Appendix A
Panel Organization

1. Panel on Structural Geology & Geoengineering

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

2. Panel on Hydrogeology & Geochemistry

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

3. Panel on the Engineered Barrier System

Chair:	Dr. Ellis D. Verink	Staff:	Dr. Sidney J.S. Parry
Members:	Dr. Dennis L. Price		
	Dr. Donald Langmuir		
Ex Officio:	Dr. Don U. Deere		

4. Panel on Transportation & Systems

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

5. Panel on the Environment & Public Health

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

6. Panel on Risk & Performance Analysis

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

7. Panel on Quality Assurance

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

Appendix B
Meeting List for 1990–91

January 18-19, 1990

Meeting (open)
Panel on Containers & Transportation
Pleasanton, California
Topic: Briefings on the waste package environment and waste package container
Transcript available

January 18, 1990

Board Meeting (closed evening session)
Pleasanton, California
Topic: Board activities
Minutes available

January 19, 1990

Board Meeting (closed evening session)
Pleasanton, California
Topic: Board activities
Minutes available

February 1, 1990

Technical Exchange (open)
Panel on Structural Geology & Geoengineering
Denver, Colorado
Topic: DOE presentation on the exploratory shaft facilities (ESF) alternatives
Transcript not available (meeting not recorded)
Presentation briefing book available

March 2-3, 1990

Board Meeting (closed)
Tucson, Arizona
Topic: Board-related activities
Minutes available

March 19-20, 1990

Joint Meeting (open)
Panel on Risk & Performance Analysis and the Panel on Structural Geology & Geoengineering
Denver, Colorado
Topic: Repository system design requirements
Transcript available

March 20, 1990

Ad Hoc Board Meeting (closed evening session)
Denver, Colorado
Topic: Board activities
Minutes available

March 22, 1990

Release of First Report to the U.S. Congress and the U.S. Secretary of Energy

April 7, 1990

Technical Exchange (open)
Panel on Structural Geology & Geoengineering
Las Vegas, Nevada
Topic: Briefings by DOE on the ESF alternatives analysis study, repository configuration, and repository construction methods
Transcript not available (meeting not recorded)
Presentation briefing book available

April 7, 1990

Board Meeting (closed evening session)
Las Vegas, Nevada
Topic: Board-related activities
Minutes available

April 8, 1990

Board Meeting (closed morning session)
Las Vegas, Nevada
Topic: Board-related activities
Minutes available

April 12, 1990

Technical Exchange (open)
Panel on Structural Geology & Geoengineering
Las Vegas, Nevada
Topic: DOE briefings on seismic issues at the proposed repository site
Transcript not available (meeting not recorded)
Presentation briefing book available

April 24-26, 1990

Meeting (open)
Panel on Environment & Public Health
Las Vegas, Nevada
Topic: Presentations by the State of Nevada, the Western Shoshone National Council, and the DOE and its contractors
Two-day field trip
Transcript available

May 18, 1990

Technical Exchange (open)
Panel on Transportation & Systems with the Nuclear Regulatory Commission (NRC)
Arlington, Virginia
Topic: NRC's role in several key issues relating to safe handling and transportation of spent nuclear fuel
Transcript not available (meeting not recorded)
Presentation briefing book available

May 26-June 2, 1990

Board Trip to Sweden and the Federal Republic of Germany
Discussion of Board observations in *Third Report*

June 1990

No meetings

July 23, 1990

NRC Briefing (open morning session)
Atlanta, Georgia
Topic: NRC briefing on licensing support system (LSS)
Transcript available

July 23, 1990

Board Meeting (closed afternoon session)
Atlanta, Georgia
Topic: Board activities
Minutes available

July 24-25, 1990

Board Meeting (closed evening sessions)
Atlanta, Georgia
Topic: Board activities
Minutes available

July 24-25, 1990

Joint Meeting (open)
Panel on Structural Geology & Geoengineering and the Panel on Hydrogeology & Geochemistry
Atlanta, Georgia
Topic: ESF alternatives study and surface-based testing program
Transcript available

July 26, 1990

Board Meeting (closed)
Atlanta, Georgia
Topic: Board activities
Minutes available

August 17, 1990

Public Hearing: Panel on Transportation & Systems
Amargosa Valley, Nevada
Topic: Transportation and systems issues affecting the proposed repository
Transcript available

August 28-29, 1990

Meeting (open)
Panel on the Engineered Barrier System
Pleasanton, California
Topic: Briefings by DOE and contractors on DOE strategy for development of packaging for spent fuel and high-level waste; overview of current spent fuel studies
Transcript available

September 1990

No meetings

October 10, 1990

Board Meeting (open morning session)
Arlington, Virginia
Topic: NRC/Electric Power Research Institute presentations on performance assessment
Transcript available

October 10, 1990

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

October 11, 1990

Technical Exchange (open)
Panel on Structural Geology & Geoengineering
Arlington, Virginia
Topic: DOE briefings on surface-based testing prioritization and Calico Hills risk/benefit analysis
Transcript not available (meeting not recorded)
Presentation briefing book available

October 15, 1990

Public Hearing: Panel on Environment & Public Health
Reno, Nevada
Topic: Environment and public health issues relating to the possibility of the development of a high-level waste repository at Yucca Mountain, Nevada
Transcript available

October 16, 1990

Meeting (open)
Panel on the Environment & Public Health
Reno, Nevada
Topic: Briefings by representatives from DOE, Western Shoshone National Council, State of Nevada, and the State's Nye County Office on Socioeconomic Issues
Transcript available

October 22, 1990

Meeting (open)
Panel on Transportation & Systems
Washington, D.C.
Topic: Transportation safeguard and operational activities
Transcript available

November 1-2, 1990

Meeting (open)
Panel on Quality Assurance
Arlington, Virginia
Topic: Briefings by the DOE and the NRC on quality assurance requirements and implementation process
Transcript available

November 19, 1990

Public Hearing: Panel on Transportation & Systems
Reno, Nevada
Topic: Transportation issues concerning the development and operation of a high-level waste repository at Yucca Mountain, Nevada
Transcript available

November 19-20, 1990

Technical Exchange (open)
Panel on Structural Geology & Geoengineering
Denver, Colorado
Topic: DOE and contractors brief panel on interim report activities on ESF alternatives analysis study
Transcript not available (meeting not recorded)
Presentation briefing book available

November 28, 1990

Release of *Second Report to the U.S. Congress and the U.S. Secretary of Energy*

December 1990

No meetings

January 15, 1991

Board Meeting (closed)
Arlington, Virginia
Topic: Board activities
Minutes available

January 16, 1991

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

January 17, 1991

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

January 17, 1991

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

February 1991

No meetings

March 1, 1991

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

March 6-7, 1991

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

March 14-15, 1991

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

March 26-27, 1991

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

April 16, 1991

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

April 17, 1991

Board Meeting (open)
Natural and Anthropological Analogues (cont.)
(closed afternoon session)
Reno, Nevada
Transcript available for morning session
Minutes available for afternoon session

April 18, 1991

Board Meeting (closed)
Reno, Nevada
Topic: Board activities
Minutes available

May 20-21, 1991

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

June 9-15, 1991

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

June 25-27, 1991

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

July 15, 1991

Meeting (open)
Panel on Structural Geology & Geoengineering
Arlington, Virginia
Topic: Management Systems Improvement Strategy (MSIS); and exploratory studies facility (ESF) design review update
Transcript available

July 16-17, 1991

Board Meeting (open)
Arlington, Virginia
Topic: Office of Civilian Radioactive Waste Management (OCRWM) research priorities and budget; international waste management programs; EPA standards, NRC regulations, and the DOE's 10 CFR 960
Transcript available

July 18, 1991

Board Meeting (closed)
Arlington, Virginia
Topic: Board activities
Minutes available

August 12-14, 1991

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

August 15, 1991

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

September 18-19, 1991

Meeting (open)
Panel on Structural Geology & Geoengineering
Las Vegas, Nevada
Topic: Exploratory studies facility (ESF) design review
Transcript available

September 25-26, 1991

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

October 8-10, 1991

Board Meeting (open)
Las Vegas, Nevada
Topic: Thermal loading / repository design
Transcript available

October 11, 1991

Board Meeting (closed)
Las Vegas, Nevada
Topic: Board activities
Minutes available

November 12-13, 1991

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

December 1991

No meetings scheduled

January 7–8, 1992

Board Meeting (open)
Arlington, Virginia
Topic: to be determined

January 22–23, 1992

Meeting (open)
Panel on Structural Geology & Geoengineering
Newport Beach area, California
Topic: to be determined

February 10–11, 1992

Meeting (open)
Augusta, Georgia
Topic: Savannah River high-level waste vitrification operations
Transcript available

February 12–13, 1992

Meeting (open)
Panel on Transportation & Systems
Location to be determined
Topic: to be determined

April 8–9, 1992

Board Meeting (open)
Dallas, Texas
Topic: Thermal-loading emplacement, early site-suitability evaluation, performance assessment.

May 11–15, 1992

Meetings (open)
Panel on the Engineered Barrier System
Hanford Plant, Richland, Washington
Idaho National Engineering Laboratory, Idaho Falls, Idaho
Topic: High-level waste vitrification operations

July 7–10, 1992

Board Meeting (open)
Denver, Colorado
Topic: Monitored retrievable storage (MRS) technology, waste acceptance, and transportation and waste management systems

October 13–14, 1992

Board Meeting (open)
Las Vegas, Nevada
Topic: to be determined

Appendix C
Presenters List

The following people made presentations to the Board or panel(s) from February 1, 1991, through July 31, 1991. This list is arranged alphabetically by organization. Citizens and independent consultants are listed at the end.

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Appendix D
The Canadian Approach to Managing the Disposal of Spent Fuel

Introduction

The Canadian nuclear power program contributes to the electrical power supply of Quebec and New Brunswick, but its primary role is to supply more than 60 percent of Ontario's electricity, where it has been a major source of electricity since the early 1970s. Nuclear power in Ontario comes from two sources: the eight nuclear reactors at the Pickering Generating Station east of Toronto and eight reactors at the Bruce Generating Station, near Port Elgin. Four additional reactors at the New Darlington Generating Station, near Newcastle, are scheduled to go into full service in 1993.

Canadian reactors generate nuclear power through a heavy water process that uses natural uranium to cause a reaction. Natural uranium consists mostly of uranium-238, with a very small percentage of uranium-235 (0.7%). For a nuclear reaction to occur, the atoms in uranium-235 must be split in a sustained chain reaction. This chain reaction, or "fissioning," creates the constant amount of heat needed to generate electricity. However, once the atoms are split, they travel so fast it is difficult for them to collide and cause a chain reaction. An atom in heavy water called deuterium is used as a "moderator" to slow down and cause the neutrons of uranium-235, to collide more frequently and sustain a chain reaction.*

Because the Canadians use natural uranium in their reactors, they have a large amount of waste. Current designs are for a repository that will dispose of 191,000 metric tons of spent fuel or 10 million fuel bundles from approximately 23 reactors assuming projects operate for more than 100 years.**

Canadian deuterium uranium (CANDU) fuel bundles are made of sealed metal tubes packed with pellets of uranium. A bundle is about 50 centimeters long and weighs about 23 kilograms. Spent fuel bundles are stored in pools at each station. Canada has had no significant reprocessing experience, nor are there currently any plans to reprocess.

Total costs of repository development are projected to be about $9 billion (Canadian), spread over about 70 years, for 191,000 metric tons of spent fuel (projected for the year 2035). The construction phase would last about 10 years. Waste would be emplaced over a 40-year period.

Current Management Approach

Rather than national legislation regulating high-level waste disposal management, such as the U.S. Nuclear Waste Policy Act (NWPA), Canada has a process entailing direct federal-provincial bargaining that has resulted in the existing efforts to develop a disposal strategy. Since nuclear energy production takes place almost exclusively in Ontario, that province's

* J.A.L. Robertson, *Nuclear Power in Canada: The CANDU System*, July 1990; and *Heavy Water*, brochure published by Ontario Hydro.

** Heiki Tamm, Director, Environmental Review Office, AECL, in a presentation before the NWTRB at AECL, Pinawa, Manitoba, June 10, 1991.

government and the federal government negotiated an agreement in 1978 that provides the basis for a joint federal-provincial effort:

- Ontario, via the provincial utility Ontario Hydro (OH), is responsible for research into interim storage of spent fuel and waste transportation.

- The federal government (under the crown corporation Atomic Energy of Canada Limited - AECL) is responsible for R&D on immobilization and disposal of high-level waste. OH provides some technical support to the AECL. The AECL also set up the Technical Advisory Committee (TAC), made up of independent experts to review its work.

Since the early-1980s the Canadian approach to establishing a disposal concept has been to decouple the concept of developing a repository from the process of siting one. This decoupling reflects a 1977-1978 situation in which citizen concern about siting significantly impeded R&D. Current efforts focus on demonstrating that a technically and politically acceptable disposal concept exists. The national goal is to achieve concept acceptance by the mid-1990s. There will be no effort to locate a site until or unless a disposal concept has been accepted by the public.

At present, the concept has been referred by the AECL to Environment Canada (Ministry for Environment) and is currently undergoing rigorous review by the Environmental Assessment Panel created under a federal environmental assessment and review process (EARP). This process, administered by the Federal Environmental Assessment Review Office (FEARO) is being used to predict potential environmental consequences of siting various facilities, such as airports, dams, and solid waste sites.

A Scientific Review Group (SRG), whose members are appointed by and responsible to the Environmental Assessment Panel, is examining the technical aspects of the disposal concept.

The Environmental Assessment Panel's review will be broad and will examine a range of issues including

- the criteria to be used to evaluate the concept;

- the general criteria for managing spent fuel as compared to those for managing wastes from other energy and industrial sources;

- various approaches to long-term fuel management including storage with a capability for continuing human intervention like monitoring, retrieval, remedial action, and passive disposal;

- the degree to which Canada should relieve its future generations of the burden of looking after the fuel;

- the social, economic, and environmental implications of the Canadian concept;

- the use of different geologic media and the experiences of other countries;

- the impact of reprocessing on the volume of the waste;

- the process and criteria for siting a facility; and

- the next steps to be taken with respect to the management of spent nuclear fuel.

The Environmental Assessment Panel issued guidelines for AECL and OH to follow in preparing an environmental impact statement. These guidelines are based on information gathered by the Environmental Assessment Panel and the SRG and on information gleaned from nationwide hearings held by the Environmental Assessment Panel during 1990.

In response to the guidelines, AECL and OH will submit an environmental impact statement to the Environmental Assessment Panel, who will in turn evaluate this work. A final impact statement is not expected until at least 1992. Once the Environmental Assessment Panel is satisfied with the level of information received from AECL and OH, it will hold more public hearings. Once the Environmental Assessment Panel has reviewed information from these hearings, a report will be submitted to Environment Canada and the Ministry of Energy, Mines and Resources. Environment Canada will then make a recommendation to the Canadian government and the province of Ontario. The process will take at least until the end of 1994, if not later.

If the governments of Canada and Ontario receive a recommendation they decide is unacceptable, they could commission further research and development or examine different options developed by other countries. There is no provision for breaking a federal-provincial deadlock. In such a case, both sides would probably continue to work to resolve problems. If the recommendation is accepted, the governments will determine the next steps in the process.

Transportation

Transportation of used fuel in Canada takes place on a limited basis only for research and development purposes. OH has developed a shipping cask constructed of stainless steel more than 25 centimeters thick. Each cask holds 192 fuel bundles and weighs 35 metric tons when full. After meeting a series of tests designed to simulate accident conditions, the cask was approved by the Atomic Energy Control Board (AECB) in 1987.

During transport, the cask would be the single item moved on a flatbed tractor/trailer designed to handle heavy loads. A tie-down system would firmly secure the cask to the trailer.

OH also is designing a rail transport version of the cask, which would weigh 65 metric tons and hold 384 or 576 spent fuel bundles, depending on the weight limits of the railroad. A special train would take the casks from the nuclear generating station to the disposal facility.

Water transport is a viable option since all of Ontario's nuclear generating stations are located on Lake Ontario and Lake Huron. Under this scenario, the casks would be placed on a unique barge, which would be moved by tugboat to a special port. While in transit, the casks would be held in place below deck with a system of tie-downs designed to withstand heavy collisions. Each barge would transport about 7,000 fuel bundles in either 12 rail casks or 36 road casks.

Fuel shipments would be subject to federal and provincial acts and regulations, including the Atomic Energy Control Act (1946), the National Transportation Act, the Nuclear Liability Act; the Transport of Dangerous Goods Act and Regulations, the Environmental Protection Act, the Railway Act, and the Canadian Shipping Act. OH would provide an emergency response plan.

Interim Storage

By the end of 1988, there were about 12,300 metric tons (33,900 metric tons projected for the year 2000) of spent fuel stored in pools at reactor sites. At Whiteshell Nuclear Research Establishment, Manitoba, Douglas Point, and at the prototype Gentilly-1, spent fuel is being stored in concrete canisters containing steel liners.

A cooling period for spent fuel of up to 50 years is being assumed in one of the AECL's conceptual repository designs, but there is no minimum interim storage period. The AECB states that it could in principle review a license application for the permanent disposal of new (hot) fuel, but sees technical disadvantages. For the present, spent fuel is being stored at reactor. OH is investigating both wet and dry storage for the additional spent fuel that cannot be stored in existing at-reactor wet storage facilities.

If a monitored retrievable storage (MRS) facility becomes necessary or desirable, it will more than likely be built at an existing reactor site. Under such a scenario, the design life of an MRS would be on the order of 100 years.

Research Facilities and Testing Programs

As of March 1990, there were eight research reactors operating at Canadian universities: four in Ontario, two in Quebec, and one each in Nova Scotia and Alberta. Other research facilities include the AECL facilities at Chalk River, Ontario, and Pinawa, Manitoba, where there is a research reactor designed to operate at up to two megawatts. An Underground Research Laboratory (URL) is located near the Whiteshell Nuclear Research Establishment in Pinawa.

As of March 31, 1990, there were 16 separately licensed waste management facilities in operation, ten in Ontario, two each in Quebec and Alberta, and one each in Saskatchewan and New Brunswick. Two additional facilities are associated with the Chalk River Nuclear Laboratories in Ontario, the Whiteshell Nuclear Research Establishment in Manitoba.

The following is a summary of five aspects of Canada's multifaceted R&D program.

Engineered Barriers

Canada is researching and testing a variety of potential engineered barriers for their contribution to radionuclide containment.

Used Fuel. Studies conducted at an immobilized fuel test facility indicate that used fuel is an extremely stable waste form that can serve as a barrier. The studies tested interactions between radioactive nuclear fuel wastes, natural rock barriers, and materials under consideration for the engineered barriers in an underground used nuclear fuel disposal vault (repository). The vault contains nine large concrete canisters to house experiments with highly radioactive materials and allow scientists to study the effects of water, heat, pressure, and radiation on the materials that may be used in a disposal vault. Most radioactive material would remain in ceramic fuel pellets, which are difficult to dissolve in water and are sealed inside zirconium alloy tubes that may provide an additional barrier to water penetration.

Containers. Corrosion-resistant containers will act as another barrier. Test results show that titanium or copper containers would have the necessary corrosion properties to prevent access of ground water for several hundred years. Glass beads are compacted around the used fuel bundles and into the spaces between the fuel and the container shell to provide internal support against underground pressures. The containers have been designed to last for at least 500 years in the kind of ground water found in the Canadian Shield. The containers will be emplaced at temperatures up to 100 degrees Celsius.

Shipping casks. Currently, Ontario Hydro is working on the development of a dry storage container for both storage and transportation, and possibly as a disposal container. High compressive strength and low pH cement pastes and concrete mixes are being developed. Ontario Hydro also is looking at titanium, nickel-based alloys, and copper as container materials. Longer-term containment in ceramics also is being studied.

Waste forms. Glasses, ceramics, and glassceramics are being evaluated for containing reprocessing wastes, should reprocessing become policy.

Repository Sealing. Research shows that a special mixture of clay-sand sealing materials packed around the containers has the ability to limit groundwater movement and trap escaping radioactive material. On contact with water, the clay would swell and provide a seal around the containers. When ground water eventually gets through and the container corrodes, the clay would retard the rate of movement of the dissolved waste particles. Rooms and tunnels of the disposal repository would be backfilled with similar clay mixed with sand and crushed rock. Any significant fractures in the rock around the repository would be grouted with clay or cement, as would shafts and boreholes. Full-scale shaft sealing and container sealing tests will be carried out in the URL.

Candidate materials for buffers, backfill, and shaft seals include sodium bentonite, calcium bentonite, shale, clay, silica sand, and crushed granite.

Natural Barriers

Natural barriers are another possibility. Extensive surface mapping, drilling, and hydrogeologic investigations have been carried out at research sites in the Canadian Shield to obtain information about rock characteristics and ground-water flow.

Tests have been conducted to determine the mechanical, physical, and chemical properties of the rock, the physical and chemical characteristics of ground water, the nature of ground-water/rock radionuclide interactions, movement of ground water through the rock, the thermal stress caused by heat transfer from the fuel to the rock, and the mechanical stresses resulting from the excavated openings in the rock mass.

A technology has been developed that allows scientists to establish the geologic and hydrogeologic characteristics of rock masses to depths of 1,000 to 1,200 meters. At the URL, a shaft has been sunk to 445 meters, and experimental rooms have been built at 240 meters. The URL is being used to study the physical and chemical effects of excavation in granite and to demonstrate the technology necessary for safe disposal of used nuclear fuel.

Environmental Research

Environmental research has been carried out to develop an understanding of processes in the biosphere and to understand the migration of radioactive material in the surface environment. Models and computer codes to identify impacts have been designed.

Disposal Facility Engineering

Extensive engineering studies have determined that the technology exists to build and operate a disposal repository. The design, construction, operation, closure, and decommissioning of a disposal repository would be a large industrial project. The repository would be built 500 to 1,000 meters deep in stable rock in the Canadian Shield. The area would be approximately 2 square kilometers.

Containers of spent fuel would be placed in boreholes in the floors of the emplacement rooms. Dry silica sand would be used to backfill the boreholes between the sealing material and the container. Then the top layer of sealing material would be added. The backfill in the rooms would be sprayed into the area, and the rooms would be sealed with concrete bulkheads, which are then contact grouted to the rock. The containers could still be retrieved at this point.

Analogues

Analogue testing at Cigar Lake ore body has uncovered natural uranium crystals that were formed about 1,300 million years ago. This discovery gives confidence that geologic systems can contain uranium oxide for very long periods of time.

The Canadian concept for managing disposal of radioactive waste proposes that bentonite clay be packed around the waste containers because bentonite swells when it contacts water. However, the disposal containers will measure up to 100 degrees Celsius; there will be high pressures in the repository; and salty water may be present. Some natural clays, such as those near volcanoes or deep in the earth's crust, have been exposed to similar conditions. Studies at two such deposits, one in Sardinia underlying volcanic rock and the other in Sweden buried more than 1,000 meters below the island of Gotland, have shown that, as expected, the clays have changed. They still swell and retain their sealing properties, however, even after millions of years.

Program Landmarks

1946	Government of Canada, in the Atomic Energy Control Act, issues regulations and creates the Atomic Energy Control Board to regulate all stages of the nuclear fuel cycle. AECB also is taking the lead in developing the waste disposal concept.
1952	Government of Canada creates the Atomic Energy of Canada Limited to develop the peaceful uses of nuclear energy and develop CANDU heavy water reactors, radioisotopes, and irradiation equipment, except in the province of Ontario, where Ontario Hydro (OH), a provincially owned utility, assumes responsibility.
1977	Two government studies recommend focusing on deep geologic disposal in granitic rock of Canadian Shield.
1978	Canada and Ontario announce a joint program to assess and develop the technology for the safe management and permanent disposal of nuclear fuel waste in the granitic rock of the Canadian Shield. AECL, a federal crown corporation, is responsible for R&D on immobilization and disposal; OH is responsible for R&D on interim storage and transportation. Research begins on site in Canadian Shield (on waste forms, etc.).
1979	AECL creates a Technical Advisory Committee, made up of eminent independent scientists and engineers representing Canada's technical community, to provide ongoing review of the AECL's waste management program.
1980	AECL begins research in granitic rock at the Underground Research Laboratory near Pinawa, Manitoba.
1981	The federal government and the province of Ontario decouple siting a repository from developing a concept for waste disposal. They announce that a complete review of the concept will take place in the early 1990s.
1982	AECL issues first interim assessment of the waste disposal concept to scientific, regulatory, and public groups for comment.
1986	AECL issues second interim assessment.
1987	Ontario Hydro develops and tests and AECB licenses spent fuel transport casks.
1987	Two parliamentary standing committees investigate waste disposal in Canada and issue reports.
1988	The Ministry of Energy, Mines and Resources refers the waste disposal concept and all work done to date to Environment Canada for review by an environmental assessment panel under the Federal Environmental Assessment and Review Office. The panel's first task is to develop a set of guidelines for AECL and OH to use as they prepare an environmental impact statement.
1989	The panel creates the Scientific Review Group to conduct a specific, in-depth, critical examination of scientific and engineering aspects of the waste disposal concept.
1990 **May and June**	The panel organizes information meetings in 16 cities in the provinces of New Brunswick, Quebec, Ontario, Manitoba, and Saskatchewan. The panel staff provide information on review process, the mandate of the panel, opportunities for public involvement, funding, and timing of the next events.
1990 **July**	The panel recommends and the federal government initiates a program that helps public hearing participants investigate the issues.
1990 **October and November**	The panel holds scoping, or issue identification meetings, to develop guidelines for the environmental impact statement. Meeting participants include general public, native organizations, organized interest groups, government agencies, and the SRG.

1991 **June**	The panel issues guidelines to be used by AECL in preparing a comprehensive environmental impact statement. The panel receives comments for 60 days before finalizing and issuing the guidelines to AECL/OH.
1992	AECL and OH will complete and submit the environmental impact statement to the panel. It then will go to the SRG for evaluation, then back to the panel, which will submit it to a public review process. If the panel feels the statement responds to the guidelines, it will proceed to the public hearing stage of the process.
1994	After the public hearing process, the panel will review all information and prepare a report for Environment Canada and Ministry of Energy, Mines and Resources.
1995–1996	Environment Canada will make the final decision as to the acceptability of the concept for disposal of spent nuclear fuel. The Canadian and Ontario governments will then review the Ministry's recommendation.

Organizations Involved in Managing Canada's Nuclear Waste Disposal Program

A brief description of the authority and responsibilities of each of the organizations involved in Canada's nuclear waste management program follows. Organizations are listed in alphabetical order.

Atomic Energy of Canada Limited (AECL), a crown corporation, was established to apply nuclear science and technology to the benefit of Canada. AECL's Research Company is the second largest research organization in Canada with more than 3,000 management, technical, and support staff at its two laboratories in Pinawa (Whiteshell) and Chalk River. AECL's Waste Management Program Responsibility Centre, one part of the company, is centered at the Whiteshell Nuclear Research Establishment at Pinawa. Together with Ontario Hydro, it is responsible for developing disposal technologies for radioactive waste. AECL and Ontario Hydro spend $60 million (Canadian) a year on R&D in waste management.

Atomic Energy Control Board (AECB) was established in 1946 by the Atomic Energy Control Act. The Board, which consists of five members, reports to parliament through the Ministry of Energy, Mines and Resources. It is the AECB's responsibility to control the development, application, and use of nuclear energy in Canada. It also represents Canada in international measures of control. The AECB administers the Nuclear Liability Act, designating nuclear installations and prescribing basic insurance to be carried by the operators of such nuclear installations. Regulatory control of nuclear facilities and materials is achieved through a comprehensive licensing system, extending to the import and export of nuclear materials and involving Canadian participation in the activities of the International Atomic Energy Agency and compliance with the Treaty on the Non-Proliferation of Nuclear Weapons.

Bruce Nuclear Power Development (BNPD) is Ontario's largest energy center and one of the largest centers of energy production in the world. It includes a heavy water plant, a bulk steam system, low- and medium-level radioactive waste storage facilities, a nuclear training center, and various administrative and service buildings. There are eight reactors, four completed in the late 1970s and four completed between 1984-1987. Also at the BNPD site is the Bruce Energy Center, an industrial and agricultural park that offers an economical, reliable, and secure supply of medium pressure steam from the BNPD.

Environment Assessment Panel (EAP) on nuclear waste is one of a number of panels working under the auspices of FEARO. Its purpose is to review Atomic Energy of Canada Limited's concept of geologic disposal of nuclear fuel wastes in Canada. It also will look at a broad range of nuclear fuel waste management issues.

The panel will concentrate its activities in those provinces where nuclear reactors are located: Ontario, Quebec, and New Brunswick. The EAP's final report will be submitted to Environment Canada and the Ministry of Energy, Mines and Resources in approximately 1995-1996. The EAP's final report will address (1) whether AECL's concept for geologic disposal of nuclear fuel wastes is safe and acceptable or should be modified; and (2) the future steps to be taken in the management of nuclear fuel wastes in Canada.

Ministry of Energy, Mines and Resources (EMR) is the department responsible for implementing the Canadian waste program. The department oversees the work of Atomic Energy of Canada Limited. AECB also reports to parliament through the EMR Ministry. Of particular note, in 1977 the EMR commissioned an independent expert group to provide the government and the Canadian public with views on the subject of nuclear waste disposal. Reports concluded that after considering available options, burial in geologic formations of igneous rock in the Canadian Shield was the preferred option for research in Canada. This concept was further developed by AECL and is now undergoing review as part of the environmental assessment review process.

Federal Environmental Assessment and Review Office (FEARO) oversees the environmental assessment review process on behalf of Environment Canada. This process was initiated in 1973, strengthened in 1977 and 1984, and is currently undergoing review once again. EARP is a planning tool for predicting the consequences of siting controversial facilities such as airports, waste management sites, and dams. Its purpose is to identify unwanted effects before they occur and determine appropriate mitigation. In addition to administering and coordinating the activities of a number of environmental assessment panels, the office provides departments with procedural guidelines, alters the guidelines when special circumstances warrant, publishes summaries of its decisions, and issues an annual report.

Ontario Hydro (OH) is a provincial utility that generates and delivers electricity to 315 municipal utilities, more than 100 large industrial customers, and close to 900,000 small businesses. OH gets its power from nuclear-, falling water-, oil-, and coal-driven power plants. It also purchases power from other provinces and from the United States. Responsibilities include operation of (10,000 Mega Watts electric) Canadian nuclear power plants; management of reactor wastes; and development of technology for interim storage and transportation of spent fuel. OH has developed engineered storage for low-level waste and designed, built, and licensed a full-sized cask for large-scale transport of spent fuel.

In conjunction with AECL, OH also has or is in the process of studying four dry-storage systems: (1) convection vaults; (2) concrete casks; (3) concrete integrated casks (for storage, transportation, and disposal); and (4) metal casks.

Scientific Review Group (SRG) is to conduct a specific, in-depth examination of the scientific and engineering aspects of the concept developed by AECL to dispose of high-level nuclear fuel wastes in igneous rock of the Canadian Shield. Set up in 1989 by the members of the EAP, who also appointed its members, the SRG reports its findings to EAP. Members of SRG were appointed following careful scrutiny of their backgrounds for any potential conflict of interest; they are appointed to serve in a personal and professional capacity, not as representatives of

any organization. The SRG may, if required, seek technical assistance from other sources including government agencies, universities, and the consulting community to assist in carrying out its responsibilities. Publication of interim and final reports from the SRG are available to the public.

Technical Advisory Committee (TAC) was established in mid-1979 following recommendations in early government reports and suggestions from parts of the scientific community. Its purpose is to act as an independent review committee and report to the AECL vice-president of waste management on the extent and quality of the nuclear fuel waste management program. Specific responsibilities are to (1) review the contents of proposed research projects, (2) suggest alternatives and additions as deemed appropriate, (3) review scientific methods used, (4) ensure that the best available technology is being applied to the program, (5) review program results, (6) ensure that conclusions drawn are valid within the limits claimed, and (7) recommend any specific areas of work for which research should be undertaken, either by existing staff or through research contracts. TAC currently has 16 members, appointed by AECL for three-year terms from a list of nominees submitted by major scientific and engineering societies in Canada. Members meet regularly as a full committee and also use a subcommittee structure (geoscience, engineered barriers, bioscience, and systems analysis).

Whiteshell Nuclear Research Establishment (WNRE) is the site of the Underground Research Laboratory (URL) and the place where AECL conducts the bulk of its research on spent fuel disposal. Capital investments in WNRE and URL are $121 million (Canadian), and annual operating costs are nearly $40 million. At URL, studies are being conducted on disposal in deep granitic formations. Spent fuel/high-level waste disposal studies began in 1986. Shaft construction (420 meters deep) began in 1988. Geotechnical characterization (440 meters deep) was completed in 1989. Other research at WNRE includes the following.

- HTF (Hydrostatic Test Facility) tests the performance of waste container materials in underground disposal conditions.
- IFTF (Immobilized Fuel Test Facility) tests effects of water, heat, and pressure on spent fuel and high-level waste forms, containers, buffer, and rock in radiation fields; uses high-level waste radiation source in concrete canisters.
- WIPE (a nonradioactive pilot plant) developed a high-level waste conditioning process for the CANDU-based thorium fuel cycle; 10 kg/hr glass rate using rotospray calciner and joule-heated ceramic melter (started up in 1983).
- LBRMF (Large Block Radionuclide Migration Facility)
- BITF (Borehole Instrumentation Test Facility)
- Radioactive reprocessing pilot plant to develop CANDU-thorium fuel cycle technology and provide for high-level waste studies.
- Storage of WR-1 fuel in cylindrical concrete “canisters” or casks (2.5 meters in diameter, 5.5 meters high, with inner steel and metallic lead liners). Fuel is in six sealed “baskets” backfilled with helium; casks are loaded dry in hot cell; licensed for maximum thermal rating of 4.4 kW, up to 6,000 kg Uranium.

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Appendix E
Department of Energy Response to the Recommendations Made in the Board's *Third Report* (May 1991)

As part of its effort to keep the Nuclear Waste Technical Review Board informed of its progress, the Department of Energy submitted to the Board on September 18, 1991, a summary of initial responses to recommendations the Board made in its *Third Report*. The Board has included those responses along with the transmittal letter in this report. Inclusion of these responses does not necessarily imply Board concurrence.

Department of Energy
Washington, DC 20585

September 18, 1991

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

Dear Dr. Deere:

This letter transmits the Department of Energy's (DOE) responses to the Nuclear Waste Technical Review Board's recommendations made in its Third Report to the U.S. Congress and the U.S. Secretary of Energy that was issued on May 28, 1991. Our responses address the Board's 15 recommendations and one conclusion in the 7 broad areas (structural geology and geoengineering; engineered barrier system; transportation and systems; environment and public health; quality assurance; hydrogeology and geochemistry; and international activities) covered in your report.

I am pleased to note, as reflected in our responses to the Board's May 1991 report and preceding reports, that our strategies, activities, and plans are highly consistent with the Board's recommendations. This consistency helps build confidence that our technical program is well conceived and is responsive to constructive suggestions provided by independent expertise such as that of the Board. A sound program, as a result of comprehensive critique and review, is essential as we embark on new activities to evaluate the Yucca Mountain site and to design the pre-disposal system.

As you know, we recently began, for the first time since 1986, new surface-disturbing activities at the Yucca Mountain site. This work begins our effort to evaluate the suitability of the site as soon as possible. I anticipate that the plans, activities, and findings for this effort will be a significant part of the Board's agenda in the future.

We have also initiated work leading to design and integration of the transportation and storage systems, with the objective of meeting the Secretary's goal to begin spent fuel receipt from reactors in 1998. We expect that these activities will also be the subject of constructive review and guidance from the Board.

Our program activities are being selected and implemented in accord with strategic principles recently established through intensive effort by our staff and with the participation of affected and interested parties. These

principles, together with our policies and strategic plans, are set forth in our Draft Mission Plan Amendment which is soon to be issued for public comment. I would like to take this opportunity to invite the Board's comments on this highly important document.

We greatly appreciate the Board's reviews and advice on the content and performance of our program. The Board has had significant positive impact on our technical progress, and we look forward to its continuing contributions.

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 *Third Report to the U.S. Congress and the U.S. Secretary of Energy* May 1991

INTRODUCTION

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

The Board is required to report, not less than two times per year, to the Congress and the Secretary of Energy, its findings, conclusions, and recommendations. The Board has issued three reports to date. The third report, issued on May 28, 1991, includes 15 recommendations in 6 broad areas: (1) structural geology and geoengineering; (2) the engineered barrier system; (3) transportation and systems; (4) the environment and public health; (5) quality assurance; (6) hydrogeology and geochemistry. Also included in the third report is a conclusion supporting a seventh broad subject area, international activities.

These recommendations and DOE's responses are presented in this report. Each recommendation is quoted verbatim from the Board's report of May 28, 1991, and is followed by the response.

STRUCTURAL GEOLOGY AND GEOENGINEERING

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

Recommendation 1:

The DOE should reexamine its test plans to ensure that the saturated zone of the Calico Hills unit and Prow Pass member will be adequately evaluated - considering its appreciable contribution to waste isolation as determined in the CHRBA study.

Response:

DOE regards the saturated zone to be one component of the natural barrier system at the Yucca Mountain candidate site. DOE recognizes that present day and expected future conditions and processes within the saturated zone may sufficiently retard aqueous-phase radionuclide transport to satisfy all applicable rules and regulations governing allowable releases to the accessible environment from the repository system. In this regard, it should be recalled that when the Yucca Mountain candidate site was initially identified for evaluation as a potential site for a repository, the conceptual design located the repository within the saturated zone. Only when it was recognized that thick unsaturated zones in arid environments could offer appreciable advantages for waste containment and isolation was empha-

sis redirected from the saturated zone to the unsaturated zone at the Yucca Mountain candidate site. In shifting emphasis, however, DOE did not intend to ignore or otherwise underrate the waste isolation capabilities of the saturated zone. The site characterization program as described in the SCP and its associated Study Plans is intended to provide the data needed to assess the waste isolation capability of the saturated zone beneath and beyond the Yucca Mountain candidate site. These data will be derived from borehole cores, from hydraulic and tracer testing in boreholes penetrating the saturated zone, and from samples and testing in the Exploratory Studies Facility.

Strictly speaking, the Calico Hills Risk Benefit Analysis (CHRBA) study did not "determine" that the saturated zone within the Calico Hills and Prow Pass units would make an "appreciable contribution" to waste isolation. Rather, the CHRBA study used expert judgment as a basis for reinterpreting the discussion of saturated zone groundwater travel time presented in Section 3.9.4.2 of the SCP. The SCP analysis of groundwater travel time was based on a set of highly-conservative "fast-pathway" assumptions that neglected both mechanical and geochemical processes of radionuclide retardation. The CHRBA study elicited judgments of effective retardation factors appropriate to the saturated zone within a five kilometer radius of the potential repository. The numerical retardation factors that were elicited from the technical experts represent composite values for radionuclide transport within the saturated zone and are not referenced to any particular pathway or hydrogeologic unit or units. These retardation-factor values were expressed probabilistically, were not based on any explicit performance calculations or assessments, and consequently, were not deterministic. The CHRBA results merely reflect the expectation that when appropriate allowance is made for the effects of radionuclide retardation, the saturated zone at the Yucca Mountain candidate site is likely to significantly impede radionuclide transport from the unsaturated zone to the accessible environment. This expectation, however, will be evaluated quantitatively as part of the overall site characterization process.

Recommendation 2:

The DOE should continue with the preliminary design of the ESF on the basis of the selected and optimized version of the three highest-ranked options from the ESF alternatives study.

Response:

Currently, the Yucca Mountain Site Characterization Project Office (YMP) is completing the review and approval of an ESF Title I Design Summary Report based on the Reference Design Concept, a synthesis of the top three choices from the ESF Alternatives Study, Options 30, 23, and 24. Option 30 is characterized by dual ramp accesses to an ESF underground layout in the southern end of the potential Geologic Repository Operations Area (GROA). Option 23 is similar to Option 30 with an ESF underground layout in the northern end of the potential GROA. Option 24 combines shaft and ramp access to an ESF layout in the same location as Option 23.

The resultant ESF Reference Design Concept is composed of a north ramp (Access 1) and a south ramp (Access 2) connecting to exploratory drifting in both the Calico Hills unit and overlying Topopah Spring Member. The Calico Hills drifting is planned to characterize the ability of the unit to act as a radionuclide barrier beneath the potential repository horizon. Drifting in the Topopah Spring Member (TSW1) will include the main ESF underground layout for characterization of the potential repository horizon and evaluation of repository scale openings and components. The principal concentration of

drifting for the main ESF underground layout is located in the northeast corner of the potential GROA in the TSW1 horizon. Additionally, allowance has been made in the Reference Design Concept for an optional vertical shaft (Access 3) to be used solely for testing in the strata overlying TSW1.

The approved ESF Title I Design Summary Report will be the basis for the Title II design effort.

Recommendation 3:

The DOE should continue with repository conceptual design throughout the design phases for the ESF. Different geometric layouts and thermal-loading alternatives for the repository should be explored.

Response:

DOE agrees that continuation of the repository conceptual design process in parallel with the ESF design phases is desirable. However, budgetary constraints have required prioritization of the program elements and, with early site suitability evaluation as the current priority, DOE has chosen to concentrate on surface-based site characterization activities. Continuing repository design efforts are concentrating on those items critical to the ESF design and the site characterization efforts. For example, the proposed repository / ESF interface drawings are being developed, as are computer models to determine the impacts of the ESF envelope on the GROA. Additionally, the potential repository conceptual design in the SCP will be modified as ESF Title II design phases are completed.

ENGINEERED BARRIER SYSTEM

The following Board recommendations to DOE pertain to the design of the Engineered Barrier System (EBS) and the content of the applicable licensing regulations.

Recommendation 4:

High priority should be assigned to developing a more robust engineered barrier system. A workshop on engineered barriers, which was recommended in the Board's Second Report and which has been scheduled for June 18-20 in Denver, Colorado, is a logical first step.

Response:

DOE agrees that the development of a robust Engineered Barrier System (EBS) is desirable. However, current budgetary constraints have curtailed much of the development effort at this time. Higher program priorities, including site characterization, waste acceptance in 1998, and the transportation system infrastructure, prevent allocating additional funds to the EBS development effort. DOE will continue to develop the EBS following the structure outlined in the Waste Package Plan (WPP) and the methodology presented at the DOE-sponsored Engineered Barrier System Workshop of June 18-20, 1991, as program funding allows. The schedule information in the WPP has been superseded by other program priorities.

The information presented at the workshop is currently being reviewed by DOE and its contractors to identify technologies and concepts that require further evaluation or are appropriate for potential inclusion in the EBS. DOE will continue to keep the Board apprised of the new developments.

Recommendation 5:

The Board recommends that the DOE seek clarification of some NRC regulations. The NRC should be able to provide definitions for terms like "substantially complete containment" and the "proof to be required to demonstrate such containment".

Response:

DOE and the Nuclear Regulatory Commission (NRC) meet periodically to establish topics and schedules for interactions. DOE has discussed with NRC the need to identify and resolve issues, including the interpretation of regulatory terms and requirements, as early as possible to prevent unnecessary delays during licensing. DOE is presently evaluating various regulatory and technical issues to identify the most appropriate timing and approach for DOE action to seek resolution. The approaches being considered range from rulemaking proceedings initiated either by NRC or by petition from DOE (e.g., the DOE petition for rulemaking to establish an accident dose limit for repository operations) to submittal of topical reports by DOE on specific issues for formal review by NRC and possibly by the Advisory Committee on Nuclear Waste (e.g., DOE has proposed to submit a topical report on investigation of earthquake and faulting hazards at the site). DOE intends to interact with NRC in a manner which is conducive to convergence and closure of issues, such as those cited above.

TRANSPORTATION AND SYSTEMS

The following Board recommendation concerns the interactions and interfaces of the various components of the overall waste handling system.

Recommendation 6:

A workshop should be scheduled on ways to minimize the handling of waste in the life-cycle process. The workshop should address the interactions among the major system components - storage, transportation, and disposal. The scope should include potential technologies, possible regulatory impediments, and institutional incentives and barriers to such an integrated system.

Response:

DOE agrees that a workshop would be helpful in identifying and resolving issues surrounding multiple handling of waste, but believes such a workshop should be preceded by a system study. The study would address the issues identified by the Board, including potential technologies, possible regulatory impediments, and institutional incentives and barriers. Results of the study would then be used as the focus of a workshop to address the evaluated issues.

DOE will initiate planning for the system study and subsequent workshop to discuss ways to minimize waste handling in the life-cycle process, as recommended by the Board. DOE will work with the Transportation and Systems Panel and staff to identify specific topics for the study and potential participants for the workshop.

ENVIRONMENT AND PUBLIC HEALTH

These Board recommendations pertain to increasing the public knowledge of the program, including non-DOE experts in the decision-making process, and updating the regulations responsible for ensuring public health and environmental safety.

Recommendation 7:

The DOE should consider developing a comprehensive regional program to expand the public's understanding of the potential risks associated with the development of a high-level nuclear waste repository, as well as of other nuclear and non-nuclear activities. Special efforts should be made to develop a dialogue involving non-DOE experts.

Response:

DOE believes that the best way to expand the public's understanding of the potential risks of managing radioactive wastes is to interact and communicate more effectively with parties concerned with the program. DOE is taking several initiatives toward this end.

Broadening participation of affected governments, interested parties, and the public in decision-making

DOE is committed to involving external parties in the development of policy alternatives before decisions are made. A "Director's Forum" is being established for representatives of affected governments, interested parties, and the public to meet with OCRWM to discuss upcoming program decisions and policy alternatives. DOE will also seek to build constructive working relationships with external parties through the expanded use of cooperative agreements and other meetings outside the Forum. To support these interactions, DOE will identify issues and technical milestones that are potentially of concern to external parties.

Strengthening two-way communication with the general public

Effective two-way communication with the public is essential if the program is to succeed. The "public" is made up of numerous audiences with unique backgrounds and concerns. DOE is improving its information products by identifying specific audiences and their concerns, developing appropriate messages, and using suitable information channels to convey them. Training will also be provided to help OCRWM communicate more effectively, both orally and in writing. DOE will seek opportunities to address a wider range of organizations and systematically evaluate feedback from public speaking engagements. DOE will also reach out to local and specialized media, and make OCRWM more available for interviews and informal discussions.

Maintaining the support of the scientific community

Earning the confidence of the scientific community is fundamental to earning the confidence of the larger public. From the inception of the program, DOE has worked hard to interact with the scientific community and will continue to do so. OCRWM participates extensively in conferences sponsored by scientific, technical, and professional organizations. Our participation serves not only to keep the scientific communities informed, it also exposes our work to their scrutiny and encourages independent technical comment.

Engaging the education community

Building public understanding of radioactive waste management is a long-term effort. This understanding must be developed within the broader context of energy and environmental concerns. To help the public make informed judgments about the risks of producing energy and managing its by-products, DOE is developing a variety of educational programs. These activities are integrated with the overall DOE effort to promote understanding and awareness of science at all levels, improve teachers' skills, encourage careers in science and engineering, and develop curricula materials.

In summary, these initiatives will establish an ongoing process for interacting and communicating more effectively with external parties. This, in turn, will provide a solid foundation for building public understanding of risks.

Recommendation 8:

The EPA and the NRC should be encouraged to modify and clarify 40 CFR 191 and 10 CFR 60, respectively. The regulations should be risk based, fully protective of public health and the environment, but not too prescriptive. In addition to being consistent and mutually compatible, they should be presented in a clear and understandable manner and be applicable to and defensible in the licensing arena. Furthermore, they should reflect current internationally accepted environmental standards and be compatible with the uncertainties intrinsic to long-term geologic processes.

Response:

DOE has encouraged the Environmental Protection Agency (EPA) and NRC to improve their regulations with respect to critical terms and concepts and the degree to which compliance with complementary, but independent, environmental standards and subsystem performance objectives can be successfully demonstrated. DOE has communicated its concerns with respect to regulations to NRC and EPA via comments on proposed rules (e.g., 40 CFR 191), petitions for rulemakings (e.g., Accident Dose Criteria of 10 CFR 60), and other formal correspondence (e.g., comments on NRC Update of Regulatory Strategy and Schedules for the High-Level Waste Repository Program dated June 7, 1990 SECY 90-207). DOE also agrees with the Board's recommendation that the regulations should be risk based, and fully protective of worker and public health and safety, and of the environment.

QUALITY ASSURANCE

The following Board recommendations concern the content and implementation of the DOE Quality Assurance (QA) Program.

Recommendation 9:

The Board praises the DOE for initiating a two-way process to identify and resolve QA implementation issues that have been identified by DOE management and researchers. The Board concurs with the DOE's QA managers that the QA process should not be coupled with highly detailed management/administrative procedures. The Board recommends that the DOE continue this process to ensure that the program considers the concerns of the scientists.

Response:

DOE continues to strive for improvement in the process of addressing the concerns of the scientific community with respect to QA implementation. Recent changes in the QA program have been evolutionary, and will continue to be dependent on acquired experience and exercise of applicable procedures. DOE will continue to address management and administrative issues for the most effective and efficient manner in which to conduct a complex, highly-integrated, and research-oriented technical program that must operate in a regulatory environment.

Recommendation 10:

The Board recommends that the DOE move in a timely way to implement the measures agreed to at the QA workshops.

Response:

DOE agrees that measures from the QA workshops should be implemented in a timely manner. Several of the measures agreed to at QA workshops have been implemented and corrective measures have been institutionalized through revised procedures.

Recommendation 11:

The Board recommends that the QA grading process be improved to provide for greater flexibility in accommodating exploratory research.

Response:

DOE appreciates the Board's encouragement and support for efforts to resolve QA implementation issues. The QA grading process that had been used by the project until 1990 was streamlined to provide greater management flexibility. DOE monitors the conceptual and procedural aspects of this process on a continuing basis, and seeks opportunities to further streamline the QA grading process, while still meeting the regulatory requirements incumbent on the program. The QA workshops on

grading have addressed the issue, and the participants have presented a list of recommendations to DOE management. On June 18, 1991, DOE issued a "QA Grading Vision Statement" that responded to the workshops' recommendations. DOE believes that, by these efforts, it is providing for greater flexibility in accommodating exploratory research.

HYDROGEOLOGY AND GEOCHEMISTRY

The following recommendations pertain to the hydrogeology and geochemistry of the proposed repository site and the test programs to verify the expected behavior.

Recommendation 12:

The Board strongly supports the DOE's new policy to improve internal program communication, review, and planning between DOE managers and scientists involved in related disciplines in the program. The DOE should, however, implement a programwide plan and policy for routine external peer review.

Response:

DOE is continually working to improve communication among project participants. New efforts in this area include conducting periodic meetings between participants doing similar work such as the geochemical work related to the far-field at Los Alamos National Laboratory and the geochemical characterization of the near-field environment by Lawrence Livermore National Laboratory. In addition, DOE is conducting topical meetings where individuals representing all participants are invited to attend. One such meeting was conducted July 29-31, 1991, on the topic of groundwater chemistry.

DOE has traditionally used external peer reviews in the high-level waste program and will continue to do so. DOE has just completed a major peer review of the unsaturated zone hydrology program and has formed a peer review panel for studies of rock mechanics. DOE also intends to establish a formal process for the selection of the members of the peer review panels in order to ensure independent and objective reviews; this process may be similar to that already used by the National Academy of Sciences. DOE will continue to make its peer review process as open as possible and document the program changes that result from peer reviews. Further peer reviews in other technical areas, such as geochemistry, will be considered on a case-by-case basis.

Recommendation 13:

Recent communication has shown that the DOE is committed to studying the applicability of laboratory measurements in geochemistry and hydrology to site characterization. The Board also is concerned with this applicability and recommends that the DOE continue to address it.

Response:

DOE has been concerned with whether data generated in a laboratory is valid for making predictions about radionuclide migration under natural conditions at Yucca Mountain. While laboratory measurements are easy to perform, the direct applicability of these tests for performance assessment

analyses is uncertain due to the differences in scale, rock / waste ratios, and the geologic, geochemical and hydrogeologic representatives of the laboratory samples. DOE is planning field tests for both the saturated and unsaturated zones to evaluate sorption models and parameters. The in situ sorption values determined under natural conditions at Yucca Mountain will be compared with laboratory results. This will assist in validating the conceptual models for radionuclide transport. In the case of the saturated zone testing, multiple experiments will be conducted to compare calculated values of transport with measured values. Unsaturated zone testing will utilize the same methods, but the duration of these experiments will be considerably longer. One of the key constraints on field testing is the restrictions on using radionuclides at the site. Potential analogue tracers will be investigated and characterized in order to conduct field experiments that provide data on radionuclide transport.

The study plans that relate to these activities are the Testing of the C-Hole Sites with Reactive Tracers, (8.3.1.2.3.1.7,R1), which has been issued by DOE and was sent to NRC on April 10, 1991, and the Field Validation Testing of Radionuclide Transport (8.3.1.3.7.2), which is currently being prepared.

Recommendation 14:

The Board believes that the DOE's proposed plan for applying experimental radionuclide sorption results to performance assessment at Yucca Mountain is well conceived. However, inadequate design, documentation, and analysis of many published radionuclide sorption results make it doubtful that they can be used to define conservative sorption behavior. The Board suggests that the DOE model future experimental sorption results using a surface complexation approach. This would lead to a more comprehensive understanding of an explanation for these results, without which we cannot have confidence that such results represent conservative sorption behavior for a particular radionuclide.

Response:

DOE agrees with the Board's suggestion that the sorption program should use the surface complexation approach to modeling experimental sorption results. DOE has used in some cases and will use in the future, the surface complexation approach to investigate the mechanisms by which different radionuclides adsorb onto mineral surfaces. However, DOE believes that the surface complexation approach cannot, at this time, be generalized to predict sorption behavior in complex electrolyte systems and other multi-mineralic systems. The surface complexation approach will be used as part of the proposed minimum Kd strategy that involves a single mineral. Currently, work is ongoing both at Los Alamos National Laboratory and Stanford University using the surface complexation approach in the investigation of Np sorption behavior on the single minerals of hematite, quartz, and albite.

DOE also agrees that many of the published sorption data are not documented well enough to permit their use in performance assessment calculations. However, much of the YMP-sponsored sorption data is useable because unlisted parameters are known and are being documented. At this time, all sorption experiments are performed under a qualified QA program assuring adequacy of experimental design, documentation, and traceability.

Recommendation 15:

The Board endorses the DOE's intention to perform some future sorption experiments under unsaturated conditions and to use waters with compositions that might be expected at the site after waste emplacement.

Response:

DOE intends to conduct sorption experiments under unsaturated conditions by passing solutions through columns of solid materials. The techniques of using both vacuum and a centrifuge to maintain unsaturated conditions are being investigated to determine their differences and relative feasibility. The results of a literature review will be completed at the end of 1991 and experiments will be conducted when adequate resources become available.

DOE is concerned about the different compositions of groundwater at Yucca Mountain, both naturally-occurring and changes induced by waste emplacement, and how these differences affect not only sorption behavior but also the solubility and speciation of radionuclides. A groundwater chemistry interaction meeting was held on July 29-31, 1991, to further our understanding of this important technical issue.

DOE is presently using groundwater compositions in the experimental programs that may bracket the range of naturally-occurring groundwater compositions. As actual water chemistry data become available, these compositions will be evaluated and any necessary changes to the experimental program will be implemented.

INTERNATIONAL ACTIVITIES

The following response is to the Board's conclusion on International Activities contained in its Third Report.

"The Board's experience has shown that much can be gained by remaining apprised of technical activities underway in countries that are developing and implementing high-level waste disposal programs." (NWTRB Third Report Page 41, Sec. B, para. 1)

DOE concurs with the Board's conclusion that the U.S. has much to gain by remaining involved in international developments regarding high-level waste disposal programs. DOE's Office of Civilian Radioactive Waste Management (OCRWM) has conducted an active program of international activities over the years, involving a number of mechanisms for participation, including bilateral agreements, multi-lateral agreements, and participation in international organizations such as the Organization for Economic Cooperation and Development's Nuclear Energy Agency and the International Atomic Energy Agency. Within these mechanisms, information is acquired through a wide range of activities, including cooperative testing and technology development efforts involving laboratory, underground and surface-based field testing, safety assessment model development and testing, personnel exchange, information exchange, as well as participation in working groups focused on specific subjects.

In an effort to further enhance the integration of international work into the U.S. domestic program, OCRWM has established an International Program Working Group with representation from all of its program offices and with responsibilities to periodically review and evaluate OCRWM's interna-

tional activities and their contribution to the U.S. program. OCRWM's efforts to remain informed of current foreign developments in nuclear waste management are also enhanced by our International Program Support Office, which publishes a variety of documents (highlights reports, national briefing summaries, international fact books, topical reports) which are intended to keep the U.S. program apprised of significant international developments relevant to nuclear waste management.

Currently, OCRWM is actively pursuing a number of specific cooperative agreements with other nations. Approval is being sought for Project Agreement 3 (an extension of a testing program initiated with Switzerland in 1985), which focuses on fracture flow, diffusive transport, and geophysical measurement techniques. Also, we are finalizing Subsidiary Agreement 2 with Canada, which will include a broad spectrum of laboratory and field testing, as well as safety assessment activities. In addition, discussions have been initiated with Sweden regarding collaboration in its Hard Rock Laboratory. We will continue to pursue additional opportunities for nuclear waste management cooperation with other nations.

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Glossary

Because this report will be of interest to nontechnical as well as technical readers, a 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 in a general sense 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 outside of the controlled area (the area that will be marked by suitable monuments extending no more than 5 kilometers in all directions from the repository boundary).

Alluvium: A surface or near-surface deposit of unconsolidated or poorly consolidated gravel, sand, silt, or clays deposited by a stream or other body of running water

Alpha-emitting wastes: Radioactive waste that releases alpha particles during decay. Alpha particles are positively charged and made up of two neutrons and two protons. Transuranic wastes are classified as alpha-emitting and due to their long half-life often must be isolated from the biosphere for long periods of time. (See transuranic waste.)

Analogue: A thing or part that is analogous. As used in this report, a given natural setting or anything affected by, or resulting from, human activity that can provide information on aspects of repository performance. Analogues generally are broken into two categories: natural and anthropological. Natural analogues occur through natural phenomena. Anthropological analogues result from human activity. "Archaeological analogue" generally is used to refer to an analogue resulting from the activities of ancient cultures.

Backfilling: The placement of materials, originally removed or new, into the excavated areas of a mine, including waste-emplacement holes, drifts, accessways, and shafts

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

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)

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

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

Borings: Holes drilled into the earth, usually vertically from the surface, but may be inclined

Caisson: As used in the DOE programs, a caisson is a cylindrically shaped pipe, set vertically and with its open end upwards, packed with solid materials such as crushed tuff, and used to study the transport and sorption of dissolved species under saturated or unsaturated flow conditions. Caissons are often several feet in diameter.

Canadian Shield: Exposed Precambrian basement rocks extending over large portions of eastern and central Canada. It consists predominately of granitic and metamorphic rock. The former is being considered as a host rock for the Canadian repository concept.

Canister: The structure surrounding a waste form (e.g., spent fuel rods) that facilitates handling for storage, transportation, and / or disposal

Cap rock: A comparably impermeable rock overlying a permeable formation.

Cask: A massive 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.

CASTOR: Cask certified for on-site storage: holds 21 pressurized water reactor fuel assemblies

Characterization: The collecting of information necessary to evaluate suitability of a region or site for geologic disposal

Colloidal particles: (and **colloidal transport and filtration**) Colloidal particles are usually smaller than 1 micrometer (μm) in diameter and under many conditions can remain in suspension in water indefinitely without settling. They may then be transported at about the same velocity as ground water, but are sometimes filtered out when the water moves though the small pores of a rock, such as through the matrix pores of a tuff.

Complex: A species formed by the association, usually of a positive and a negative ion (or ions), both of which may be dissolved, or one of which may be on a solid surface. (See **surface complexation model**). For example, UO_2CO_3 is a dissolved complex formed by association of uranyl ion ($UO_2$2+) and carbonate ion ($CO_3$2-).

Container: A receptacle designed to hold spent fuel or radioactive material to facilitate movement and storage

CONSTAR: Cask awaiting receipt of a certificated of compliance

Coprecipitation: The precipitation of a dissolved, usually trace, substance with and in a precipitate formed of major dissolved species, for example, the coprecipitation of uranium with a ferric oxide solid

Decision analysis: A structured approach whose aim is to enhance the decision-making process. It includes a logical decomposition of the problem, the solicitation of expert judgment, means for working out internal inconsistencies in these judgments, and the explicit treatment of uncertainties. Intuitively it can be thought of as "a formalization of common sense for decision problems which are too complex for informal use of common sense" (R. Keeney 1982).

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.

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

Engineered barrier system (EBS): 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 waste form, waste containers, material placed over and around such containers, and backfill materials.

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.

Folding: A curving or bending of a planar structure, such as rock strata or bedding planes. A fold is usually a product of deformation.

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

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 excavated geologic media. 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.

Ghost Dance Fault: A near vertical north-south trending fault that crosses the eastern side of the Yucca Mountain geologic block

Ground motion: The vibratory movement of the ground caused by earthquakes. It is often characterized in terms of acceleration, velocity, or displacement.

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

High-angle joint and fault system: A system of near-vertical joints and faults

High-level waste (HLW): (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 waste have been converted

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

Hysteresis: A phenomenon exhibited by a system or material in which response depends nonlinearly on past responses. As used with respect to unsaturated flow, in the nonunique relationship between moisture content and matric potential (which depends on the wetting history of the medium), the wetting curve has a lower water content for a given potential than the drying curve.

Igneous: Rock or minerals that solidified from molten or partly molten material (i.e., from a magma). Igneous rocks constitute one of the three main classes into which rocks are divided, the others being metamorphic and sedimentary.

Igneous activity: The emplacement (intrusion) of molten rock (magma) into material in the earth's crust or the expulsion (extrusion) of such material onto the earth's surface or into its atmosphere or surface water

Illite: A clay mineral that is less sorbent of metal ions and radionuclides than are the smectite clays (see **smectite**)

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

Interim storage or storage: Temporary storage of 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

Isotopic exchange: A reaction in which a specific isotope of an element distributes itself between two or more substances. For example, carbon-14 (C-14 or ^{14}C)

tends to distribute itself by the isotopic exchange between the carbon of CO_2 (gas) and the carbon of the mineral calcite ($CaCO_3$).

K_d (distribution coefficient): Mass of species being sorbed on the solid phase, per unit mass of the solid phase, divided by concentration of species being sorbed in solution. Normally reported in cubic centimeters per gram (cm^3/g).

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.

Matric potential: The energy required to extract water from a porous medium to overcome the capillary and adsorptive forces

Matrix properties (flux related): The physical and chemical properties that describe the relationship of porous rock material to water or moisture. These can include: permeability, sorptivity, porosity, moisture content, matrix storage capacity, and hydraulic conductivity.

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

Monitored retrievable storage 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

Natural analogue: See **analogue**

Near field: The region where the natural hydrogeologic system has been altered by the excavation of the repository or the thermal environment created by the emplacement of high-level waste

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

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

NUHOMS: Nutech Horizontal Modular Storage System: a concrete bunker system licensed for storing spent fuel. Several sizes exist, which hold different number of fuel assemblies.

Osmotic potential: The energy one must add to a solution to equilibrate the solution with pure water across a perfect semipermeable membrane.

Performance allocation: The process whereby components of the proposed repository system are assigned expected quantified levels of performance

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.

Plutonic rock: Rock formed at considerable depth by crystallization of magma or by chemical alteration. It is characteristically medium- to coarse- grained, of granitoid texture.

Pneumatic potential: The potential energy capability of air and other gases

Portals: Openings 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

Quality assurance (QA): 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

R_d (retardation coefficient): Equals the average linear velocity of the ground water divided by the velocity of the midpoint of the concentration profile of the retarded constituent

Radiation-induced corrosion: A corrosion process that is initiated or controlled by chemical species that are produced by irradiation

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 measurable or predictable movement of radionuclides, generally by liquids or gases, through a rock formation

Recharge: The process of addition of water to the saturated zone; here, that moisture that is expected to pass through the repository horizon eventually reaching the water table

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 the fissionable parts are recovered for repeated use

Richards equation: Describes transient flow through an unsaturated porous medium. Its use requires knowledge of the characteristic curves (i.e., the relationship between moisture content and matric potential and between content and hydraulic conductivity).

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.

Rock matrix: The solid framework of a porous rock

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

Sensitivity analysis: The process of varying an independent variable in a calculation and observing the relative effect on the final answer

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

Site characterization: See **characterization**

Smectite: A group of clay minerals that are generally strongly sorbent of metal ions such as Mg^{2+} and also of radionuclide cations (positively charged ion)

Solute: A substance present in a solution in undissolved form.

Sorption: The deposition or uptake of radionuclides or other species from gas or solution onto geologic materials (e.g., granite, basalt, tuff)

Sorption characteristics: Attributes exhibited by rocks and minerals that affect the deposition and/or uptake of radionuclides or other species on their surfaces

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

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

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

Surface complexation model: There are several surface complexation models. Such models describe the sorption of dissolved species on the surfaces of minerals or other solids. The sorption process is modeled as if it involved the formation of complexes between the dissolved species and surface sites on the solid.

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 zone: Those regions of the repository where temperature has been increased by the presence of high-level waste

Transuranic: Contains 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 (WIPP) 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.

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

Unsaturated zones: Rock / geologic formations that are located above the regional ground-water table

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 canister: A metal vessel for spent fuel or solidified high-level waste. Before emplacement in the repository, the canister may be encapsulated in a disposal container.

Waste package: The waste form and any containers, shielding, packing, and 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. They primarily occur and are formed by weathering of basalts and tuffs.

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