Chapter 2
Other Board Activities

During 1998, the Board evaluated elements of the DOE's radioactive waste management program in addition to the site-characterization efforts at Yucca Mountain. In this chapter, the Board reports on those evaluation activities.

I. Review of Material Related to Hydrothermal Upwelling at Yucca Mountain

The Board completed its review of material (11 reports) first submitted to it in summary form by Mr. Jerry Szymanski at its January 1997 meeting in Pahrump, Nevada. The documents argue that there is evidence of ongoing, intermittent hydrothermal upwelling at Yucca Mountain and that large earthquake-induced changes in the water table are likely at Yucca Mountain. As a result, the documents maintain that the Yucca Mountain site is unsuitable for development as a repository for spent nuclear fuel and high -level radioactive waste. After its January 1997 meeting, the Board received requests from both the Committee for the Truth about Yucca Mountain (Chrisman 1997) and the Attorney General of the State of Nevada (Del Papa 1997) to review this material.

This is not the first time that Mr. Szymanski has raised these questions. His ideas were thoroughly reviewed by outside experts, including a panel appointed by the National Research Council of the National Academy of Sciences (NAS). This prestigious and broadly based review was published in 1992 by the National Academy Press in a report titled *Ground Water at Yucca Mountain—How High Can It Rise?* (NAS / NRC 1992). As stated in the Board's December 1992 report (NWTRB 1992), the Board saw no reason to disagree with the 17-person NAS panel's unanimous conclusion: "The panel concludes from the geological features observed in the field and geochemical data that there is no evidence to support the assertion [by Mr. Szymanski] that the water table has risen periodically hundreds of meters from deep within the crust" (NAS / NRC 1992). The Board's December 1992 report also noted that if significant new data or modifications were presented in the future, the Board would consider reviewing them at that time.

The Board examined the material submitted in 1997, and, because some new information had been presented, the Board decided to evaluate the quality and significance of this information. For assistance in this evaluation, the Board contracted with four highly qualified scientists. The scientists were chosen because of their expertise in critical areas, their reputations among their peers (many of whom the Board staff spoke to), their lack of affiliation with the Yucca Mountain Project, and their lack of previous involvement in evaluating Mr. Szymanski's ideas.

The consultants were Dr. Robert J. Bodnar, C. C. Garvin Professor of Geochemistry and Director of the Fluids Research Laboratory, Department of Geological Sciences, Virginia Polytechnic Institute & State University (Dr. Bodnar's expertise is in fluid inclusions and the geology and geochemistry of ore deposits.); Dr. Patrick R. L. Browne, Associate Professor and Director of the Geothermal Institute, University of Auckland, New Zealand (Dr. Browne's expertise is in hydrothermal alteration of volcanic rocks and fluid-rock interactions.); Dr. Stuart Rojstaczer, Associate Professor and Director of the

Center for Hydrologic Science, Duke University (Dr. Rojstaczer's expertise is in the role of subsurface fluid flow in geologic and human-induced hazards and the hydrologic effects of earthquakes.); and Dr .John Valley, Professor and Chairman of the Department of Geology and Geophysics, University of Wisconsin-Madison (Dr. Valley's expertise is in metamorphic petrology and stable-isotope geochemistry.).

The Board conducted its review, making use of its own expertise and that of its consultants. Four questions were posed to the consultants (Drs. Bodnar, Browne, and Valley for evidence of hydrothermal activity and Dr. Rojstaczer for earthquake-induced changes in the water table) that centered on the significance of the new information presented with respect to the conclusions drawn in the 1992 NAS report (NAS / NRC 1992). These questions also were the focus of the Board's review:

1. Are there significant new data and interpretations since the 1992 NAS report?

2. What is the quality of these data and interpretations?

3. How much credence do these data and interpretations lend to the hypothesis of ongoing, intermittent hydrothermal activity and large earthquake-induced changes in the water table at Yucca Mountain?

4. If these data and interpretations significantly affect the conclusions of the 1992 NAS report, how can the issue be resolved?

The Board emphasizes that the purpose of its review was to evaluate the information submitted to the Board, not to conduct a systematic review of all the information that has been collected on this topic, including the extensive work carried out for the DOE's Yucca Mountain Project by the U.S. Geological Survey (USGS) and the National Laboratories. A systematic review of all the information available by 1992 was carried out by the panel that prepared the 1992 NAS report.

In addition to reviewing the 11 reports submitted by Mr. Szymanski, 3 additional reports provided by the Nevada Attorney General's office, and a number of other important documents referenced in these reports, Board staff spoke directly to several of the reports' authors. A Board member (Dr. Donald Runnells), a Board staff member (Dr. Leon Reiter), and Dr. Bodnar also attended an international meeting in which fluid inclusion evidence for and against future hydrothermal upwelling at Yucca Mountain was presented and discussed. Following that meeting, Dr. Yuri Dublyansky (the lead author of several of the reports) spent several days with Dr. Bodnar at Dr. Bodnar's Fluids Research Laboratory at Virginia Polytechnic Institute.

The Board has reached the following conclusions:

- The material reviewed by the Board does not make a credible case for the assertion that there has been ongoing, intermittent hydrothermal activity at Yucca Mountain or that large earthquake-induced changes in the water table are likely at Yucca Mountain. This material does not significantly affect the conclusions of the 1992 NAS report.

- There are several areas where additional research could be used to evaluate further the hypotheses of ongoing, intermittent hydrothermal activity and large earthquake-induced changes in the water table at Yucca Mountain. However, because of the lack of any substantive evidence supporting either of these hypotheses, the Board views additional research on these issues, if not already carried out, as generally having a lower priority than more important issues in the evaluation of repository performance.

- However, some fluid inclusions found in mineral deposits at Yucca Mountain do provide direct evidence of the past presence of fluids at elevated temperatures (at least 72°C) in the vicinity of the proposed repository. This could be an indicator of some degree of past hydrothermal activity. The critical question is, "At what time in the past were such fluids present?" If fluids at elevated temperatures were present less than 100,000 years ago, as some of the reviewed reports claim, this could lend credence to the hypothesis of ongoing hydrothermal activity at Yucca Mountain. On the other hand, if these fluids were present around 10,000,000 years ago or earlier, they could be associated with volcanic events related to the original formation of

Yucca Mountain and would have no bearing on the hypothesis of ongoing hydrothermal activity. The Board believes that the ages of fluid inclusions should be determined. A joint program between federal and State of Nevada scientists for collecting, dating, and analyzing fluid inclusions would be one way to make this determination in a way that would reduce some of the past disagreements associated with sample collection and handling.

II. Waste Package Workshop

In its recent reports and correspondence, the Board has urged strongly that the DOE identify, and then carefully examine, alternative designs for the subsurface facility and for the waste packages (NWTRB 1997a and 1998b; Cohon 1998a and 1998b). Examples of alternative waste package designs that could merit examination include (1) a waste package design with the materials of the outer and inner shells reversed in comparison to the current design and (2) a double-shell waste package with the outer shell made of a corrosion-resistant material and the inner shell made of a different corrosion-resistant material. The Board convened a waste package workshop in May 1998 to identify alternative waste package designs and associated research needs.

A. Planning for the Workshop

The 1½-day workshop was held on May 18 and 19, 1998, in Falls Church, Virginia (NWTRB 1998d). It was conducted as a panel meeting under the aegis of the Board's Panel on the Repository. The primary purpose of the workshop was to develop a firm technical basis for reviewing and evaluating the scientific and technical merits of any waste package designs arising from the DOE's program. The primary products of the workshop were a list of alternative waste package designs and a list of associated research needs. For encouraging a free exchange of ideas and as much "brainstorming" as possible, as well as participation by the public, a roundtable format was used for the entire workshop, except for a few initial presentations.

Participants in the roundtable included five Board members (Drs. Bullen, Craig, Nelson, Parizek, and Sagüés), two members of the Board's staff (Drs. William Barnard and Carl Di Bella), and five invited panelists: Dr. John Kessler (of EPRI), Dr. Digby Macdonald (of SRI International), Dr. Joe Payer (of the Department of Materials Science and Engineering, Case Western Reserve University), Dr. David Shoesmith (of the Department of Chemistry, University of Western Ontario, formerly with Atomic Energy of Canada, Limited), and Dr. Michael Streicher (a corrosion consultant, formerly with E. I. Du Pont de Nemours and Co., Inc., and the University of Delaware). Dr. Kevin Coppersmith of Geomatrix, Inc., served as facilitator for the workshop.

The workshop began with a few short presentations giving (1) the ground rules for the workshop, (2) the status of the DOE's program for disposing of spent fuel, and (3) the description of the current waste package design. A fourth presentation, proposing a simple way to approximate the interactions that various underground facility designs would have with various waste package designs, also was made.

The purpose of the fourth presentation was to separate underground facility design from waste package design. The separation was considered necessary because the duration of the workshop was too brief to allow full discussion of both underground facility design and waste package design and their associated research needs. Although the separation worked for the workshop, it is clear that underground facility design and waste package design are highly interdependent and therefore must be taken together for any comprehensive examination.

B. Alternative Waste Package Designs

In the reference waste package design, the waste package has a 10-cm-thick carbon-steel outer wall and a 2-cm-thick nickel-alloy inner wall. The current design includes four waste package capacities for commercial spent fuel: 12 pressurized-water reactor (PWR) assemblies, 21 PWR assemblies, 24 boiling-water reactor (BWR) assemblies, and 44 BWR assemblies. The packages are up to 1.7 m in diameter and 5.4 m in length. Alternative designs identified at the workshop are listed below.

1. Current base design: a carbon-steel outer shell shrunkfit over an Alloy 22 inner shell.

1a. Same as 1 except that the outer shell fits loosely over the inner shell.

2. An Alloy 22 outer shell over a carbon-steel inner shell (i.e., reversal of the two shells of the current base design).

3. An Alloy 22 outer shell over a nodular cast-iron inner shell.

3a. Same as 3 except that rod consolidation would be used (to increase waste package capacity), thickness of the waste package wall would be increased (so that the radiation field outside the waste packages would be low enough for humans to work near the waste packages), and significant ventilation would be used (to maintain temperatures low enough for humans to work near the waste packages).

4. An Alloy 22 outer shell over a graphite inner shell.

5. A titanium outer shell over an Alloy 22 inner shell.

6. A titanium or Alloy 22 outer shell over a "structural material" (e.g., stainless steel or a low-cost nickel alloy) inner shell.

7. A three-shell waste package with a titanium or Alloy 22 outer shell, an Alloy 22 or titanium middle shell, and a "structural material" inner shell.

8. Any waste package design that would allow emplacement in vertical boreholes (with ventilation).

9. Lower-capacity waste packages and extensive use of backfill.

10. Any waste package design that would allow emplacement in horizontal boreholes (with ventilation).

Although the panelists did not state that the list of design alternatives was necessarily the complete list of all reasonable alternatives, no additional alternatives were identified during the workshop. The Board will use these alternatives to help evaluate the completeness of the DOE's studies on alternative waste package designs. The Board does not take the position that one or more of these alternatives is superior to the reference waste package design. The Board believes that all the alternatives are worthy of at least a screening evaluation and expects that the screening evaluation will result in some of the alternatives being chosen for comprehensive evaluation.

C. Research Needs

After examining waste package alternatives, the panelists identified research needed to support alternatives. "Research" was defined in a very broad sense: It could include laboratory or field experiments, analysis (e.g., running thermodynamic models on computers), more-complete specification of requirements, or even the novel application of commercially available technology. The panelists developed a list of research needs for each alternative.

The Board has not reviewed the DOE's waste package research program formally since the workshop. Informally, the Board is aware that some of the research needs identified at the workshop were being addressed in the DOE program at the time the workshop was held and that the other research needs are being supported by new DOE initiatives.

Longer-range programs also need to be started. These programs are needed for improving the fundamental understanding of long-term corrosion resistance of passive films and long-term stability of metastable phases (such as in Alloy 22).

D. Conclusions

- The workshop resulted in the identification of several waste package alternatives that deserve careful examination by the DOE.

- Numerous research needs were developed at the workshop, most of which are applicable regardless of the waste package design that finally is chosen. Much of the research is under way. There are a few conspicuous gaps, however, and they need to be addressed. Short-term gaps include (1) the determination of the chemistry of the water after it has interacted with the waste package and (2) the study of natural analogues. Long-term gaps include programs for improving the fundamental understanding of long-term behavior of passive films and long-term phase stability.

- Although a simple method for separating waste package design from underground design sufficed for the purposes of the workshop, one of the clear lessons from the workshop is that the waste package and the underground facility (together, the engineered barrier system) are too interdependent to be separated. Thus, the development and analysis of each alternative waste package design must be accompanied by the simultaneous development and analysis of an underground facility design that is most appropriate for it.

III. Transportation

Although no immediate activity is expected, transportation of spent nuclear fuel continued to be of significant interest to the Board in 1998.

In developing its transportation program, the DOE might learn much from experiences in Europe and Japan, where there is already large-scale transportation activity. In those countries, there is an antinuclear element that the industry must deal with. Germany has had a great deal of difficulty in moving spent nuclear fuel, and the shipments from Japan to France and the United Kingdom have generated protests.

The DOE also might learn some lessons from what is taking place in Europe and should make every effort to build trust and a good working relationship with the groups, especially in Nevada, that will be affected by a large-scale shipping campaign. One possible approach to maximizing safety and to preventing undue burdens on the nationwide railroad network could be the use of dedicated trains for transporting spent nuclear fuel. The Board also feels that the design of the transportation cask should be integrated with that of the rail car. An integrated design concept would be a way to increase safety and performance.

IV. Environmental Impact Statement for a Yucca Mountain Repository

The DOE is preparing an environmental impact statement (EIS) for a Yucca Mountain repository (Dixon 1998). The EIS would accompany a recommendation to the President (currently scheduled for 2001) for developing a repository at the site and also would be submitted to the NRC, accompanying the application for a license for the facility in 2002. The proposed action in the EIS is to construct, operate, and eventually close a repository at Yucca Mountain for the geologic disposal of 63,000 metric tons of commercial spent nuclear fuel and 7,000 metric tons of DOE-owned spent nuclear fuel and high-level radioactive waste. The no-action alternative would be to leave those materials in storage at their current locations.

Three "implementing alternatives" will be evaluated for developing a repository, defined by low, intermediate, and high thermal loads.[19] For each alternative, two packaging options will be evaluated: (1) sealing wastes in multipurpose canisters at the generator sites and (2) transporting wastes in casks and repackaging the wastes at the repository site. For each implementing alternative, five transportation options also will be evaluated, consisting of predominantly (1) truck or (2) rail cross-country shipment to Nevada and (3) rail, (4) heavy-haul, or (5) legal-weight truck shipment within Nevada. Two expanded inventory "modules" will be considered: (1) disposal at Yucca Mountain of the entire U.S. inventory of spent nuclear fuel and high-level radioactive waste and (2) disposal of other highly radioactive wastes that may require permanent isolation (USDOE, YMPO 1997). For the no-action alternative, two scenarios will be evaluated: (1) loss of institutional controls at storage sites after 100 years and (2) continuation of institutional controls at those sites for 10,000 years (Dixon 1998).

The DOE plans to publish its draft EIS in July 1999, initiating a public comment period of several months. The final EIS is scheduled to be published in August 2000. The Board plans to review and comment on the draft EIS after its publication.

19. "Thermal load" is the amount of waste emplaced per unit area of the repository. In the EIS, thermal loads of less than 40 metric tons per acre, 40-80 metric tons per acre, and more than 80 metric tons will be considered.

V. Strategic and Performance Plans

In late 1997, the Board developed a 5-year strategic plan in compliance with the Government Performance Results Act. The Board also established its performance plan for fiscal year 1999, which includes specific objectives to be accomplished during that period. In January 1998, the Board held a public session in conjunction with its regular Board meeting in Amargosa Valley, Nevada, to obtain comments from the interested public on both its strategic and its performance plans. The Board also solicited comments on both plans from others having oversight roles for, or involvement in, nuclear waste management issues, including key congressional staff, the DOE, and the NRC. Copies of the strategic plan and the performance plan for the coming year are included in appendices to this report.

The Board's strategic plan underscores the importance of an independent technical and scientific review of the civilian radioactive waste management program for achieving the overall national goal of ensuring that civilian spent nuclear fuel and high-level radioactive waste are safely packaged, transported to, and disposed of in a permanent repository at a suitable site. The Board's performance objectives for fiscal year 1999 reflect the goals stated in the strategic plan and flow from the Board's technical and scientific review of DOE work, including (1) designing components of an engineered barrier system, (2) developing an environmental assessment of the site, (3) planning related to the safety of waste-transportation corridors, and (4) conducting research supporting a decision on the suitability of the site.

Procedures were established in the performance plan for conducting an annual evaluation of the Board's performance in meeting its objectives for the previous year. The Board will consider whether the reviews, evaluations, and other activities included in its performance goals have been completed; whether the results of reviews, evaluations, and other activities undertaken under the auspices of the program have been communicated in a timely, understandable, and appropriate way to the Secretary of Energy and Congress; and whether the recommendations made by the Board had a positive effect on the program. The first of these program evaluations will be conducted at the end of fiscal year 1999, and the results will be included in the Board's summary report for that period.

VI. Board Visit to Waste Isolation Pilot Plant

Members of the Board met with managers of the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, and toured the facilities on March 10, 1998. The visit included the opportunity to hear firsthand from George Dials, then general manager of the Carlsbad Area Office of the DOE, and Wendell Weart, formerly Senior Scientist for the WIPP program and now Senior Fellow at Sandia National Laboratories in Los Alamos, New Mexico. The Board's visit included a tour of the waste-handling building and the underground facilities. Board members also were briefed on the WIPP compliance- and application-review processes. On the basis of their experience, those involved made the following observations to the Board.

- In evaluating the performance assessment for WIPP, the regulator(s) tended to make conservative assumptions in assessing the probabilities and consequences of events and processes.

- When submitting the license application for a first-of-a-kind facility, such as WIPP, having credible sources, other than the proponent, provide analysis of the scientific and technical conclusions of the proponent was helpful.

- Strong leadership is required to integrate and focus scientific investigations. A shared vision and a focused management plan can help eliminate unnecessary work and help complete necessary work more quickly.

The Board members also noted that the managers instituted a ranking system to manage the science at WIPP. This major effort resulted in reducing the experimental work in progress from 116 activities to 8. Other important decisions that affected the scientific and technical work at WIPP were to (1) evaluate 18 different engineered alternatives, (2) adopt a more-phased approach to securing a license, and (3) commission an international peer review.[20]

VII. International Activities

Several members of the Board participated in two international trips in 1998 in an effort to continue the Board's objective of remaining informed about scientific, technical, and program developments in the nuclear waste disposal programs of selected developed countries. Board members traveled to Sweden and Finland from May 4 to 9. A second delegation of five members visited Germany from June 8 to 11. One major purpose of the visits was to give new Board members the opportunity to visit several nuclear waste facilities firsthand and to receive briefings on the scientific and technical progress in the nuclear waste programs of the countries.

In addition to the two trips, the Board participated in several briefings in the Washington, D.C., area. The first, arranged by the British Embassy, consisted of a meeting of selected Board members with five members of the Select Committee on Science and Technology of the House of Lords, United Kingdom. The committee is conducting an inquiry into the management of nuclear waste following the decision of the government in 1997 to uphold Cumbria County's decision to deny U.K. Nirex Ltd.'s planning application for a rock-characterization laboratory near Sellafield. Members of the Board and staff also met with representatives from a study committee organized by The Institute of Applied Energy in Japan, who were visiting several foreign countries collecting research on international approaches to postclosure management of potential repositories for high-level radioactive waste. Last, the Board and staff met with a delegation of France's Atomic Energy Commission (CEA), who were visiting various organizations and facilities as part of an ongoing study of the long-term conditioning and storage of high-level radioactive waste, mandated in 1991 by French law.

A. Germany

A delegation of the Board traveled to Germany to visit nuclear waste facilities. From June 8 to 11, the delegates visited several sites[21] and were briefed on many of the scientific and technical aspects of the management, storage, transportation, and potential disposal of high-level radioactive waste and spent nuclear fuel in Germany. The Board's visit focused on the design, development, testing, and fabrication of storage, transportation, and disposal casks; the site-characterization work at the potential disposal site at Gorleben; and the system for moving spent nuclear fuel and for storing and preparing high-level waste for permanent disposal.

Considerable progress has been made in developing the Pollux cask, a packaging system for the transport, interim storage, and final disposal of spent-fuel rods (Janberg and Spilker 1998). The Board members believe that the effort that has gone into designing, fabricating, and testing this cask is worth exploration by those involved in similar work for the U.S. program.

The Board members noted the use of natural convection to ventilate the entire underground exploratory system at Gorleben. The exploratory facility at Gorleben is at the southern edge of the proposed repository block and is accessed by two shafts that are approximately 7 m in diameter. The intake shaft extends to 940 m, and the exhaust shaft extends to 840 m. Work is under way to extend the facility around the proposed block. There is no forced-draft fan on the intake shaft and no induced-draft fan on the exhaust.

20. The DOE commissioned an international review team in June 1996. It included experts appointed by the Organization for Economic Cooperation and Development, the Nuclear Energy Agency, and the International Atomic Energy Agency.

21. The Board's visit included the following sites: (1) Gesellschaft für Nuklear-Service mbH and Gesellschaft für Nuklear Behälter mbh cask development, fabrication, and testing facilities in Essen; (2) the Ahaus interim storage site, operated by Brennelement-Zwischenlager Ahaus GmbH; (3) the Pilot Conditioning Plant, Radwaste Interim Storage Facility, and Transport Cask Interim Storage Facility, which are located at Gorleben and are operated by Brennelementlager Gorleben mbH; (4) the proposed site of a permanent repository, which is located at Gorleben and is undergoing site characterization by Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH; and (5) the Endlager für radioaktive Abfälle Morsleben, which is a permanent disposal site for low- and intermediate-level radioactive waste near Morsleben.

Unrestricted natural convection flow in the winter is high enough that a damper at the exploratory facility level has to be used to reduce air flow. In designing any alternative repository plans for Yucca Mountain, it may be worth drawing on the experience of those involved in designing the ventilation system at Gorleben, as well as the ventilation studies undertaken by Nye County, Nevada.

B. Sweden

A small delegation from the Board visited the municipality of Oskarshamn in southeastern Sweden on May 4 and 5. The purpose of the visit was to tour the Swedish Nuclear Waste Company's (SKB) facilities and to meet with representatives of Oskarshamn, one of four municipalities that have volunteered to undertake the first step in a process that could result in a permanent repository being located in their municipality. Three other municipalities have volunteered and are in the first phase of the prestudy process. They are Nyköping, Östhammar, and Tierp.

Members of the Board had the opportunity to meet with the people in Oskarshamn who are heavily involved in establishing an environmental impact assessment (EIA) process. The EIA Forum was created by the community after it volunteered to undertake the first of three phases of a volunteer process established in Sweden to designate a final repository site. The three phases are (1) feasibility studies, (2) site investigations, and (3) detailed investigations. The EIA forum is intended, among other objectives, to enable the residents of the municipality to participate in the decision-making as the community moves to determine whether it wants to proceed to site investigation.[22]

The EIA Forum is a significant effort in that it is the first initiative of its kind in the world for disposing of spent nuclear fuel. Through the EIA Forum, the municipality has formalized a process in which the locality is empowered to make key decisions about whether it wants to proceed to other phases of the site selection process. The community has organized six working groups: long-term safety and geoscience, technologies, land use and environment, social science, encapsulation, and information. Their effort to date is aimed at reaching a realistic assessment of the effect that a permanent repository would have on their community.

During its visit, members of the Board's delegation had the opportunity to tour the following SKB facilities: the Hard Rock Laboratory at Äspö, the interim storage facility (CLAB), and the Encapsulation Laboratory in Oskarshamn. During its visit, the Board also was briefed on the scientific and technical work being performed in support of the SKB's KBS-3 waste isolation concept.[23] The purpose of the Encapsulation Laboratory is to demonstrate on a full-scale basis that one canister per day that meets the safety requirements can be produced. The Encapsulation Laboratory also will be used to test operational problems, estimate the reliability and maintenance of the equipment and the plant, and estimate the capability of the equipment.

The SKB canister, which is undergoing full-scale laboratory manufacturing trials, is an evolution of past designs. It consists of 50 mm of copper with cast iron inside. The cast-iron inner component has been added as a stand for the fuel elements and as a support for the copper mantle. The canister serves as two barriers; the copper prevents groundwater from contacting the fuel, and the cast iron converts what water may be left into hydrogen gas and iron oxide. SKB states that if the canister is manufactured properly, galvanic interactions will not be a problem. The design basis for the canister includes a corrosion allowance and takes into account hydrostatic pressure and the forces from the packing material around the canister. Plans are to pack sodium bentonite around the waste packages to minimize water ingress. The tunnels will be backfilled with sodium bentonite and (1) sand or (2) sand and crushed rock.

A prototype repository is being built at the Äspö laboratory. Canisters made at the canister laboratory

22. Details of the process and policy that constitute Oskarshamn's EIA Forum are in *EIA Forum for Studies of the Final Disposal System for Spent Nuclear Fuel in Oskarshamn Municipality* (Kalmar 1998).

23. A summary of this concept is in *This Is How We Manage Sweden's Radioactive Waste: Activities 1997* (SKB 1998b). More-detailed descriptions are available in SKB's RD&D Programme 98, (SKB 1998a).

will be emplaced with precompacted bentonite buffer blocks and rings. No nuclear fuel will be used, but some of the canisters will be heated with electricity. Instruments will be used to verify predictions about the performance of the repository during its initial operating stage and to provide practical experience in handling and retrieving of waste. The prototype will be in operation for at least 20 years.

C. Finland

The same delegation that visited representatives of the Swedish program traveled on to Finland for meetings and a site visit on May 7 and 8. The visit included meetings with representatives of Posiva Oy, a small company responsible for the management and final disposal of spent nuclear fuel in Finland. The Board members also met with representatives of the Radiation and Nuclear Safety Authority (STUK) and the Ministry of Trade and Industry, which oversees the policy, licensing, and funding of nuclear waste activities in Finland. The Board members then traveled to Loviisa to tour the site characterization in progress at Hästholmen, one of four sites undergoing preliminary site characterization. The three other sites are Olkiluoto in Eurajoki, Romuvaara in Kuhmo, and Kivetty in Äänekoski. The sites also have been evaluated as part of an EIA program conducted by Posiva Oy.[24]

The Finnish nuclear waste management and disposal program continues to operate effectively and efficiently. Posiva Oy has approximately 30 full-time employees, and contractors are used to a great extent. The program remains on schedule. That schedule calls for completion of a preliminary site investigation at each of the four sites in 1999. In 2000, a final disposal site will be selected. An investigation shaft will be built, and underground site characterization will be conducted from 2000 to 2010, when construction of the encapsulation plant and the final repository will begin. The established date for beginning final disposal is 2020.

Posiva Oy estimates that approximately 1,500 canisters of spent fuel, or 2,600 metric tons, will need to be disposed of. This is based on a 40-year life of the nuclear power plants at Olkiluoto and Loviisa. Current plans are to build 15 kilometers of underground tunnels, on the floor of which holes for fuel canisters will be bored. The fuel will be transported by road or rail and, in a few alternatives, by sea. The disposal concept is very similar to the SKB's in Sweden because of the similarities in the geology and hydrology of the two countries. The canister that will be used for disposal, however, differs somewhat from the Swedish canister. It consists of an external canister of copper tightly surrounding an inner canister of nodular cast iron. The copper is used to prevent corrosion caused by groundwater; the nodular cast iron is used because it is strong enough to withstand the mechanical stresses prevailing in the bedrock.

24. A description of the EIA process in Finland, including a description of the current waste isolation concept and a summary of the conditions that must be met at each of the sites in order to build a repository there, is in *The Final Disposal of Spent Nuclear Fuel—Environmental Impact Assessment Programme* (Posiva Oy 1998).

Abbreviations and Acronyms

ACNW	Advisory Committee on Nuclear Waste
Board	U. S. Nuclear Waste Technical Review Board
BWR	boiling-water reactor
CFR	*Code of Federal Regulations*
CFu	Crater Flat undifferentiated unit
CHn	Calico Hills nonwelded unit
^{36}Cl	chlorine-36
DOE	U.S. Department of Energy
EBS	engineered barrier system
ECRB	enhanced characterization of the repository block
EIA	environmental impact assessment
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESF	Exploratory Studies Facility
EWDP	Early Warning Drilling Program
GWTT	groundwater travel time
HLW	high-level radioactive waste
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
M&O	DOE's management and operating contractor
MTU	metric ton of uranium
NAS	National Academy of Sciences
Np	neptunium
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWPAA	Nuclear Waste Policy Amendments Act
NWTRB	U.S. Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management, U.S. Department of Energy
PTn	Paintbrush Tuff nonwelded unit
PWR	pressurized-water reactor
RFP	request for proposal
SKB	Svensk Kärnsbränslehantering (Swedish Nuclear Fuel and Waste Management Company)
SZ	saturated zone
SZEE	saturated zone expert elicitation
TBM	tunnel-boring machine
TCw	Tiva Canyon welded unit
TSw	Topopah Spring welded unit
TSPA	total system performance assessment
TSPA-VA	total system performance assessment-viability assessment
USGS	U.S. Geological Survey
UZ	unsaturated zone
VA	viability assessment
WIPP	Waste Isolation Pilot Plant
WPDEE	waste package degradation expert elicitation

Glossary

The following list of terms has been compiled to aid in the reading of this report. It is not meant to be a formal glossary or to have the completeness of a dictionary; rather, it is meant to help the reader understand some of the terms used regularly by the Board.

accessible environment. The earth's surface and the rock more than 5 kilometers beyond the repository.

alluvium. Clay, silt, sand, gravel, or similar material deposited by running water.

analogue. A thing or part that is analogous. As used in this report, a phenomenon that can provide information on or add understanding to aspects of repository performance. Analogues are of two types: natural and anthropogenic. Natural analogues occur through natural phenomena. Anthropogenic analogues result from human activity.

aquifer. Permeable saturated rock through which groundwater flows.

areal mass loading. The concentration of emplaced spent fuel, averaged over the area of the repository and expressed in kilograms per square meter or in metric tons per acre.

backfill. Solid materials placed in excavated areas underground to fill voids (i.e., crushed tuff).

barrier. Something that prevents or retards the passage of radionuclides toward the environment.

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

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

chlorine-36 (^{36}Cl). A long-lived radioactive isotope of chlorine produced by irradiation of natural chlorine, argon, or other materials by cosmic rays or neutrons. Atmospheric testing of nuclear weapons in the 1950's temporarily increased concentrations of chlorine-36. The resulting "bomb pulse" levels of chlorine-36 can sometimes serve as a tracer to determine how precipitation from the 1950's has moved through soil and rocks, such as those present at Yucca Mountain.

cladding. Thin metallic material that encases nuclear fuel

colloid. A particle that can be suspended easily, or a suspension of very fine particles.

colloidal transport. Because colloidal particles can be suspended for long periods without settling, they may be transported at the same velocity as groundwater.

container. A receptacle used to hold radioactive waste (usually spent fuel).

corrosion-allowance materials. Materials that fail because of generalized corrosion and that tend to fail more rapidly than corrosion-resistant materials.

corrosion-resistant materials. Materials that fail primarily because of localized corrosion and that tend to fail more slowly than corrosion-allowance materials.

critical group. The group that is representative of the individuals in the population who, on the basis of cautious but reasonable assumptions, are at the highest risk from exposure to repository releases.

defense-in-depth. Incorporation of multiple barriers in the design of a repository to make the performance of the overall system less susceptible to the unexpected failure of any individual barrier.

dilution. Reducing the concentration of radioactive materials that might be released from a repository.

disposal. Isolation of radioactive wastes from the accessible environment involving no foreseeable intent of recovering them. Isolation occurs through a combination of engineered and natural barriers rather than through human control.

dose. See **radiation dose**

dose-based standard. A regulatory limit on the radiation dose allowed, as contrasted with standards that restrict allowable health risks, quantities of radioactive materials released to the environment, concentrations of radioactive materials in air or water, or other measures of radiological releases from a repository.

drift. A near-horizontal excavated passageway through the earth; a tunnel.

east-west cross drift. A small exploratory tunnel across the proposed repository for enabling scientists to examine the geologic and hydrologic conditions.

emplacement drift. Tunnels in which radioactive waste will be placed in the repository.

engineered barrier system (EBS). The constructed components of a disposal system designed to slow down or prevent the release of radionuclides from the underground facility. It includes the waste form, the waste package, materials placed over and around the waste package, and any barriers used to seal penetrations directed into and within the underground facility.

Enhanced characterization of the repository block (ECRB). DOE's proposal for an east-west exploratory tunnel containing three test alcoves and two boreholes to provide more preliminary information on the repository block.

environmental impact statement (EIS). A detailed written statement for supporting a decision on whether to proceed with major U.S. Government actions affecting the quality of the human environment.

expert elicitation. The formal process through which expert judgment is obtained.

expert judgment. An evaluation based on an assessment of data, assumptions, criteria, or models by one or more experts in a field.

exploratory studies facility (ESF). An underground facility constructed for performing exploration and testing of the site's suitability to host a geologic repository.

fault. A plane in the earth along which differential slippage of the adjacent rocks has occurred.

flow path. The direction that underground water and any contaminants it may contain flow.

fluid inclusion. A tiny (1-100 micron in diameter) cavity containing liquid, gas or both, formed by the entrapment of liquid in crystal irregularities.

flux. The rate at which groundwater flows through the earth. Flux is the volume of flow per unit area of earth perpendicular to the direction of flow.

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

fracture flow. Flow through the fractures in a given medium.

geochemistry. Study of the amounts and distribution of chemical elements in minerals, rocks, soil, water, and the atmosphere. Geochemistry at the Yucca Mountain site is concerned primarily with the potential migration of radionuclides to the accessible environment. Geochemists are studying the chemical and physical properties of the minerals, rocks, and waters that might affect the migration of radionuclides from a repository.

geologic repository. A system for disposing of radioactive waste in excavated geologic media, including surface and subsurface areas of operation and the adjacent part of the natural setting.

groundwater . Water that exists or flows beneath the land surface.

groundwater travel time (GWTT). The time it takes groundwater to travel from the edge of the disturbed zone to the accessible environment.

high-level waste. Highly radioactive material from reprocessing spent nuclear fuel, including liquid waste produced directly in reprocessing or any solid material derived from such liquid waste. Any other highly radioactive material that the Nuclear Regulatory Commission determines requires permanent isolation by disposal in a geologic repository.

hydrogeology. The science dealing with subsurface water and with related geologic aspects of surface water. At the Yucca Mountain site, emphasis is placed on the study of liquid transport through the rock matrix and fractures. Groundwater is a primary means by which radionuclides could be transported from the repository to the accessible environment.

infiltration. Water entering soil or rock after precipitation rather than becoming runoff into rivers, streams, ponds, etc. The terms "infiltration" and "net infiltration" also are used to refer to water that penetrates deeply into soil or rock (beneath plant root zones) rather than returning to the atmosphere by evapotranspiration.

infiltration flux. The rate at which water from precipitation enters the rock below the surface root zone. See **flux**.

interim storage. Storage of spent fuel or high-level radioactive waste with the intention and expectation that the waste will be moved later to a permanent repository.

license application. A document submitted to the Nuclear Regulatory Commission containing general information and a safety analysis for a nuclear reactor, a geologic repository, or an interim storage facility for spent nuclear fuel and high-level radioactive waste.

lithophysal, nonlithophysal. Lithophysal and nonlithophysal zones denote the relative abundance of lithophysae found in different rock strata. Lithophysae, sometimes called "stone bubbles," are cavities in silicic volcanic rock that are formed, soon after the volcanic rocks are deposited, because of the presence of vapors under very high pressure.

matrix. In hydrology, the solid framework of a porous system.

near field. The region where the natural hydrologic system has been altered by the excavation of the repository or by the thermal environment created by the emplacement of high-level waste.

nonwelded tuff. A tuff that has not been hardened and welded together by intense temperature and pressure and that contains fewer fractures than welded tuff does.

Nuclear Waste Policy Act (PL 97-425). The federal statute enacted in 1982 that established the Office of Civilian Radioactive Waste Management and defined its mission for developing a federal system for the management and geologic disposal of commercial spent nuclear fuel and other high-level radioactive wastes as appropriate. The Act also specified other federal responsibilities for nuclear waste management, established the Nuclear Waste Fund to cover the cost of geologic disposal, authorized interim storage until a repository is available, and defined interactions between federal agencies and states, local governments, and Indian tribes.

Nuclear Waste Policy Amendments Act of 1987 (P0-203). The legislation that amended the Nuclear Waste Policy Act to limit repository site-characterization activities to Yucca Mountain, Nevada; establish the Office of the Nuclear Waste Negotiator for seeking a state or an Indian tribe willing to host a repository or a monitored retrievable storage facility; create the Nuclear Waste Technical Review Board; and increase state and local government participation in the waste management program.

peak dose. The largest dose projected per unit time (e.g., per year or human lifetime) after repository closure.

performance assessment (PA). An analysis that predicts the behavior of an entire system or a part of a system under a given set of conditions on the basis of an assumed measure of performance.

postclosure. The time after the closure of the repository.

preclosure. The time before the closure of the repository.

radiation dose. The amount of energy deposited in a unit of mass of a material. Any of several modified doses, including dose equivalent and effective dose, that more closely approximate the biological harm to humans from exposure to ionizing radiation.

radionuclide. An atomic nucleus that is radioactive.

radionuclide transport. The movement of radionuclides, generally as dissolved solids or gaseous forms, through a rock formation.

recharge. The addition of water to the saturated zone or the water added.

repository. See **geologic repository**.

repository block. The part of Yucca mountain in which placement of the proposed repository is being considered.

retardation. The physical or chemical process that causes some dissolved radionuclides to move more slowly than the water they are dissolved in.

saturated zone (SZ). The part of the earth's crust in which all voids are filled with water under pressure at least as great as atmospheric pressure.

seepage flux. The magnitude and distribution of percolating water that drips into the emplacement drifts and, potentially, onto the waste packages.

self-shielded waste package. A waste package with sufficient intrinsic radiation shielding so that people can perform occasional activities on or near it without receiving radiation exceeding standards for workers.

shrinkfitting. Joining (or mating) layers of metal by using heat to expand the outer shell, inserting the inner shell, and allowing the outer shell to cool around the inner shell.

site assessment. The full range of activities needed to evaluate the suitability of the Yucca Mountain site, including site characterization; laboratory research; performance assessment; and design of the repository, waste packages, and engineered barriers.

site characterization. See **characterization**.

sorption. The binding, on a microscopic scale, of dissolved molecules or atoms on mineral surfaces in contact with fluid. The sorption of dissolved radionuclides can lead to their retardation.

sorption characteristics. The ability of rocks and minerals to bind, reversibly or irreversibly, radionuclides or other chemical species on their surfaces.

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

spent nuclear fuel. Fuel that has been withdrawn from a nuclear reactor after irradiation, the constituent elements of which have not been separated by reprocessing.

structural geology. Study of the deformational features of rocks induced by processes such as folding, faulting, and igneous activity. Study of the processes.

suitability determination. The formal recommendation by the DOE to the President on whether the Yucca Mountain site can safely host a repository for high-level waste.

thermal energy. Heat produced by the radioactive decay of waste.

thermal load. The amount of heat produced by emplaced waste and affecting the near field and overall repository material, including geophysical and engineered barriers (usually measured in kilowatts per acre).

thermohydrology. The study of how heat affects the movement of water in geologic formations.

total system performance assessment (TSPA). Analyses undertaken by the DOE to assess the ability of the potential repository at Yucca Mountain to provide long-term waste isolation.

transparent (performance assessment). Easy to detect or perceive. Using clear language and easily understood concepts or assumptions to arrive at credible, traceable, and logical conclusions.

unsaturated zone (UZ). Geologic formations located above the regional groundwater table.

viability assessment (VA). A congressionally mandated report that the Secretary of Energy provided to the President and Congress in 1998 and that includes repository and waste package designs, a total system performance assessment, a license application plan, and estimates of repository cost and schedule.

volcanism. The process by which molten rock and its associated gases rise from within the earth and are extruded onto the earth's surface and into the atmosphere.

waste acceptance. The processes necessary for the DOE to take title to and physical possession of spent nuclear fuel or high-level radioactive waste from owners and generators of the wastes.

waste containment and isolation. Separation of waste from the environment so that any radioactive material reentering the environment will be kept within prescribed limits.

waste form. Radioactive waste materials and any encapsulating or stabilizing matrix. Examples include used reactor fuel elements and borosilicate glass "logs."

waste package. The radioactive waste materials and any encapsulating and stabilizing matrix, as well as any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.

water table. An underground boundary below which the rock pores are completely filled with water and above which they are only partly filled with water.

welded tuff. Rock made of volcanic ash that has been hardened and welded together by heat, pressure, and possibly the introduction of cementing minerals. Welded tuff contains more fractures than nonwelded tuff does.

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