, potential unfavorable geologic or biospheric changes and disruptive events, such as faulting and human intrusion. The probabilities of the disruptive events were considered in the analyses.

The analyses resulted in a wide range of individual doses depending on the scenarios and the recipients considered. The scenario assuming unfavorable geochemical conditions was analyzed to be the most critical one. The most sensitive recipient was, as expected, the well pathway (i.e. the use of ground water originating from a borehole well).

None of the scenarios analyzed resulted in higher individual dose rates (or, in the case of disruptive events, the expectation value of dose rate) than the dose limit 0.1 mSv/a (10 mrem/a), adopted by the safety authority for the review of the safety assessments. The long-term release rate of radioactive substances into the biosphere was also well below the criterion adopted by the safety authority for the review. Consequently, the Finnish Centre for Radiation and Nuclear Safety took in its review a previously positive position in regard to the safety of the proposed disposal concept.

## Research

There is no underground research laboratory in Finland, and there are no plans to establish such a facility in the future. Finland is participating in the OECD/NEA Stripa project. The field work for the investigation of the site candidates for a repository of spent fuel are presently under way at five locations. Some experimental underground research also may be planned in the repository for reactor wastes at Olkiluoto.

## International Relations

Finland is a member of the International Atomic Energy Agency and the Organization for Economic Cooperation and Development/Nuclear Energy Agency.

Finland collaborates with Sweden, Canada, Denmark, Norway, and Switzerland on waste management studies.

Finland's Center for Radiation and Nuclear Safety and the U.S. NRC have reviewed their cooperative agreement on information exchange in nuclear regulation, originally signed in 1980.

A cooperative agreement was signed between the CEC and Finland in 1989.

TVO and IVO have formal bilateral cooperative agreements with the SKB (Sweden), NAGRA (Switzerland), and AECL (Canada).

Finland also is actively participating in the OECD/NEA Stripa project, BIOMOVS, PSACOIN, CHEMVAL, CoCo, INTRAVAL and VAMP.

Purchases of fuel cycle services: disposal of spent fuel by former USSR for IVO (current status unknown); uranium conversion/enrichment, fuel element fabrication from various foreign countries, including the former USSR and China for TVO.

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7. *Spent Fuel Disposal Concept, TVO Finland*, Jukk-Pekka Salo, Workshop on Engineered Barrier System, Strasbourg, France, November 2-3, 1991

# Switzerland

## Background and General Information

The information in this section was gathered from various sources — in some cases from foreign translations — and has not been verified with Swiss experts.

NOTE: For a list of sources used to produce this section, please refer to the bibliography.

**Switzerland**

**Table 4 – Nuclear Power Generation[1]**

| | | |
|---|---|---|
| Population | 1988 | 6.5 million |
| Electric Power Plant Capacity | 1988 | 15.3 GWe (20% nuclear) |
| | 1990 | 15.4 GWe (20% nuclear) |
| | 1995 | 15.5 GWe (19% nuclear) |
| | 2000 | 16.8 GWe (18% nuclear) |
| Electric Power Production | 1988 | 60.7 TWh<br>61% hydro / geoth.<br>**38% nuclear**<br>1% solids |
| | 1990 | **36% nuclear** |
| | 1995 | **36% nuclear** |
| | 2000 | **34% nuclear** |
| Nuclear Power Plant Capacity | 1990 | 2.9 GWe |
| | 2000 | 3.8 GWe |
| Reactor Mix | 1990 | BWR:[2] 2 (1972-84)<br>PWR: 3 (1969-79) |

[1] *International Nuclear Fuel Cycle Fact Book, May 1991.*

[2] *BWR - boiling water reactor; PWR - pressurized water reactor*

*NOTE: The federal government is in favor of nuclear power, but local opposition has delayed its expansion.*

## The Swiss Nuclear Waste Management Strategy

With a population of 6.5 million people, Switzerland is a small country, with 36 percent of its current electric power production coming from nuclear facilities (See Table 4). The remainder of Switzerland's electricity is produced by hydropower. There are no large fossil-fueled power stations in Switzerland. Swiss nuclear power production comes from five light water reactors (LWR). Two boiling water reactors (BWR) with a total output of 700 Megawatts (MWe) are located at Beznau, and one pressurized water reactor (PWR) located at each of three sites: Mühleberg (320 MWe), Gösgen (930 MWe), and Leibstadt (990 MWe).

The two BWRs were commissioned in 1972 and 1984. The three PWRs were commissioned between 1969 and 1979.

The Swiss government comprises the Federal Assembly (parliament), within which is the Federal Council (ministers that represent the executive branch, similar to the U.S. Cabinet). The Federal Council formulates the administration's policy decisions on nuclear energy and makes licensing decisions. The Swiss government favors maintaining and expanding the country's current nuclear power capability.

The next lower geopolitical unit is the canton (similar to a state in the United States). The cantons act as a buffer between the Federal Assembly and the local governments. It is in the local governments and among the general population that resistance to nuclear energy and nuclear waste runs the highest.

The Swiss people are concerned about high-level nuclear waste, and these concerns are compounded by the fact that the country is small and densely populated, making the task of finding a place to site a repository very difficult. For this reason, Swiss federal policy supports a cooperative international repository.

In Switzerland, the producers of nuclear waste (the utilities) are responsible for waste management. Therefore, in 1972 the electric utilities involved in nuclear power production joined the Swiss federal government, which is responsible for waste from medicine, industry, and research, to form the National Cooperative for the Storage of Radioactive Waste (NAGRA). The NAGRA is responsible for final disposal and related work. The utilities remain responsible for spent fuel reprocessing and transport, waste conditioning, and interim storage.

**The Swiss Fuel Cycle**

The Swiss have selected a fuel cycle involving reprocessing and plutonium recycling[3]. However, the option of direct disposal of spent fuel remains open. General policy is to purchase most services from other countries, including reprocessing of spent fuel. All Swiss nuclear fuel to be discharged through 1993 has been contracted out for reprocessing. Swiss nuclear power plants generate about 90 metric tons of spent fuel annually. Contracts are in place for a total of 599 metric tons of spent fuel to be reprocessed in France, and 165 metric tons in the U.K.

Spent fuel has been going to La Hague, France, and Sellafield, U.K., for reprocessing since the early 1970s. Both wet and dry cask systems have been used for transport. Casks have varied, with some weighing up to 120 metric tons. Transport out of Switzerland occurs by truck and rail, but primarily rail will be used to transport reprocessed waste back to the centralized interim storage facility (ZWILAG; see last section), which will be located in Baden, and is projected to be operational by 1994.

High-level waste will be stored at the ZWILAG facility for *approximately 40 years after unloading from the reactor*, until the heat load is reduced, and a low repository temperature can be maintained. Return of vitrified high-level waste from foreign reprocessors will begin sometime in 1993. Table 5 provides the projections on the types and amounts of spent fuel Switzerland will need to dispose of.

**System Costs and Funding**

The costs of waste management are borne directly by the waste producers, (i.e. mainly by the electricity supply utilities). A minor contribution (calculated as a "power equivalent") is made by the Swiss Confederation, which is responsible for the management of wastes arising from medicine, industry and research.

*3 From 1969 to 1982, Switzerland also participated in joint deep-sea disposal activities with Belgium and the Netherlands. Radioactive waste from medicine, industry and research for certain nuclear reactors was dumped over 4000 meters deep around 700 kilometers from Ireland and Spain. The EIR (Federal Institute for Reactor Research), Würenlingen prepared, conditioned, transported and disposed of the waste. Despite positive safety analyses, deep sea disposal has been stopped, and its future is in doubt due to political opposition.*

**Table 5 – Amount and type of spent fuel[1]**

| | Date | Metric Tons |
|---|---|---|
| Cumulative Spent Fuel | 1980 | 380 |
| Light water reactors | 1980 | 380 |
| | 1985 | 650 |
| | 1990 | 1,090 |
| | 2000 | 2,000 |
| | | Cubic Meters |
| Cumulative Waste[2] | | |
| Waste from Demolition & Decommissioning | | 95,000 |
| Low- and intermediate-level waste[3] | | 80,000 |
| High-level waste glass | | 750 |
| | or | |
| Spent Fuel | | 2,500 |

[1] *International Nuclear Fuel Cycle Fact Book, May 1991.*

[2] *For planning purposes, 40-yr operation, or a total of 4 gigawatts of produced electricity, is assumed.*

[3] *Switzerland and Finland use the international standards to classify nuclear waste. High-level waste is the waste stream resulting from the first cycle of fuel reprocessing. It contains long-lived radionuclides found in spent fuel and requires both heavy shielding and cooling to be handled safely. Intermediate-level describes waste with significant beta/gamma activity but generally low alpha activity. It requires some radiation shielding, but no cooling. Low-level waste contains negligible amounts of long-lived radionuclides and can be handled without shielding. Decommissioning waste consists of parts of the nuclear reactor activated and/or contaminated during operation of the reactor. This system is slightly different from that used in the United States where waste generally is classified as high-level, low-level, or transuranic waste.*

As in the United States, Switzerland has established a fund to finance radioactive waste disposal operations. Swiss tariffs on electricity are collected from the users and support a number of projects, including the costs of the NAGRA's work, future repository construction, and nuclear power plant decommissioning.

NAGRA's costs, which constitute a major part of total expenditures, totalled about 350 million Swiss francs in 1988.[4] NAGRA estimates that total high-level waste repository construction costs will be about 600 million Swiss francs (391 million U.S. dollars). Total program costs, including construction of the repository are estimated by NAGRA to be 1.5 billion Swiss francs (977 million U.S. dollars). NAGRA also estimates that operational costs would equal the 1.5 billion Swiss francs.

## Nuclear Waste Legislation

In June 1957, the Swiss federal parliament amended the constitution so that nuclear legislation now falls within the sole jurisdiction of the Federal Assembly, rather than of the cantons. In 1978, a federal order revised the Atomic Energy Act of 1959 and placed test borings for waste repositories under the preparatory acts for nuclear installations, eliminating the right of local governments to veto such test borings. The Federal Order of 1978 also reduced the veto rights of the cantons in siting matters to those of consultation. Local governments now lobby through their cantons to object to particular sitings. The federal government has preemptive rights, but will use them only as a last resort.

In the 1978 revision of the Atomic Energy Act, parliament required producers of radioactive waste to be responsible for its disposal. The revisions also stipulated that to license a new nuclear power plant, proof and guarantee of final waste disposal must be demonstrated. The Swiss Department of Transport, Communications, and Energy ruled in 1979 that all current operating licenses would expire at the end of 1985 if no such project guaranteeing this goal were available.

The NAGRA submitted its Project Gewähr (see section on Project Gewähr below) report in 1985 to satisfy the requirement for proof and guarantee of final

4 *1 Swiss franc = $0.68 U.S.*

disposal. The Federal Council, reached an affirmative decision in June 1988 that Project Gewähr had satisfied the stipulation. The Federal Council concluded that safe disposal of high-level waste and transuranic waste had been demonstrated to be feasible, but that further proof of the availability in Switzerland of an acceptable and sufficiently large site was needed.

The Swiss would prefer the option of high-level waste and transuranic waste disposal outside Switzerland in a foreign national or international repository, if one becomes available, but realize that this is unlikely.[5] In the absence of an international repository, the Swiss plan to create the most redundant and the safest repository concept possible. Their R&D strategies are focusing on a combination of engineered and geologic barriers with particular emphasis on the buffer surrounding the waste container. This multiple-barrier approach includes a leach-resistant glass matrix; a corrosion-resistant steel canister surrounding the glass cylinder; a large buffer of highly compacted, impermeable bentonite surrounding the canister; and, finally, the host rock and its overburden.[6] Researchers are looking at various waste package designs and backfill options, as well as several media (crystalline rock and sedimentary formations).

The general strategy in Switzerland is to develop two waste repositories: a horizontally accessed rock cavern in a geologic host rock with considerable overburden for low- and intermediate-level waste, and a deep repository in crystalline rock or sedimentary formations for vitrified high-level waste or unreprocessed spent fuel elements and alpha wastes. Transuranic waste from reprocessing is now intended for disposal in the high-level waste repository. Construction of the repository for low- and intermediate-level wastes appears certain, and development of the high-level waste repository is planned, up to the point of site selection.

## Project Gewähr

In 1985, the NAGRA completed a deterministic safety assessment for a hypothetical repository in crystalline rock in Switzerland. This assessment, called Project Gewähr, set out a multi-element approach to nuclear waste management. Total interim storage time from discharge to final disposal of high-level waste was projected at 40 years. This conceptual project used generic calculations that assumed a flowpath of 5,000 meters ending in fluvial gravels of the Thine River Basin. The annual total flow through the repository was conservatively estimated at 4.3 cubic meters per year. The canister is assumed to have disappeared at 1,000 years, although the canister corrosion products ensure reducing chemical conditions around the waste matrix over the entire release period, thus greatly slowing oxidation. Resulting doses for the base case of realistically conservative assumptions were “completely insignificant.”

Using computer models and varying the parameters, researchers tested what hypothetical doses could result from taking less conservative values for hydrologic and geochemical parameters into the calculations. Some of these analyses yielded more significant dose commitments, but the conservatism used to obtain these results requires probabilistic evaluation of the likelihood of encountering such pessimistic conditions. No significance was attached to the actual analytical results, but the results are being used in guiding and challenging site studies to define, as realistically as possible, the range of site parameters.

The Project Gewähr reference model site was depicted based on data obtained mainly from a *single* borehole. The safety analysis showed that the assumed site characteristics allowed the performance objectives to be met, *provided that a sufficiently large area of host rock with the modeled properties exists.* Finding such a body of rock has not been a high priority at this time since concept development, underground testing, and performance assessment are currently the focus of the Swiss program. Therefore,

5 *The idea of possibly participating in an international repository program is a recurring theme in the literature.*

6 *Overburden is the depth of rock above the repository horizon.*

the Federal Council has ordered the NAGRA to undertake additional investigations of other geologic media.

A deep borehole program investigating the properties of the buried granite of northern Switzerland continues, with associated hydrologic modeling and migration experiments underway at the Grimsel underground laboratory, which will not be the location of the repository.

Swiss regulatory authorities have accepted the results of Project Gewähr (high-level waste disposal in granite) and similar preliminary analyses for low- and intermediate-level waste disposal concepts as sufficient to suggest that disposal of nuclear waste can be done safely.

Having completed concept feasibility and safety studies, the Swiss timeline calls for the beginning of the site-selection phase for low- and intermediate-level waste repositories. The concept safety assessment work has provided a foundation upon which site-selection and data-development work are being planned. Expectations are that a specific medium will be selected for further study in 1993. Analyses of the relative importance of selected information to system performance helps guide priorities in site testing, and the relative importance of modeling assumptions is helping guide priorities in validation-oriented studies. Performance assessment is being used to coordinate and guide a comprehensive laboratory, field, and natural analogue investigations program.

## The Swiss Geologic Waste Repository

The schedule for the Swiss geologic repository for high-level waste begins with the selection of one site in either crystalline or sedimentary rock for further investigations in 1993. By 1998, an application for an underground research laboratory (URL) will be filed for that site. The final site characterization should be concluded by 2010, and engineering and construction of the repository will continue until about 2025. The Swiss repository for high-level waste is projected to begin operation sometime after 2020, provided that the results of geologic investigations are favorable and that the licensing process is not delayed.

Safety conditions to be met by the repository are two: radionuclides that escape into the biosphere must not at any time lead to individual doses exceeding 10 mrem (0.1 mSv) per year, and a repository must be designed in such a way that it can be sealed at any time within a few years. After it has been sealed, it must be possible to dispense with safety and surveillance measures.

The NAGRA has developed its own criteria governing the evaluation of suitable geologic environments for high-level waste disposal. The four primary factors are (1) suitability of the host rock; (2) permissible ambient rock temperature of the repository and the resulting maximum depth of the repository; (3) sufficient distance from large, tectonically disturbed zones; and (4) suitable hydrodynamics (i.e., sufficiently long flow paths and low volumes of groundwater flow). Before final closure of the repository, a long-term, in-situ experiment will take place — materials used in the repository will be observed and a safety evaluation will be performed. Retrieval of the waste would be technically difficult but not impossible.

**Major Milestones**

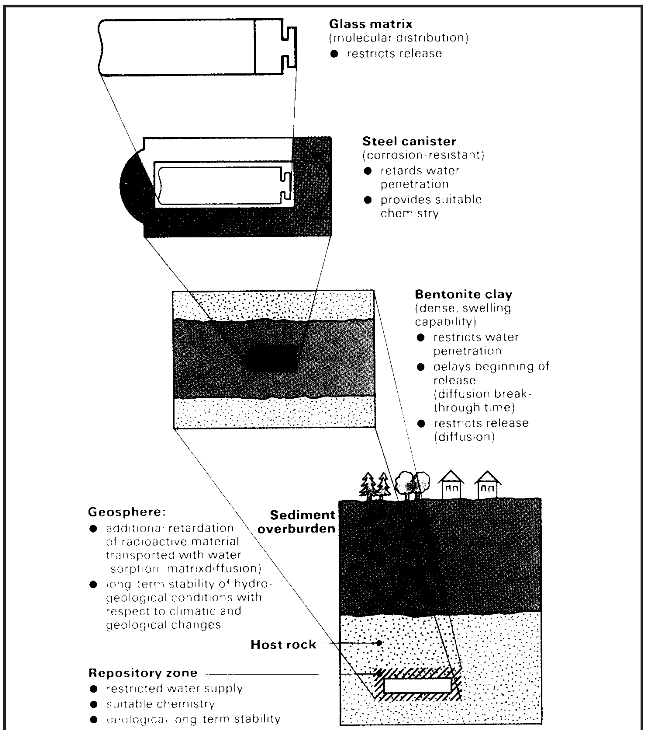
1985 Submitted feasibility study for waste disposal in Switzerland
1988 Parliament accepts feasibility of disposal
1992 Begin operation of facility for dry cask storage of spent fuel
1993 Select LLW/ILW repository site from candidate sites
1993 Begin receiving HLW glass from France and the U.K.
1993 Select specific medium (and site) for further study for the HLW repository
1998 Commission LLW/ILW repository
2005 Make decision on final development of HLW repository
2010 Submit license application for HLW repository
2025 Commission repository for HLW or spent fuel and alpha waste

## The Swiss Waste Package

The current reference waste package system for high--level waste is a multibarrier system (see Figure 7). It includes a leach--resistant glass matrix, a stainless steel canister, a thick steel overpack, and a layer of highly compacted bentonite. The waste form is borosilicate glass, with about 13 wt % waste oxides. The configuration of high--level waste in a canister is the same as in France and the U.K., or 360 to 400 kg (150 liters) of glass in a cylindrical canister (0.43m in diameter, 1.335m high, with a 5mm wall thickness and a 170 liter volume).

The cast steel overpack has a maximum total length of about 2.0 meters, a maximum outer diameter of 0.94 meters, and a wall thickness of about 25 centimeters. The total weight of the filled and sealed disposal container is 8.5 metric tons. The buffer material will be prefabricated blocks of bentonite in the shape of annular circular segments for stacking within the circular disposal tunnels and around the horizontally emplaced disposal containers. The total thickness of bentonite around each container would be about 1.4 meters.

Figure 7 The Swiss Multibarrier System



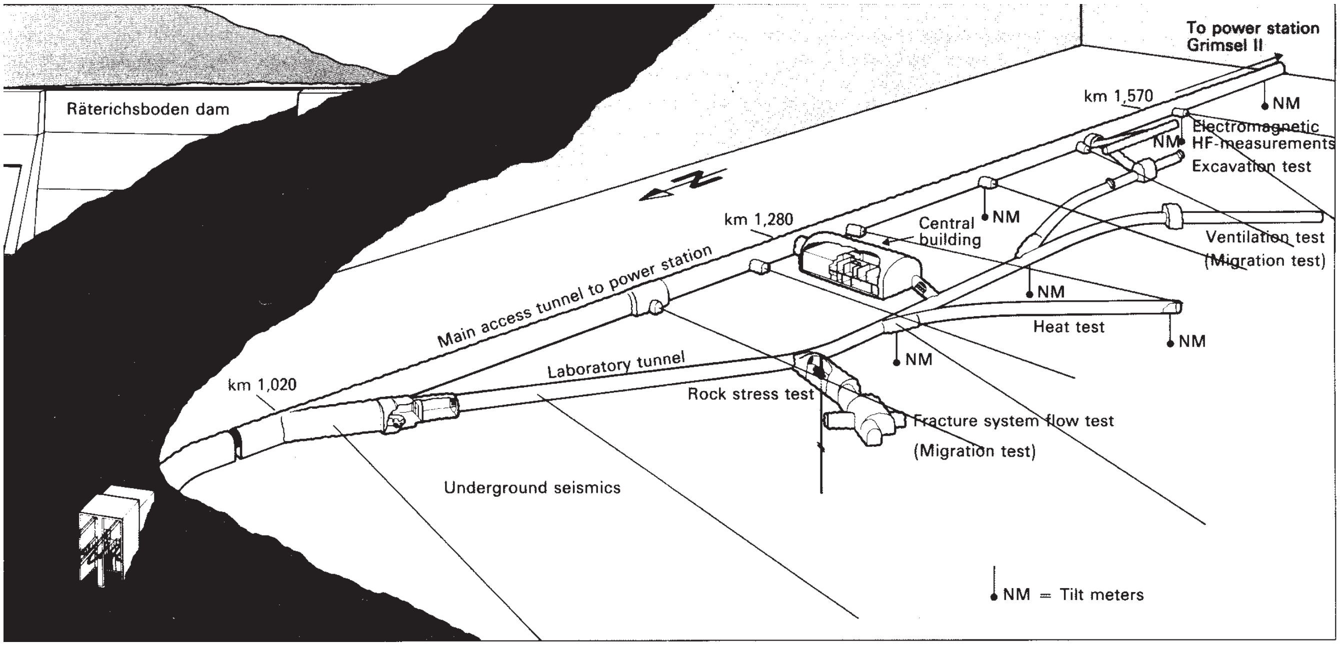

For intermediate--level waste, the waste package system is a dissolution--resistant solidification matrix (cement or bitumen), concrete backfill material, concrete silo walls, and bentonite backfill.

The repository containers for high--level waste are designed to withstand the repository conditions for a minimum lifetime of 1,000 years. The compacted bentonite (greater than 1m thick) is expected to retain radionuclides for about 100,000 years. The heat from radioactive decay will result in a maximum temperature of about 150°C at the outer wall of the disposal container. The swelling pressure of the backfill material and the hydrostatic pressure will not exceed a value of 30 MPa.

## Research and Development – Grimsel Pass

An Underground Research Laboratory (URL) was established at the Grimsel Pass in the Swiss Alps. The Grimsel URL is situated in granite about one kilometer inside the mountain. The rock overburden is about 450 meters. The research program includes projects within the scope of international cooperative agreements. The granite at Grimsel Pass is particularly suitable for rock mechanical, geophysical, and hydrogeologic investigations, because within a restricted area, dry and impermeable rock areas, damp zones, and water--bearing fissures can be found. An extensive research program has been carried out at the Grimsel Test Site since 1984. The program includes: nondestructive rock examination using electromagnetic high frequency measurements (short borehole radar); cross--hole tomography; tilt measurements carried out in six boreholes, 20--30 meters deep, using precision pendulums; various tests regarding rock mechanics (tunnel breakout, rock stress, heat test, etc.); and an extensive hydrogeologic experimental program that looks at radionuclide migration, fracture system flow and rock permeability. A schematic drawing of the URL is provided in Figure 8.

Figure 8 Grimsel Underground Rock Laboratory




Research has included corrosion tests on container and overpack materials, which have resulted in the selection of cast steel as the reference concept. Laboratory investigations have been conducted on the mechanical and chemical behavior of bentonite materials. The Grimsel area is not under consideration as a final repository site, and no tests using radioactive wastes are planned.

## Swiss Facilities Involved in Nuclear Waste Management

**ZWILAG** (Interim Waste Storage Facility) — will provide interim storage for spent fuel, high--level waste, and low-- and medium--level wastes. The facility was voter--approved in 1989 and will be managed by the local council and the nuclear utilities. Construction is expected to take at least two years (start up in 1992) at a cost equal to $4.8 million U.S. ZWILAG is owned by a consortium of Swiss nuclear utilities.

**Grimsel Rock Laboratory** — Provides a particularly suitable rock body for rock mechanical, geophysical and hydrogeological investigation. The characteristic rock of the Grimsel area is granite. In contrast to the deep--lying crystalline in the intended repository location in northern Switzerland, the Grimsel's alpine granite is relatively easily accessible and is further enhanced by the access tunnels of the pumping station of the Oberhasli AG power plant.

## International Relationships

DOE/NAGRA Agreement for Cooperation in Radioactive Waste Management (ongoing)

**Scope:** Preparation and packaging of wastes; field and laboratory testing; storage; geologic disposal; environment and safety design and operational issues; transportation requirements; public acceptance issues.

**Emphasis:** Information exchange and direct cooperation, in particular, concerning Grimsel Pass URL activities.

NRC/NAGRA Agreement on Cooperation in Radioactive Waste Management Safety Research (1986–1991)

**Scope:** Experimental/analytical studies relating to safety research.

**Emphasis:** General information exchange.

Switzerland also is a member of the International Atomic Energy Agency and the Organization for Economic Co--Operation and Development/Nuclear Energy Agency.

Switzerland has cooperative agreements with SKB/Sweden; CEA/France; Euratom/EED; ONDRAF/Belgium; PNC/Japan; BfS, BMFT, GSF, BGR/Germany; and TVO/Finland.

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# Glossary

The following glossary of scientific and technical terms has been compiled to aid in the reading of this report. The glossary is not meant to be a formal glossary, nor to have the completeness of a dictionary, but rather, it is intended to help the reader understand some of the technical terms used regularly by the Board.

**Accessible environment:** The atmosphere, land surface, surface water, oceans, and portions of the earth's crust that are accessible to humans through air and water

**Aluminosilicate:** A compound in which silicon and aluminum atoms are joined by sharing linking oxygen atoms. Silicate compound in which some of the silicon atoms have been replaced by aluminum.

**Analogue:** A thing or part that is analogous. As used in this report, a naturally occurring phenomenon or something resulting from human activity that can provide information on or add understanding to aspects of repository performance. Analogues generally are broken into two categories: natural and anthropogenic. Natural analogues occur through natural phenomena. Anthropogenic analogues result from human activity. "Archaeological analogue" generally is used to refer to an analogue resulting from the activities of ancient cultures.

**Anthropogenic:** Caused by humans. (See **Analogue**.)

**Anion:** The dissolved negative ion of a salt

**Apatite:** A group of phosphate mineral with the general formula $X_5(YO_4)_3Z$, where X is usually Ca or Pb, Y is P or As and Z is F, Cl, or OH

**Areal power density:** The concentration of thermal energy produced by emplaced waste, which is averaged over the area of the repository and expressed in watts per square meter or in kilowatts per acre

**Backfilling:** The placement of materials, originally removed or new, into underground excavated areas, including waste-emplacement holes, drifts, tunnels, and shafts

**Baseline:** Defined and controlled element (e.g., configuration, schedule, data, values, criteria, or budget) against which changes are measured and compared

**Biosphere:** The zone of planet earth where life naturally occurs, extending from the deep crust to the lower atmosphere. Earth's living organisms.

**Block:** An undeformed mountain-sized section of rock that may be bounded by large faults and / or large-scale topographic features (e.g., river valleys)

**Borehole:** An excavation, formed by drilling, that is essentially cylindrical and is used for exploratory purposes

**Borehole emplacement:** The DOE's baseline plan calls for the emplacement of canisters of spent fuel and high-level waste in boreholes excavated in the walls of tunnels in the proposed repository

**Borings:** Holes drilled into the earth

**Borosilicate glass:** A silicate glass containing boric acid and used to immobilize or encapsulate and stabilize commercial or defense high-level waste from reprocessing

**Burnup:** A measure of reactor fuel consumption expressed as the percentage of fuel atoms that have undergone fission, or the amount of energy produced per unit weight of fuel. Burnup history refers to the length of time spent fuel remains in the reactor. There is a direct correlation between burnup history and thermal output.

**Calcine:** A solid that has been heated to a high temperature without melting, usually in the presence of oxygen

**Canister:** The structure surrounding a waste form (e.g., high-level waste immobilized in borosilicate glass) that facilitates handling, storage, transportation, and / or disposal. Before emplacement in a repository, the canister may be placed in a disposal container.

**Cask:** A container used to transport and / or store irradiated nuclear fuel or high-level nuclear waste. It provides physical and radiological protection and dissipates heat from the fuel. (See **Universal cask**.)

**Characterization:** The collecting of information necessary to evaluate suitability of a region or site for geologic disposal. Data from characterization also will be used during the licensing process.

**Colloid:** A suspension of very fine-grained material

**Container:** A receptacle used to hold radioactive material (usually spent fuel)

**Curie (Ci):** The unit used in measuring radioactivity. One curie equals $3.7 \times 10^{10}$ spontaneous nuclear disintegrations per second; also the quantity of a material having the activity of one curie.

**Disposal:** The isolation of radioactive materials from the accessible environment with no foreseeable intent of recovering them. Isolation occurs through a combination of constructed and natural barriers, rather than by human control. The Nuclear Waste Policy Act of 1982 specifies emplacement in mined geologic repositories.

**Disturbed zone:** That portion of the surrounding rock whose physical or chemical properties have changed as a result of construction or “as a result of heat generated by the emplaced radioactive waste such that the resultant change of properties may have a significant effect on the performance of the geologic repository” (10 CFR 60).

**Drift:** A near-horizontal, excavated passageway through the earth

**Engineered barrier system:** The constructed, or engineered, components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. It includes the thermal-loading strategy, repository design, waste form, waste containers, material placed over and around such containers, and backfill materials.

**Environmental issues:** Issues covering the potential effects that site-characterization activities and development, operation, and closure of a repository could have on the environment, which includes air, water, soil, biologic, cultural, and socioeconomic resources at and downstream, in surface water or ground water, or downwind from the site for thousands of years. Environmental issues also include reclamation and restoration after, or mitigation of effects of, site characterization and repository construction, operation, and closure.

**Evapotranspiration:** The overall process of water vapor escaping into the atmosphere by evaporation from soil surfaces, by evaporation from open bodies of water, and by transpiration from the soil by plants

**Exploratory facility:** An underground opening and structure constructed for the purpose of site characterization

**Exploratory shaft facility (ESF):** An exploratory facility defined in the Site Characterization Plan consisting primarily of two adjacent shafts. Now called the exploratory studies facility.

**Exploratory studies facility (ESF):** New designation for the exploratory shaft facility

**Fault:** A plane in the earth along which differential slippage of the adjacent rocks has occurred

**Fault displacement:** Relative movement of two sides of a fault such as that which occurs during an earthquake

**Fission product:** A nuclide produced by the fission of a heavier element

**Flux:** The rate at which ground water flows across an area of porous or fractured media, which is at right angles to the direction of the flow

**Fracture:** Any break in a rock (i.e., a crack, joint, or fault) whether or not accompanied by displacement

**Frit:** A mixture of calcified solids from which glass is made; its consistency is usually that of a sand or powder

**Fuel ageing:** Storage of radioactive materials especially spent nuclear fuel, to allow the decay of radionuclides. Young spent fuel has a higher thermal output than aged spent fuel.

**Fuel assembly:** (See **Fuel rod**.)

**Fuel rod:** A rod or tube made out of zircaloy into which fuel material, usually in the form of uranium pellets, is placed for use in a reactor. Many rods or tubes, mechanically linked, form a fuel assembly or fuel bundle.

**Geochemistry:** Geochemistry at the Yucca Mountain site is concerned primarily with the potential migration of radionuclides to the accessible environment. Geochemists are studying the chemical and physical properties of the minerals, rocks, and waters that might affect the migration of radionuclides from a repository.

**Geoengineering:** Refers to the design, construction, and performance of the exploratory studies facility, surface drilling operations, and underground openings at the repository, taking into account the engineering properties of the geologic materials and their spatial variations

**Geologic block:** That portion of Yucca Mountain in which placement of the proposed repository site is being considered

**Geologic repository:** A system, requiring licensing by the Nuclear Regulatory Commission, that is intended to be used, or may be used, for the disposal of radioactive waste in an excavated geologic medium. A geologic repository includes (1) the geologic repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.

**Ground water:** Water that exists or flows in a zone of saturation between land surfaces

**Ground-water table:** The upper surface of the zone of water saturation in rocks, below which all connected interstices and voids are filled with water

**Half-life:** The time required for a radioactive substance to lose 50 percent of its activity by decay. Some radioactive materials decay rapidly. For example, the fission products strontium-90 and cesium-137 have half-lives of about 30 years. Others decay much more slowly: plutonium-239 has a half-life of about 25,000 years.

**High-level waste:** (1) Irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been converted. (See **Reprocessing**.)

**Holocene epoch:** That period of geologic time extending from 11,000 years ago until the present

**Host rock:** The rock in which the radioactive waste will be emplaced; specifically, the geologic materials that will directly encompass and be in close proximity to the underground repository

**Human factors engineering:** A technical discipline that applies what is known about human psychological, physiological, and physical limitations to the design and operation of systems to enhance safety

**Hydrogeology:** Refers to the study of the geologic aspects of surface and subsurface waters. At the Yucca Mountain site, emphasis is placed on the study of fluid transport through the rock matrix and fractures. Ground water is considered to be a prime means by which radionuclides (atoms that are radioactive) could be transported from the repository to the accessible environment.

**Hydrolysis:** The chemical reaction between water and the ion of a weak acid or a weak base

**Inclined dry-drilling:** Drilling (at an angle) in which rock and cuttings are lifted out of a borehole by a current of air, rather than a drilling fluid

**Infiltration:** The flow of a fluid into a solid substance through pores or small openings; specifically, the movement of water into soil or porous rock

**In-place disposal:** Disposal of a waste material without moving it

**Interim storage or storage:** Temporary storage of spent fuel or high-level waste with the intention and expectation that the waste will be removed for subsequent treatment, transportation, and / or isolation

**Isotope:** A class of atomic species, of a given element, having differing atomic weights but identical atomic numbers and slightly differing chemical and physical properties

**Jointed rock:** Rock containing fractures or partings without displacement

**Kinetics:** Study of the rates of chemical reactions

**Leach:** To partially or completely dissolve and remove chemical components of a solid usually by an aqueous solution. The rate at which this occurs is the leach rate.

**Long-lived waste package:** Generally used in this report to refer to a waste package that has the capability to contain wastes for at least many thousands of years

**Low-level (radioactive) waste:** Radioactive material that is neither high-level radioactive waste, spent nuclear fuel, transuranic waste, nor byproduct material as defined in Section 11a(2) of the Atomic Energy Act of 1954. An example is contaminated medical waste.

**Magma:** The molten rock material from which igneous rocks are formed

**Metric ton:** 1,000 kilograms; about 2,205 pounds

**MTHM:** Metric tons of heavy metal (nuclear fuel)

**Monitored retrievable storage (MRS) facility:** A facility to collect spent fuel in a central location, where it can be stored until the fuel can be accepted at a repository

**Multipurpose cask:** A concept for a cask that can be used for more than one purpose, for example, to store and transport, and perhaps dispose of spent fuel

**Natural analogue:** (See **Analogue**.)

**Nevada Test Site (NTS):** A geographic area located in southern Nevada that is owned and operated by the U.S. Department of Energy and devoted primarily to the underground testing of nuclear devices

**Nonvolatile:** A material that changes from a solid or liquid state to a gaseous state insignificantly at a temperature of interest

**Nonwelded tuff:** A tuff that has not been consolidated and welded together by temperature, pressure, or a cementing mineral

**Noble metals:** Silver, mercury, gold, and the platinum metals (ruthenium, rhodium, palladium, osmium, iridium, and platinum)

**Performance assessment:** Any analysis that predicts the behavior of a system or a component of a system under a given set of constant or transient conditions. In this case, the system includes the repository and the geologic, hydrogeologic, and biologic environment.

**Plutonium:** A radioactive element with an atomic number of 94. Its most important isotope is fissionable plutonium-239, produced by neutron irradiation of uranium-238.

**Portal:** Opening to the underground; the rock face at which a tunnel is started

**Postclosure:** The period of time after the closure of the repository

**Preclosure:** That time prior to the backfilling of the repository

**Pressurized water reactor:** A reactor system that uses pressurized water in the primary cooling system. Steam formed in a secondary cooling system is used to turn turbines to generate electricity.

**Public health issue:** An issue involving potential direct or indirect effects on, or risk to, human health during repository development, operation, and after closure. The possible public health and environmental consequences of the handling and transportation of high-level radioactive waste from points of origin to the repository are also of concern.

**Quality assurance:** The management process used to control and assure the quality of work performed

**Quaternary period:** The second part of the Cenozoic Era (after the Tertiary) beginning about 2 million years ago and extending to the present

**Radioactivity:** The spontaneous emission of radiation from the nucleus of an atom. Radioisotopes of elements lose particles and energy through this process of radioactive decay. Radioactivity is measured in terms of the number of nuclear disintegrations occurring in a unit of time. The common unit of radioactivity is the curie (Ci).

**Radiolysis effects:** Radiation-induced dissociation of molecules; radiation-induced dissolution of molecules

**Radiometric age dating:** The calculation of the age of a material by a method that is based on the decay of radionuclides that occur in the material

**Radionuclide:** A radioisotope that decays at a characteristic rate by the emission of particles or ionizing radiation(s)

**Radionuclide migration:** The movement of radionuclides, generally in liquids or gas forms, through a rock formation

**Ramp:** An inclined tunnel. Here, ramps would allow exploration and research of rock features and other phenomena critical to characterizing an underground repository site, while at the same time allowing for future use as an entrance to the underground repository should the site prove qualified.

**Repository:** A site and associated facilities designed for the permanent isolation of high-level radioactive waste and spent nuclear fuel. It includes both surface and subsurface areas, where high-level radioactive waste and spent nuclear fuel-handling activities are conducted.

**Repository horizon:** A particular geologic sequence or layer where radioactive waste is intended for disposal. The Yucca Mountain repository horizon is 900 to 1,200 feet beneath the surface of the mountain.

**Reprocessing:** The process whereby fission products are removed from spent fuel, and fissionable parts are recovered for repeated use

**Retrievability:** The capability to remove waste packages from the repository

**Risk:** Possibility of suffering harm or loss due to some event. The magnitude of the risk depends on both the probability of occurrence of an event and the consequences should the event occur.

**Risk and performance analysis:** Here it refers to the assessment of the long-term performance of a waste repository. Such analysis provides a means for incorporating all scientific and technical aspects into an integrated description of the entire repository system. Iterative performance analysis also can be used to help determine which site-characterization studies need to be emphasized or moderated to provide information more focused on timely assessment of site suitability.

**Saturated rock:** A rock in which all of the connected interstices or voids are filled with water

**Seismicity:** (i.e., seismic activity) The worldwide, regional, or local distribution of earthquakes in space and time; a general term for the number of earthquakes in a unit of time

**Semivolatile:** A material that changes from a solid or liquid state to a gaseous state slowly at a temperature of interest

**Shaft:** A near-vertical opening excavated in the earth's surface

**Shear stress:** That component of stress that acts tangentially to a plane through any given point in a body

**Shotcrete:** Fine aggregate concrete sprayed under high pressure onto the rock face between rock bolts, after wire netting has been attached between the rock bolt plates and the rock face. The resulting reinforcement produced by the wire netting and concrete, anchored by the rock bolts, forms a semi-smooth appearance and significantly reduces the formation and fall of stress slabs.

**Silicate:** A metal salt containing silicon and oxygen in the anion

**Silica:** Natural silicon dioxide

**Site characterization:** (See **characterization**.)

**Slurry:** A thin mixture of liquid and fine solids

**Sorption:** Retardation (of transport) through the binding of radionuclides by the surfaces of geologic materials along the flow path

**Sorption characteristics:** Characteristics describing the ability of rocks and minerals to bind, reversibly or irreversibly, radionuclides or other chemical species on their surfaces

**Source term:** The compositions and the kinds and amounts of radionuclides that make up the source of a potential release of radioactivity from the engineered barrier system to the host rock

**Spent nuclear fuel:** An irradiated fuel element not intended for further use in a nuclear reactor

**Stochastic calculation:** A numerical calculation based on probabilistic laws

**Stratigraphic evidence:** Evidence obtained through the analysis of the form, distribution, composition, and properties of layered rock

**Stress slabs:** Slabs of rock (of varying thickness) that "peel" off the exposed rock surfaces of an excavation. The slabs are caused by the forces being exerted on the rock surfaces by internal rock pressure and gravity after excavation provides a void into which the pressure can be released.

**Structural geology:** Refers to the study of the deformational features of rocks induced by processes such as folding, faulting, and igneous activity. As used in this report, it also includes a study of the processes themselves.

**Subsurface water:** All water beneath the land surface and surface water

**Systems safety:** A technical discipline that provides a life-cycle application of safety engineering and management techniques to the design of system hardware, software, and operation

**Tectonic features and processes:** Those features (e.g., faults, folds) and processes (e.g., earthquakes, volcanism) that are related to the large-scale movement and deformation of the earth's crust

**Thermal energy:** Heat; in this case produced by the decay and transformation of radioactive waste over time

**Thermal load:** The amount of heat distributed and affecting the near-field and overall repository material, including geophysical and engineered barriers, that is induced by waste emplacement (usually measured in kilowatts per acre)

**Thermal-loading strategies:** The determination of waste emplacement to cause specific effects on the repository by the heat generated by the waste. These strategies are based on such criteria as whether it is desirable to initially place the repository at a temperature below or above the boiling point of water, or what effect various temperature ranges will have on long-lived waste packages. Thermal-loading is usually measured in kilowatts per acre.

**Thermal zone:** That region of the repository where the temperature has been increased by the presence of high-level waste

**Thermo-mechanical effects:** Stresses or strains induced by temperature changes

**Transportation and systems:** As used here, it refers to a system for moving spent nuclear fuel from approximately 110 commercial nuclear reactors located at 70 sites throughout the nation and transporting the high-level radioactive waste from Department of Energy defense facilities to a disposal site. It is not merely the activities associated with packaging spent fuel in a shipping cask and shipping it by highway, rail, or water. Transportation and systems also includes all processes involved before and after the trip — removing spent fuel from its storage facility, loading it into the cask, loading and unloading it at the various handling sites, storing it, and finally emplacing it in a repository.

**Transuranic:** Containing elements or isotopes having atomic numbers higher than uranium (92). TRU wastes may take a long time to decay (i.e., have a long half-life).

**Transuranic waste (TRU):** Waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, per gram of waste with half-lives greater than 20 years — except for (1) high-level radioactive wastes, (2) wastes that the U.S. Department of Energy with the concurrence of the Environmental Protection Agency Administrator has determined do not need the degree of isolation required by 40 CFR 191, or (3) wastes that the U.S. Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR 61. Research on disposal of TRU is underway at the Waste Isolation Pilot Project in Carlsbad, New Mexico, where waste consists primarily of clothing, equipment, machine parts, and some liquid waste contaminated during reprocessing at U.S. defense facilities.

**Tuff:** A rock composed of compacted volcanic ash. It is usually porous and often relatively soft.

**Tunnel:** An underground passage that is open to the surface at both ends

**Unsaturated rock:** A rock in which some or all of the connected interstices or voids are filled with air

**Unsaturated zone:** Rock / geologic formation that is located above the regional ground-water table

**Uranium:** A naturally radioactive element with the atomic number 92 and an atomic weight of approximately 238. The two principal naturally occurring isotopes are the fissionable U-235 (0.7 percent of natural uranium) and the fertile U-238 (99.3 percent of natural uranium). Uranium may be measured in metric tons of uranium (MTU).

**Volatile:** A material that changes from solid or liquid state to a gaseous state quickly at a temperature of interest

**Volatilization:** Conversion from a solid or liquid state to a gaseous state

**Volcanism:** The process by which molten rock and its associated gases rise from within the earth and are extruded on the earth's surface and into the atmosphere

**Waste package:** The waste form and any containers, shielding, packing, or other sorbent materials immediately surrounding an individual waste container

**Welded tuff:** A tuff that has been consolidated and welded together by heat, pressure, and possibly the introduction of cementing minerals

**Zeolites (zeolite minerals):** A large group of white, faintly colored, or colorless silicate minerals characterized by their easy and reversible loss of water of hydration and their high adsorption capacity for dissolved metal ions in water

**$^{14}CO_2$:** Carbon dioxide containing the radioactive isotope of carbon, $^{14}C$