SIXTH REPORT TO

THE U.S. CONGRESS

AND

THE U.S. SECRETARY OF ENERGY

FROM THE

NUCLEAR WASTE TECHNICAL REVIEW BOARD

December 1992

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
1100 Wilson Boulevard, Suite 910
Arlington, VA 22209

December 1992

The Honorable Thomas S. Foley
Speaker of the House
United States House of Representatives
Washington, D.C. 20515-6501

The Honorable Robert C. Byrd
President Pro Tempore
United States Senate
Washington, D.C. 20510-1902

The Honorable James D. Watkins
Secretary
U.S. Department of Energy
Washington, D.C. 20585

Dear Speaker Foley, Senator Byrd, and Secretary Watkins:

The Nuclear Waste Technical Review Board (the Board) herewith submits its *Sixth Report to the U.S. Congress and the U.S. Secretary of Energy* as required by the Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203.

Congress created the Board to evaluate the technical and scientific validity of the Department of Energy's (DOE) program to manage the permanent disposal of the nation's civilian spent fuel and high-level radioactive waste. Specifically, the Board is charged with evaluating the DOE's site-characterization activities at Yucca Mountain, Nevada, as well as activities relating to the design of the repository and to the packaging and transport of spent fuel and high-level radioactive waste.

Since its last report, in June 1992, the Board has continued its interaction with the DOE, the state of Nevada, and with others involved in or concerned about this important program. As a result of these interactions, the Board would like to make seven technical recommendations that it believes will aid the DOE in its endeavors to design and implement a safe and efficient radioactive waste disposal system.

In addition, during the past four years, Board members have visited five countries to discuss our respective technical and scientific programs. As a result, the Board would like to suggest a review be undertaken of specific approaches being used in other countries that could benefit the U.S. program. Specifically, the Board suggests the U.S. program consider the advantages and disadvantages of several approaches including the following.

- A management approach in which existing schedules (e.g., for repository operation) are taken seriously but do not drive the scientific and technical goals of the program (e.g., selection of a waste package)

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- The strengthened role that nuclear utilities might play to help ensure that the overall system of nuclear spent fuel and high-level waste management moves ahead in a cost-effective way

- Management approaches *and* program procedures for cost allocation and control that effectively minimize costs for overhead and infrastructure in the R&D components of the program

We believe that it is possible to meet the challenge of designing a program to manage the nation's spent fuel and defense high-level waste that is safe, efficient, *and* cost-effective.

We thank you for the opportunity to serve the nation and Congress. As our work progresses, we hope to continue to assist you in furthering the goal of safe and cost-effective management of civilian spent fuel and defense high-level waste.

Sincerely,

John E. Cantlon, Chairman

Clarence R. Allen

Garry D. Brewer

Edward J. Cording

Patrick Domenico

Donald Langmuir

John J. McKetta

D. Warner North

Dennis L. Price

Ellis D. Verink, Jr.

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Table of Contents

List of Tables

Executive Summary

In the United States today, 111 commercial nuclear power plants are licensed to operate at 70 sites nationwide. By 2030, after those plants have completed approximately 40 years of operation, experts project almost 85,000 metric tons of spent nuclear fuel will have accumulated. Congress assigned the U.S. Department of Energy (DOE) the responsibility of developing and implementing a system to manage the disposal of this spent fuel, along with defense high-level radioactive waste from reprocessing.

In 1987, Congress directed the DOE to evaluate a site at Yucca Mountain, Nevada, for its suitability as a possible location for a mined geologic repository for the permanent disposal of that waste. In the same legislation, Congress created the Nuclear Waste Technical Review Board (the Board) to evaluate the technical and scientific aspects of the DOE's program.

Board Activities this Reporting Period

The issues and recommendations reviewed in this report have evolved primarily as a result of activities undertaken by the Board and its panels from February 1, 1992, to August 31, 1992. During this period, the Board sponsored five meetings.

In addition to these meetings, the Board met with experts in the spent fuel and radioactive waste management programs in Finland and Switzerland, and in September, three Board members met with experts in Japan's engineered barrier research program. The Board has now had the opportunity to study in depth programs underway in Canada, Finland, Germany, Sweden, and Switzerland.

The Board's membership has changed. On April 19, 1992, Dr. Don U. Deere left the Board, completing his term as member and Chairman. On May 27, 1992, President George Bush reappointed John E. Cantlon to a second term on the Board and designated him Board Chairman. President Bush also reappointed two members and appointed three new members to the Board. Members Clarence R. Allen and Donald Langmuir were appointed to second terms in May and June, respectively. In February 1992, John J. McKetta, Jr., Joe C. Walter Professor of Chemical Engineering emeritus at the University of Texas, was appointed to his first term on the Board. And in May, Garry D. Brewer, dean of the School of Natural Resources and Environment and professor of resource policy and management at the University of Michigan, joined the Board. Finally, in June Edward J. Cording, professor of civil engineering at the University of Illinois at Urbana-Champaign, joined the Board.

The Department of Energy (DOE) has responded to the recommendations made in the Board's fifth report, and their responses are included in the appendices.

Other Issues

Congressional Testimony

Former Chairman Don U. Deere testified twice during this reporting period, on March 9, 1992, before the House Appropriations Committee, Subcommittee on Energy and Water Development, and on March 31, 1992, before the Senate Committee on Energy and Natural Resources. Following the Senate hearing, the Board was asked to respond in writing to 12 follow-up questions. The answers were submitted to the Senate Committee on April 22, 1992. See the Board's fifth report (NWTRB, June 1992) for a detailed discussion of Chairman Deere's testimony and the full text of the 12 follow-up questions and answers.

Status of Congressional Activities Related to the Program

During this reporting period, the 102nd Congress passed several important measures that could have significant implications for the civilian radioactive waste management program: appropriations for fiscal year 1993, which included a little more than $275 million from the Nuclear Waste Fund and $100 million in general revenue money to support the activities of the Office of Civilian Radioactive Waste Management (OCRWM) for fiscal year 1993, and the Comprehensive National Energy Policy Act, which deals with a wide range of energy issues, including the licensing of nuclear power plants and the management of high-level radioactive waste. Under provisions of the energy policy act dealing with nuclear waste disposal, the Environmental Protection Agency (EPA) is instructed to contract with the National Academy of Sciences (NAS) to undertake a one-year study to provide findings and recommendations on standards to protect public health and safety from releases of radioactive materials from the repository into the accessible environment. The bill stipulates that the standard established by the EPA through this process would be the only applicable radiation safety standard for the Yucca Mountain site.

The specific impact on the civilian radioactive waste management program of changes in the EPA standards mandated by this legislation may not be known until work is completed. However, the health and safety standards applied to the Yucca Mountain site affect many aspects of the program, including the waste package design and licensing requirements. The Board intends to monitor this situation and will have more to say on this important subject in future reports.

Little Skull Mountain Earthquake

On June 29, 1992, a magnitude 5.6 earthquake occurred beneath Little Skull Mountain, some 20 kilometers southeast of the site at Yucca Mountain, Nevada, being assessed for its suitability for repository development. The occurrence of this earthquake has raised a number of questions concerning earthquake hazards at the Yucca Mountain site. As a result, the Board invited representatives of the DOE to update it on the earthquake and its effects at the Board's July Board meeting in Denver.

The Little Skull Mountain earthquake served to remind all parties involved in determining whether Yucca Mountain is a suitable location for the nation's high-level radioactive waste that southern Nevada is a region where earthquakes do occur, and earthquake potential and its impact on waste isolation must be included in any evaluation. Based on preliminary analysis, this particular earthquake does not alter the scientific community's perception of what the seismic hazard is at Yucca Mountain. The resulting data, however, certainly could become a source of increased understanding of some details of that seismic hazard.

The Effects of Tectonics on the Water Table

Considerable scientific controversy and publicity have resulted during the past several years from the hypothesis of J.S. Szymanski that, within recent geologic time, the water table beneath Yucca Mountain has risen one or more times to the proposed repository level, and that this phenomenon might occur again in association with earthquakes during the service life of the repository (Szymanski 1989). Members of the NWTRB have visited many of Szymanski's critical field exposures and have seen versions of his report as well as the outside reviews. At this time, the Board has no reason to disagree with the unanimous opinion of the prestigious 17-person panel of the National Academy of Sciences (National Research Council 1992), which was the most broadly based of the review groups and which concluded "from the geologic features observed in the field and geochemical data that there is no evidence to support the assertion [by Szymanski] that the water table has risen periodically hundreds of meters from deep within the crust." If further significant data or modifications are presented in the future, the Board will consider reviewing them at that time.

Technical Recommendations

The technical recommendations made in Chapter 2 of this report are intended to aid the DOE in its efforts to improve the scientific work being conducted in the high-level radioactive waste management program. The following recommendations have resulted from activities undertaken by the Board and its panels during this reporting period.

Transportation and Systems

1. To ensure the safe performance of the waste management system, the program should not be overly motivated by the need to meet a tight schedule driven by target dates. Instead, the Board urges the DOE to ground all major technical decisions in sound scientific analysis that includes the careful evaluation of alternatives.

2. The Board continues to urge the DOE to conduct timely, iterative, top-level system studies so that the results can be used to identify enhancements, evaluate alternatives, rationalize acquisition decisions, and provide for contingencies, thus, reflecting sound program planning.

The Engineered Barrier System

3. The DOE should establish and document for defense wastes the relationship between the requirements of the draft Waste Acceptance Preliminary Specifications document and the regulatory requirements of 10 CFR 60.

4. A study should be initiated to assess the impact of the projected number of canisters of defense waste — projections range from 15,000 to 200,000 — on repository design and cost, as well as on total waste management system costs.

5. The DOE should perform a study to determine if the planned methodology for estimating the radionuclide composition of filled defense waste canisters is adequate for compliance purposes.

6. The Board strongly recommends that high-capacity, self-shielded waste package designs — including designs compatible with multipurpose cask concepts — be included in the set of waste package conceptual designs now being developed.

Risk and Performance Analysis

7. Based on Sandia's and Pacific Northwest's total system performance assessments, the Early Site Suitability Evaluation, and other relevant and available studies, the DOE should provide a *timely* reassessment of its priorities among the numerous studies that are part of site-characterization plans. Of critical importance is the definition of those data most needed for assessing site suitability.

Insights into the U.S. Nuclear Waste Management Program

Since the members of the Nuclear Waste Technical Review Board first convened in March 1989, they have been committed to learning about the spent fuel disposal programs of other countries.

To date, the Board as a whole has visited and met with experts in spent fuel and high-level waste management programs in five foreign countries. As a result of its study of these programs, the Board has made a number of observations, which have led to some tentative conclusions:

Conclusions

1. Unless public perception about the risks associated with nuclear power and the waste it generates can be addressed, efforts to site a permanent repository for burying such waste will continue to meet with opposition.

2. There may be a tendency toward greater managerial and financial accountability when those responsible for financing the operation of nuclear power plants and generating spent nuclear fuel and high-level waste also are responsible for disposing of it. In the U.S. system this would mean requiring the nuclear utilities to share more direct responsibility and liability for managing and disposing of their spent fuel.

3. The U.S. R&D program is larger in size and more costly than the R&D programs of other countries. Yet, most countries are conducting research in line with their program goals. The size of the U.S. program may in part be a result of the large level of funding required to support the current U.S. federal and contractor research establishment, and the need to accelerate the expenditure of funds to meet a very demanding schedule in characterizing the Yucca Mountain site. Whether the United States will realize greater benefits in its program as a result of the greater expenditure of funds and human resources remains to be seen.

4. Spent nuclear fuel and high-level waste will continue to be stored at a centralized facility or at reactor sites until decisions are made about the permanent disposal of that waste. In contrast to the U.S. program, however, other programs visited by the Board do not view long-term, interim storage as reflecting a failure to meet program goals. Indeed, interim storage of all fuel is acknowledged as fact and is incorporated into long-term plans for managing spent fuel and wastes. Interim storage plans in all of the countries visited seem to be well coordinated and integrated into the total waste management system.

5. The need felt by the U.S. DOE to establish an overly demanding schedule (currently 2001, licensing; 2010 repository operation) to meet a legislated deadline (set in the NWPA as 1998) is likely to persist; and program credibility may continue to suffer because the DOE may not be able to meet the deadlines. The Board believes that the effort to rush to meet overly demanding schedules could affect the quality of the technical and scientific work being undertaken as part of developing a program to manage and dispose of spent fuel and high-level waste.

6. Given the uncertainties that are likely to exist at any site being characterized for its suitability as a possible permanent repository, the countries visited by the Board are studying the potential contribution of a multibarrier system to help isolate radionuclides from the environment. An important component of the multibarrier system is the engineered barrier system. In contrast to the U.S. program, most other countries have devoted considerable resources from the outset of their programs to research development of the engineered barrier system.

7. Although this may change, the current U.S. approach to licensing may make the process of demonstrating site suitability more difficult than the approach being used by the other countries visited by the Board. In contrast to the U.S. approach, their approach to licensing allows considerable flexibility in the application of best available technologies so as to maximize the amount of time a repository could safely isolate radionuclides from the environment.

8. Based on the record to date, siting a permanent repository for the disposal of spent fuel and high-level waste will continue to generate controversy no matter what approach is taken. The success of a country's program may depend on the ability of that country to identify and adequately address those factors that most influence the public's perception of the siting process. Involving the public in nontechnical, as well as technical, issues *before* selecting a site may increase a country's chances of successfully siting a repository. Although such efforts are unlikely to eliminate all obstacles, they may succeed in framing a dialogue that is based more on fact than on emotions.

Summary

In summary, the Nuclear Waste Technical Review Board would like to suggest that both Congress and the U.S. Secretary of Energy review the U.S. program with respect to specific approaches countries visited by the Board are taking in the design and implementation of their programs to manage the disposal of spent fuel and high-level radioactive waste. The objective of this review is not to undertake an extensive and/or expensive study, but to simply determine if specific approaches in other countries could benefit the U.S. program. In reviewing the programs of Canada, Finland, Germany, Sweden, and Switzerland, the Board urges the U.S. program to consider the advantages and disadvantages of the following.

- A management approach in which existing schedules (e.g., for repository operation) are taken seriously but do not drive the scientific and technical goals of the program (e.g., selection of a waste package)

- The strengthened role that nuclear utilities might play to help ensure that the overall system of nuclear spent fuel and high-level waste management moves ahead in a cost-effective way

- Management approaches *and* program procedures for cost allocation and control that effectively minimize costs for overhead and infrastructure in the R&D components of the program

- The usefulness of well-integrated, long-term plans for the interim storage and disposal of *all* spent fuel and high-level waste, especially in light of the successful implementation and noncontroversial nature of the interim storage programs in some of the countries

- The success other countries have had in integrating research and development on both natural and engineered barriers

Introduction

In the United States today, 111 commercial nuclear power plants are licensed to operate at 70 sites nationwide. These plants produce almost 21 percent of the nation's electric power (Nuclear Regulatory Commission 1992). One by-product of nuclear energy production is radioactive spent nuclear fuel. Today, spent fuel is accumulating at the nation's nuclear power plants. Because of its radioactivity, it will require isolation from the public and the accessible environment for thousands of years.

In 1982, Congress assigned the U.S. Department of Energy (DOE) the responsibility of designing and implementing a system to manage the disposal of this spent fuel. Also included for disposal is the country's high-level radioactive waste from defense-related activities. Current plans call for the construction of a mined geologic repository that will isolate the waste for at least 10,000 years.

Creating a system to manage the disposal of spent fuel and high-level radioactive waste involves more than constructing a deep, geologic repository. It involves designing, developing, and implementing a complex system to package, collect, store (for either short or long periods of time), transport, and finally dispose of the radioactive waste from public utilities and defense facilities located across the country. All of the components of the system must *work together* safely and efficiently.

One major challenge involves demonstrating to the satisfaction of the regulators and the scientific and lay communities that workers in the system and the public at large can be protected and that the highly radioactive material will remain safely isolated for the long periods of time that regulating agencies require.

Because this is a first-of-a-kind project and because unprecedented, long time periods are involved, technical and scientific uncertainties will persist no matter where the repository is located, even under the best of circumstances. It should be possible, however, to increase the technical community's — and the public's — confidence in geologic disposal by taking steps to reduce the uncertainties to acceptable levels.

In 1987, Congress chose a site at Yucca Mountain, Nevada, to be evaluated for its suitability as a possible location for a repository. In that same legislation Congress created the Nuclear Waste Technical Review Board as an independent establishment within the executive branch. The Board evaluates the scientific and technical aspects of the DOE's program and submits its findings, conclusions, and recommendations to Congress and the Secretary of Energy. The Board's first report was released in March 1990. Reports are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Chapter 1
Background

The Nuclear Waste Technical Review Board (the Board or NWTRB) addresses issues and makes recommendations in this report that have evolved as a result of activities undertaken by Board members primarily between February 1, 1992, and July 31, 1992. These activities are discussed in detail in chapters 2 and 3. Several events took place during this reporting period, which, because of their timeliness, were discussed in detail in the fifth report. Those events have been so designated. Finally, the Board has undertaken numerous activities since the close of the period covered in this report. Some of these activities are address briefly here as a prelude to more complete discussion in later reports.

Chapter 1 reviews relevant issues that are not discussed in detail in other chapters; for example, recent congressional activities related to the Department of Energy's (DOE) program and the recent earthquake at Little Skull Mountain, which has drawn much attention from those following site-characterization activities at Yucca Mountain, Nevada. Chapter 2 contains a discussion of technical issues, and Chapter 3 reviews Board observations on the U.S. and other countries' radioactive waste management programs.

Board Activities this Reporting Period

From February 1, 1992, through July 31, 1992, the Board and its panels sponsored five meetings. A chronological list of the Board's activities (beginning January 1992 and including those scheduled for the future) can be found in Appendix C. A list of the people who made presentations at Board- and panel-sponsored meetings has been included in Appendix D.

In addition to these meetings, the Board met with experts in the spent fuel and radioactive waste management programs in Finland and Switzerland. The Board has now had the opportunity to study programs under way in five other countries.[1] As a result, the Board has undertaken a discussion of the similarities and differences among the programs in Canada, Finland, Germany, Sweden, Switzerland, and the United States. Background material on the Finnish and Swiss programs can be found in Appendix F.

The DOE submitted responses to recommendations made in the Board's fifth report. These can be found in Appendix E of this report. Inclusion of the DOE's responses does not imply Board concurrence.

Other Issues

Congressional Testimony

Former Board Chairman Don U. Deere testified twice during this reporting period, on March 9, before the House Appropriations Committee, Subcommittee on Energy and Water Development, and on March 31, before the Senate Committee on Energy and Natural Resources. Following the Senate

1 *In September, three Board members met briefly in Japan with experts in Japan's engineered barrier research program.*

committee hearing, the Board was asked to respond in writing to 12 follow-up questions. The answers were submitted to the Senate Committee on April 22, 1992. See the Board's fifth report (NWTRB, June 1992) for a detailed discussion of Chairman Deere's testimony and the full text of the 12 follow-up questions and answers.

Status of Congressional Activities Related to the Program

The 102nd Congress recently passed several important measures that could have significant implications for the civilian radioactive waste management program.

Program appropriations for fiscal year 1993

In September, Congress passed the Energy and Water Development Appropriations Bill, which included a little more than $275 million from the Nuclear Waste Fund and $100 million in general revenue money to support the activities of the Office of Civilian Radioactive Waste Management (OCRWM) for fiscal year 1993. The $100 million the Senate added, came out of funds formerly targeted for DOE defense activities and was designated as part of the DOE's share of the costs of disposing of defense wastes in a repository.[2] The total of $375,071,000 fell short of the DOE's requested amount by approximately $17 million, but was an increase of $100 million over the fiscal year 1992 appropriation.

In the past, the DOE has cited budget constraints in explaining its decision to postpone underground excavation and testing and to focus instead on surface-based testing. The Board has long advocated gaining visual access to the underground geology at the Yucca Mountain site to identify as soon as possible any potentially disqualifying characteristics. The Board is hopeful that part of this increase in funding will be used to expedite crucial underground excavation and testing and for important research, such as the development of a multipurpose, long-lived waste package.

In the conference report accompanying the appropriations bill, the conferees express their concern over "spiraling estimates of the costs of characterizing the Yucca Mountain site" and the "misallocation of emphasis away from Yucca Mountain and towards headquarters." The report goes on to state that "the M&O (management and operations) contractor is assuming responsibility more appropriately left to the national laboratories or other DOE contractors" and that "more money than is necessary [is being spent] for the monitored retrievable storage facility and the waste transportation program." The conference committee indicated that, "absent meaningful progress in the characterization of Yucca Mountain, a significant reduction in the size and expense of the M&O contractor, and a redirection in programmatic emphasis," the appropriations committees could give the OCRWM specific direction in the future on how program funds should be allocated (U.S. Congress, Conference Rept., 1992).

National Energy Policy Act

In October, Congress passed the Comprehensive National Energy Policy Act of 1992, which deals with a wide range of energy issues, including the licensing of nuclear power plants and the management of high-level radioactive waste. One of the most contentious issues raised in the bill concerns Yucca Mountain. Although a provision that would have allowed the DOE to proceed with site characterization without obtaining state environmental permits was removed from the final version of the bill, language inserted by the conference committee related to radiation health and safety standards caused Nevada's Senators to oppose the legislation. After a threatened filibuster failed to halt passage, the bill was adopted by voice vote on the last day of the session.

2 *The Nuclear Waste Policy Act of 1982 requires the federal government to pay for the permanent disposal of high-level defense waste.*

Under provisions of the legislation dealing with nuclear waste disposal, the Environmental Protection Agency (EPA) is instructed to contract with the National Academy of Sciences (NAS) to undertake a one-year study on standards to protect public health and safety from releases of radioactive materials from the repository into the accessible environment. The NAS study is to consider (1) whether a health-based standard calculated on the basis of doses to individual members of the public would provide a reasonable standard for protection of the public health and safety; (2) whether it is reasonable to assume that a system for postclosure oversight of the repository can be developed, based on active institutional controls that would prevent an unreasonable risk of breaching the repository's engineered or geologic barriers or increasing exposure beyond allowable limits; and (3) whether it is possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion during a period of 10,000 years.

Once the NAS has made its recommendations, the EPA is given one year to promulgate public health and safety standards. These would be based on and consistent with NAS findings and recommendations and prescribe the maximum annual effective dose to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of at a repository at Yucca Mountain. The bill stipulates that the EPA standard established through this process would be the only applicable radiation safety standard for the Yucca Mountain site.

After the EPA has completed its work, the Nuclear Regulatory Commission (NRC) is given one year to modify its criteria and technical requirements to be consistent with the EPA standards. Under the terms of the legislation, the NRC is required to base its technical requirements and criteria on several assumptions, including (1) that following repository closure, the inclusion of engineered barriers and postclosure oversight of Yucca Mountain will be sufficient to prevent any activity at the site that might breach the barriers or increase the exposure of individual members of the public to radiation beyond allowable limits and (2) that following the closure of the repository the Secretary of Energy will continue to oversee the site.

Responding to questions raised during the conference negotiations, committee members included language in the conference report meant to clarify the intent of these provisions relating to radiation safety standards. Members stated that the NAS would not be precluded from addressing issues in addition to those stipulated in the bill. Such issues include estimating the *collective* dose based on doses to individual members of the public. The statement goes on to say that the provisions of the bill were not meant to limit EPA or NRC authority related to public health and safety issues.

As a result, the specific impact on the civilian radioactive waste management program of changes in the EPA standards mandated by this legislation may not be known until the NAS, EPA, and NRC complete their work. However, the health and safety standards applied to the Yucca Mountain site affect many aspects of the program, including the waste package design and licensing requirements. The Board intends to monitor this situation and will have more to say on this important subject in future reports.

The bill also extends the Office of the Nuclear Waste Negotiator for a period of two years.

The Waste Isolation Pilot Plant

In related action, Congress passed the Waste Isolation Pilot Plant (WIPP) Land Withdrawal Act, which provides for the commencement of small-scale testing (up to 0.5% of total capacity for transuranic radioactive waste) of the WIPP in New Mexico once EPA approvals have been obtained. The bill requires the EPA to issue a radiation safety standard for the WIPP within six months of the enactment of the legislation and to approve the DOE's testing and retrieval plan within ten months. These activities can be undertaken simultaneously. Before initiating final disposal of transuranic wastes at the WIPP, the EPA must certify through a rulemaking procedure that the WIPP complies with disposal standards. If the EPA does not certify compliance within ten years, the waste must be retrieved and the land withdrawal will terminate. The legislation provides for a two-year extension to this deadline. After certification, the DOE must document continuing compliance every five years and must demonstrate annually that the waste is retrievable.

It is important to note that Congress has directed site-specific radiation safety standards to be promulgated for the Yucca Mountain site and has established a separate process for the development of a standard for the WIPP. This departs from previous policy, which would have applied uniform standards to both sites. (The previous EPA standard [40 CFR 191] was promulgated in 1985. Subpart B of the standard, dealing with waste disposal, was remanded by the federal court to the EPA in 1987, where work on a revised standard has continued.)

Changes in Board Makeup

On April 19, 1992, Dr. Don U. Deere left the Board, completing his term as member and Chairman. President Ronald Reagan appointed Dr. Deere to the Board and named him its first Chairman on January 18, 1989. As such, Dr. Deere was responsible for establishing the Board and overseeing its first years of operation.

On May 27, 1992, President George Bush reappointed John E. Cantlon to a second term on the Board and designated him Board Chairman. Dr. Cantlon has more than 20 years of academic and administrative experience at Michigan State University. He has served as dean of the graduate school, and after six years as academic vice president and provost, Dr. Cantlon was appointed to the position of vice president for research and graduate studies. He retired from these positions on September 1, 1990. Dr. Cantlon's area of expertise is environmental science.

President Bush also reappointed two members and appointed three new members to the Board. Members Clarence R. Allen and Donald Langmuir were appointed to second terms in May and June, respectively. Dr. Allen is professor emeritus in geology and geophysics at the California Institute of Technology, where he also served as director of the Seismological Laboratory. Dr. Langmuir is professor of geochemistry at the Colorado School of Mines.

In February, John J. McKetta, Jr. was appointed to his first term on the Board. Dr. McKetta is Joe C. Walter Professor of Chemical Engineering emeritus at the University of Texas. In May, Garry D. Brewer, dean of the School of Natural Resources and Environment and professor of resource policy and management at the University of Michigan, joined the Board. And in June, Edward J. Cording joined the Board. Dr. Cording, who in the past has served as a consultant to the Board, is a professor of civil engineering at the University of Illinois at Urbana-Champaign.

These appointments bring the number of current Board members to ten, one short of the limit set by Congress in the 1987 Nuclear Waste Policy Amendments Act. The President appoints Board members from a slate of nominees submitted by the National Academy of Sciences.

Little Skull Mountain Earthquake

On June 29, 1992, a magnitude 5.6 earthquake occurred beneath Little Skull Mountain, some 20 kilometers southeast of the site at Yucca Mountain, Nevada, being assessed for suitability for repository development. The occurrence of this earthquake raised a number of questions concerning earthquake hazards at the Yucca Mountain site. As a result, the Board invited DOE representatives to provide an update on the earthquake and its effects at the July Board meeting in Denver. The following narrative is based largely on information received at that meeting and in a subsequent report issued jointly by the University of Nevada at Reno and the U.S. Geological Survey to the DOE (University of Nevada 1992).

The Little Skull Mountain earthquake was preceded by tens of foreshocks and followed by literally hundreds of aftershocks. Preliminary analysis of these smaller events and the main shocks indicates that the earthquake occurred at a depth of about 13 kilometers, initiating rupture on a northeasterly trending normal fault. Normal faulting usually occurs when the earth's crust is extended. Pulling apart of the crust results in the initiation of rupture and the sliding of adjacent blocks along an inclined fault plane. This rupture probably progressed up to the northwest to a depth of about five kilometers. Although there are north- and northeast-trending faults at Little Skull Mountain, there was no evidence of surface faulting associated with this earthquake. Such a finding is consistent with other observations throughout the world from most earthquakes of this relatively small size.

The only significant damage reported in this very sparsely populated area was to the DOE Facilities Operation Center, seven kilometers north of the earthquake's epicenter (the point on the earth's surface directly above the location at depth at which an earthquake fault rupture first begins). Although there was architectural damage to the facility and many broken windows and ceiling tiles, the building did not suffer any loss of structural capacity. The highest ground motion recorded from the Little Skull Mountain earthquake was 0.2 g,[3] near the town of Lathrop Wells, 15 kilometers to the southwest. Because the Facilities Operation Center was closer to the epicenter and the fault probably ruptured in its direction, the ground motion at that facility may have been higher. Of particular interest was the lack of damage in two tunnels drilled into Little Skull Mountain, four kilometers to the west of the epicenter. This is consistent with many past observations showing reduced earthquake ground motion at depth and the inherently robust nature of tunnel linings in contact with the surrounding rock mass. This robustness results from the ability of the tunnel lining to deform with the rock mass as earthquake ground motion is imposed, without significant damage or collapse.

As a result of the Little Skull Mountain earthquake, two wells at or near Yucca Mountain equipped with continuously recording instruments showed a small (less than 0.5 meters) rise and fall in the water table. It is usually assumed that at its deepest point the proposed repository would lie some 150 meters above the present water table. Small water-table excursions such as these have been recorded from many earthquakes at many wells throughout the world and would pose no threat to the isolation of radioactive waste were a repository built at Yucca Mountain. (The possibility of earthquake-induced rises in the water table and their potential effects on the proposed repository are discussed in the next section and in Chapter 2.)

Given the fact that the Little Skull Mountain earthquake appears to be the largest known earthquake to have occurred within 100 kilometers of Yucca Mountain, one may ask whether or not it constitutes a "surprise." All earthquakes, including this one, are "surprises" in the sense that scientists cannot predict with confidence the exact times and places of expected earthquakes. However, the magnitude 5.6 Little Skull Mountain earthquake was certainly no *scientific* surprise, in view of the fact that seismic monitoring shows the epicenter was located in an area where many very small earthquakes have occurred. In fact, geologic studies have long suggested that many earthquakes still larger than this most recent event have occurred in the southern Nevada region over the past few thousands of years, including some that were probably even closer to the proposed Yucca Mountain repository.

The timing of the Little Skull Mountain earthquake is of particular interest. It and several other events in California and Nevada came on the heels of the much larger (magnitude 7.4) June 28, 1992, Landers, California, earthquake, and it is difficult not to accept some sort of causal relationship. This relationship is not well understood, but our lack of understanding of the broader issue has relatively little bearing on the seismic hazard evaluation at Yucca Mountain itself. This evaluation will be based primarily on local geologic relationships that will tell us where, how often, and how big earthquakes have been during the past few tens of thousands of years at and near Yucca Mountain, whether or not they were related to larger events in the broader region.

In conclusion, the Little Skull Mountain earthquake reminded all parties involved in determining whether Yucca Mountain is a suitable location for disposing of high-level radioactive waste that southern Nevada is a region where earthquakes do occur,

3 *Units of ground motion are in g, where g is equivalent to the acceleration exerted by the earth's gravitational field at sea level (approximately 980cm/sec^2).*

and earthquake potential and its impact on waste isolation must be included in any evaluation. Based on preliminary analysis, this particular earthquake does not alter the scientific community's perception of what the seismic hazard is at Yucca Mountain. The resulting data, however, certainly could become a source of increased understanding of some details of that seismic hazard.

Other Activities

The DOE workshop on thermal loading

On August 20-21, 1992, the DOE held a workshop to review possible repository thermal-loading strategies.[4] The goal of the workshop, as redefined at the meeting, was to decide which strategies seemed most logical and defensible. The group looked at low and high thermal loadings of the waste in a repository. Several positions were presented during the workshop. It was pointed out that there are practical limits associated with the possible thermal loadings. A low loading (about 15 kW/acre) would probably create a thermal environment in which temperatures would never exceed boiling. At a "too high" loading (about 120 kW/acre), the number of drifts that can be excavated is limited. At a "high" loading (about 60 kW/acre), above-boiling conditions might persist for 1,000 to 10,000 years.

A critical issue discussed was the DOE's theoretical, untested understanding of the magnitude and consequences of repeated evaporation and condensation (i.e., reflux) of moisture in the rock adjacent to the emplaced waste, as well as its significance to the selection of a thermal-loading strategy. It was postulated that reflux of water vapor in the unsaturated rocks adjacent to the emplaced waste will occur under temperature gradients as low as a few tens of degrees. In a low thermal-loading repository, reflux could repeatedly leach the rocks and, with accompanying evaporation, could lead to steadily increasing salinity in the percolating liquid. Such an environment could be corrosive to metal canisters and thereby offer an increased risk of waste package failure and radionuclide release.

The Board believes that to better understand such complex processes, long-term underground heater experiments in unsaturated tuffs are required. These experiments should be designed to establish conditions similar to those expected for low to high thermal loadings. Key unanswered questions that need to be evaluated are (1) the potential for steam corrosion of the metal waste package at temperatures above boiling, (2) the effect of refluxed moisture on rock hydraulic conductivity, and the scale of such effects as a function of the thermal loading. Limited laboratory experiments show that refluxing of moisture causes some minerals to dissolve and others to precipitate. It seems likely that, under certain geochemical conditions, there will be precipitation of silicates, carbonates, and sulfates that will clog matrix pores and small fractures in the tuff, reducing the hydraulic conductivity in some parts of the repository block. Elsewhere, under other thermal and related geochemical conditions, reflux of moisture could dissolve minerals, raising the hydraulic conductivity. Understanding such effects is important in assessing site suitability.

The DOE is making progress in its evaluation of thermal loading, and the Board will continue to follow the DOE's activities in this important area.

The Japanese engineered barrier system program

During a week-long trip to Japan in September, Board members Langmuir, Price, and Verink and Board staff Di Bella met with experts in the Japanese nuclear waste disposal program to discuss Japanese research on the engineered barrier system.

Following a presentation by Dr. Price at the 10th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM '92) in Yokohama, the group toured the Central Research Institute of Electric Power Industry's Yokosuka Re-

4 *The strategy for emplacing waste in the repository, with the goal of causing specific effects on the repository by the heat generated by the waste. Thermal-loading is usually measured in kilowatts per acre.*

search Center's cask testing facilities. The group then met with research management personnel at the Tokyo headquarters of the Power Reactor and Nuclear Fuel Development Corporation (PNC). PNC, which is owned by the Japanese government, is the lead Japanese research organization in the area of high-level waste disposal. Finally, the group toured and held discussions at PNC's Tokai Works near Mito and PNC's Tono mine at the Chubu Works near Nagoya.

Because of the complex nature of geologic conditions in Japan, the Japanese are investigating a multibarrier concept with a massive, robust engineered barrier system. The Japanese have a vigorous program of engineered barrier and generic research in hydrology and geochemistry, yet they have not taken the first step toward repository site selection. In fact, the entity to perform site selection has not been designated, nor have criteria or regulations governing site selection or licensing been set.

British Radioactive Waste Management Advisory Committee

Representatives of the British Radioactive Waste Management Advisory Committee (RWMAC) visited the Board's Arlington, Virginia, offices at the beginning of a trip that took them to the United States and Canada to visit facilities at the WIPP; Savannah River; Idaho Falls; Yucca Mountain, Nevada; and Pinawa, Canada. Board members Verink and Brewer met with the six-member group to discuss various items of mutual interest.

The RWMAC was established in 1978 to advise the British government on the technical and environmental implications of overall policies to manage civilian radioactive waste. Members are appointed by the Secretaries of State for the Environment, Wales, and Scotland and include physical and social scientists, medical practitioners, government policy makers, members of the nuclear industry, and representatives from various national environmental groups.

Defense high-level wastes from reprocessing

Because defense high-level wastes from reprocessing will contribute only a relatively small amount of radioactivity to the proposed repository, the Board, in its earlier years, focused on spent fuel and generic disposal issues and deferred initiating consideration of defense wastes. During this reporting period, however, the Board decided the time was appropriate to begin looking at the issues related to defense waste and to consider their potential effects on the nation's radioactive waste management system. As a result, the Board scheduled several meetings during this reporting period to discuss defense waste issues.

During this reporting period, Board members and staff toured the three DOE facilities where high-level defense wastes from reprocessing are located and held meetings in nearby communities. Chapter 2 includes a detailed discussion of these meetings.

Because of the Board's activities in the area of defense high-level waste, the members initiated contact with the Defense Nuclear Facilities Safety Board (DNFSB). The DNFSB was created by Congress in 1988 (P.L. 100-456) as an independent board to review and evaluate standards and to conduct investigations and reviews related to public health and safety at DOE defense nuclear facilities.

The September meeting on volcanism

On September 14 and 15, the Board's Panel on Structural Geology & Geoengineering held a meeting in Las Vegas on volcanism. Presentations were made by the DOE and its contractors, the NRC, contractors to the state of Nevada and individual scientists from the U.S. Geological Survey and the Massachusetts Institute of Technology. The Board was briefed on recent studies in the areas of geology, geophysics, probabilistic volcanic hazard, and potential vulnerabilities of the proposed repository to volcanic intrusion. The meeting was followed by a one-day field trip to sites of ongoing investigations into volcanism around Yucca Mountain.

A discussion of the meeting and field trip and any subsequent Board recommendations will appear in an upcoming Board report.

Board meeting on source term

The Board's third meeting of the year was held in Las Vegas on October 14-15, 1992. The main subject of the meeting was the source term in performance assessments. The source term is the concentration of radionuclides leaving the engineered barrier system under various failure scenarios. The Board heard presentations on carbon-14 releases and testing of spent fuel and uranium dioxide; geochemical speciation and reactions; and dissolution testing of encapsulating glasses. Finally, there were discussions of how the source term is being developed in practice. The Board was able to review research under way at Lawrence Livermore National Laboratory, Sandia National Laboratories, Pacific Northwest Laboratory, The Electric Power Research Institute, and the Nuclear Regulatory Commission. Two consultants to the Board, Drs. Michael Apted and Nava Garisto, presented overviews on source term issues from international perspectives. Following these presentations, the Board heard a presentation on the fiscal year 1993 budget for the Yucca Mountain site characterization project.

A fuller discussion based on the presentations at the source term meeting will appear in upcoming Board reports.

Visit to Lawrence Livermore National Laboratory

On September 29, 1992, Dr. Domenico, co-chair of the Board's Panel on Hydrogeology & Geochemistry, visited scientists and engineers of the Yucca Mountain Project at the Lawrence Livermore National Laboratory (LLNL).

The majority of the discussions focused on the details of modeling liquid and gaseous flow under elevated temperatures at Yucca Mountain. For the testing of these models and for the design of engineered components of the proposed repository, LLNL will conduct heater tests on rock from Yucca Mountain. The initial tests will be done in the laboratory. By 1996, LLNL plans to have begun a series of heater tests in Yucca Mountain itself. Given the very tight schedule, the heating rates of some tests will have to be overdriven to high temperatures so that test results are available on time.

Interestingly, LLNL scientists and engineers are increasingly adopting horizontal drift emplacement of multiple use, robust containers in their conceptualization of the engineered barrier system.

Dr. Domenico again urged the DOE to assemble an outside team of scientists and engineers, highly experienced in the practice and theory of high temperature fluid and gaseous flow, to review the consequences of the thermal loadings currently under investigation. This idea was first proposed to the DOE at the Board's meeting in Denver in July 1992.[5]

Presentation to National Association of Ratepayer Utility Commissions

On July 26, 1992, Chairman John Cantlon presented a summary of the Board's recommendations concerning the DOE's program to manage civilian spent fuel and high-level radioactive waste to the National Association of Ratepayer Utility Commissions (NARUC). Many NARUC members expressed their concern that the rate of progress and the cost-effectiveness of the DOE's program could be improved. Some members also expressed the view that the defense part of the DOE has not born its proportionate share of the R&D costs of repository site characterization and design.

The effects of tectonics on the water table

Considerable scientific controversy and publicity have resulted during the past several years from the hypothesis of J.S. Szymanski that, within recent geologic time, the water table beneath Yucca Mountain has risen one or more times to the proposed repository level, and that this phenomenon might occur again in association with earthquakes during the service life of the repository (Szymanski 1989). The Szymanski hypothesis has now been thoroughly and critically reviewed by several outside reviewers, including a panel of the National Academy of

5 *Patrick A. Domenico, follow-up discussion, July 8, 1992, transcript p 387-88, meeting of the NWTRB, Denver, Colorado.*

Sciences (National Research Council 1992), the DOE review panel (Powers et al. 1991; Archambeau and Price 1991), and a senior scientist of the U.S. Geological Survey (Evernden 1992). Each of these reports, with the exception of a minority of the DOE review panel (Archambeau and Price 1991), was quite critical of the principal tenets and conclusions of the Szymanski hypothesis. Board members have visited many of Szymanski's critical field exposures and have seen versions of his report as well as the outside reviews. At this time, the Board has no reason to disagree with the unanimous opinion of the prestigious 17-person panel of the National Academy of Sciences, which was the most broadly based of the review groups and which concluded "from the geologic features observed in the field and geochemical data that there is no evidence to support the assertion [by Szymanski] that the water table has risen periodically hundreds of meters from deep within the crust." If further significant data or modifications are presented in the future, the Board will consider reviewing them at that time.

November Board meeting on the ESF

On November 4-5, 1992, the Panel on Structural Geology & Geoengineering held a workshop on the strategy for the design and construction of the exploratory studies facility in Las Vegas, Nevada. The meeting was organized around four sessions intended to bring together construction, testing, and management perspectives. In an effort to seek broad and open participation, a major portion of each session was devoted to round-table discussions.

The workshop stimulated a lively exchange among the DOE, its contractors, members of the Board and its consultants, and others outside the DOE and resulted in further insight into (1) the means of relating site-characterization needs with construction methods and schedule; (2) the goal of obtaining efficient access to the Yucca Mountain geologic block; and (3) gaining timely information on high-priority site-suitability issues. A review of the workshop will be included in an upcoming report.

Chapter 2
Panel Activities, Conclusions, and Recommendations

Transportation and Systems

During this reporting period, the Board continued to pursue with the DOE issues raised and recommendations made in the past. These include the incorporation of system safety and human factors engineering into the DOE's radioactive waste management program, the desirability of minimizing handling, and the need for top-level system studies[1] as part of a broad systems approach to the waste management program. The importance of system safety and human factors to the program was raised in the Board's first report to Congress along with the need to adopt a systems approach to the waste management program (NWTRB, March 1990). Recommendations concerning the importance of minimizing waste handling first appeared in the Board's second report (NWTRB, November 1990). The recommendation for timely, top-level system studies was made in the Board's fifth report (NWTRB, June 1992).

Introduction and Background

At a meeting with the Board's Panel on Transportation & Systems in March 1992, the DOE reiterated its top priorities as (1) having an operational monitored retrievable storage (MRS) facility by 1998; (2) submitting the license application for repository construction in 2001; and (3) beginning disposal at the repository by 2010. The 1998 target requires not only an operating MRS facility to receive the spent fuel but also an operating transportation system to deliver the fuel from the reactor sites. To ensure that a transportation capability will exist by 1998, the DOE is initiating a procurement for shipping casks based on existing technology. This procurement effort is being superimposed on the Cask System Development Program (CSDP), an on-going program that has been developing a *new* generation of casks with a much larger capacity than existing ones. This new procurement effort for existing technology casks is being referred to as "Phase I."

At the same meeting, the panel also received updates on the DOE's efforts to incorporate system safety and human factors engineering into its program and on studies on transportation-related capabilities at and near utility sites. With respect to system safety and human factors, the panel was told that

- the management and operations contractor (M&O) is developing an environmental, safety, and health plan for the DOE program;
- system safety and human factors are part of the systems engineering process; and
- human factors engineering requirements are being documented and placed in the technical baseline.

1 *System studies of the nuclear waste management system are those in which the major components are not fixed a priori.*

The presentation at the meeting portrayed only a skeleton of the DOE framework required for a system safety and human factors program, such as the inclusion of standard Department of Defense requirements; the presentation indicated the direction of future work. Subsequent follow-up conversations with the M&O indicated that along with human factors engineering requirements, system safety requirements also are being documented. The DOE will publish this documentation, essential to the establishment of both programs, in the near future.

The Board met with the DOE and its M&O contractor on July 7–8, 1992, in Denver, Colorado. On the second day, the discussions focused on the specific "system studies" that the M&O currently is performing. The Board received some indication of the DOE's views about the waste management system, how tightly or loosely the major system components should be coupled, and how much flexibility remains in the system, given the decisions that have been made and the schedule the DOE plans to adhere to. This allowed the Board to get some idea of the scope of system studies that might be carried out. Unless otherwise noted, the following discussion is based primarily on information obtained at the July Board meeting.

Discussion

According to the M&O, the DOE program is now at the "concept definition" phase. During this phase, various alternatives and options will be defined, compared, and evaluated. However, the Board pointed out that some major concepts pertaining to parts of the system appear already to have been selected and set and are, therefore, well beyond what the DOE defines to be the "concept" phase. For example, the decision on the need for the MRS facility has been made; the functions it will perform seem to be, at least tentatively, settled; the conceptual design for the MRS facility is being completed; and a "system throughput" study with an MRS facility included in the system is being conducted. As noted above, this decision and the high priority placed on the 1998 fuel acceptance date already have resulted in the initiation of procurement of existing technology transportation casks, even though the MRS facility is yet to be sited.

The Board has urged the DOE previously to broaden the scope of its system studies so that top-level trade-offs can be made. To be useful, top-level studies are best performed during the concept phase and should not be constrained by artificial and arbitrary assumptions about either the system configuration or its operation. Timely, iterative performance of these studies will allow for the proper evaluation of system configuration alternatives in time to guide acquisition of major parts of the system. The DOE's general position appears to be that the basic decision as to the overall system configuration cannot be left open pending global system studies; and that fundamental decisions about the overall waste management system must be made at some point given what is known. Once the basic decisions have been made, a hierarchy of lower level decisions, with associated milestones, remain to be made. A "roadmap" is required to define the type of studies needed to support these decisions. The M&O currently is developing a reference system description and the "roadmap" to identify the needed studies. The "roadmap" was to be made available to the Board in the early fall of 1992.

At this stage in the DOE program, then, certain "givens" already exist about the total system. The DOE's target dates of 1998 (operating MRS facility), 2001 (repository construction license application), and 2010 (repository operation) are important "givens." These dates, in turn, influence the schedules of other decisions and perhaps some of the decisions themselves as well. For example, to meet the 2001 license application target date, development of the "license application design" of the repository is scheduled to start around 1996-1997. Therefore, an important question is how far along in the design process can the DOE feasibly carry substantially different alternatives. A decision on the repository's thermal-loading strategy needs to be made somewhere during that time frame or shortly after. This creates a very tight schedule for the development of the scientific data and rationale needed to undergird such a crucial technical decision. An analogous argument can be made concerning technical decisions about the engineered barrier system and about the waste emplacement method.

Even if top-level studies are performed, there will be little flexibility in the system with this tight schedule. Insufficient time will remain to do meaningful scientific evaluation of alternative concepts that top-level studies may identify. There may not even be enough time to test the technical validity of "baseline" or "reference" concepts. The tight schedule may be one reason why the DOE believes that, to maintain flexibility, the technologies and configurations of major components of the waste management system should be loosely coupled. In this way, changes in one component will not require vast modifications in the rest of the system.

Because of the schedule and programmatic decisions that the DOE has made to comply with its priorities, the system studies presented at the July meeting were constrained in scope and are therefore not "top-level" studies, according to the Board's definition. Some of the system parameters already have been fixed to reflect key program decisions. For example, the following assumptions are included in the "throughput study" and the alternative cask and canister studies: an MRS facility is in the system; the facility is located in the East; the allocation of acceptance rights from utilities is "oldest fuel first"; and the MRS performs a "flow through / pass through" function — a marshalling yard function in which all shipments from reactor sites are funneled through the MRS facility, and small shipments, such as those by truck, are aggregated into large shipments, via dedicated trains.

These assumptions, however, may well not be consistent with the configuration the waste management system eventually assumes. For example, an MRS facility may not be successfully sited; even if there is an MRS, the capacity limit of 10,000 metric tons currently mandated by existing legislation will likely be insufficient to address *all* of the dry storage needs before repository operations begin; the MRS may not be located in the eastern United States; and the potential volunteer MRS host may insist that the facility function only as a passive warehouse and not as a funnel that channels the flow of spent fuel from all the reactor sites.

Conclusions

1. The priorities within the program and the allocation of resources appear to be derived from target dates that have been given high priority and prominence. One consequence is that resources are being expended and actions taken that are incrementally locking in the system. One example is the "Phase I" procurement of existing technology shipping casks. Use of these casks, for example, will determine many of the functional aspects of the facility's design.

The schedule is tight, not only for assessing possible improvements, but also for verifying the technical validity of reference concepts.

2. The scope of current DOE system studies is unnecessarily constrained because some of the major parts of the waste management system (e.g., the MRS facility) already are specified and locked in. Although the possibility that a MRS facility may not be successfully sited is very real, the DOE seems to be reluctant to conduct less constrained studies, even for contingency planning.

The Board believes that unconstrained, iterative top-level studies need to be pursued because they will illuminate overall problems, identify enhancements, evaluate alternatives, and provide for contingencies, thus promoting sound program planning. Furthermore, as expressed in its fifth report to Congress, results from timely, top-level, system trade-off studies can be synchronized with major decisions involving the acquisition of major systems or system parts.

3. The Board is encouraged by the efforts that the DOE and its M&O contractor are beginning to make in incorporating system safety and human factors engineering into the waste management program, including their efforts to develop the support documents necessary for implementation.

Recommendations

1. To ensure the safe performance of the waste management system, the program should not be overly motivated by the need to meet a tight schedule driven by target dates. Instead, the Board urges the DOE to ground all major technical decisions in sound scientific analysis that includes the careful evaluation of alternatives.

2. The Board continues to urge the DOE to conduct timely, iterative, top-level system studies so that the results can be used to identify enhancements, evaluate alternatives, rationalize acquisition decisions, and provide for contingencies, thus, reflecting sound program planning.

Geoengineering

Introduction

The Board's Panel on Structural Geology & Geoengineering (SG&G) continues to focus on the evolution and design of the exploratory studies facility (ESF) and on the design of the repository system as a whole. Presentations on geoengineering issues were reviewed during this reporting period as parts of full Board meetings rather than at individual panel meetings. For this reason, Board members postponed an in-depth discussion of the status of the ESF/repository system design until the SG&G Panel could schedule an important workshop on the ESF design and construction strategy.

This workshop, which was held on November 4–5, 1992, in Las Vegas, Nevada, stimulated discussion among the DOE, its contractors, the Board and its consultants, and others outside the DOE. It resulted in further insight into (1) the means of relating site-characterization needs with construction methods and schedule; (2) the goal of obtaining efficient access to the Yucca Mountain geologic block; and (3) gaining timely information on high-priority site-suitability issues. The meeting was organized around four sessions intended to bring together construction, testing, and management perspectives. In an effort to seek broad and open participation, a major portion of each session was devoted to round-table discussions. An in-depth review of the workshop will be the focus of an upcoming Board report.

The following summarizes activities undertaken and information gained by the Board during this reporting period related to geoengineering. The discussion is divided into two sections, status of the ESF and the repository conceptual design.

Background

During the past three years, Board members have closely followed the evolution of the ESF, a part of the site-characterization program now under way at Yucca Mountain, Nevada. From the beginning, the Board emphasized the importance of initiating underground excavation as soon as possible. Surface-based testing alone will not provide the critical data needed to determine site suitability. Because of delays in the program, however, the Board has made an effort to seek a clear understanding of the DOE's priorities, the costs and resulting budget allocations, and the management strategy for the ESF final design and construction. At the same time, the Board has continued to encourage further evolution and definition of the repository system.

Status of the ESF

The DOE completed its ESF alternatives study in November 1990. The study recommended: a new layout for the ESF (alternative 30 of the study), switching from shaft to ramp access, changing from drill and blast to mechanical excavation, adding larger tunnels in both the main repository level and in the Calico Hills formation below the repository level, and crossing major geologic features at both the north and south ends of the Yucca Mountain block. As a result of the recommendations, the DOE revised the ESF design. The new design called for large tunnel diameters, the use of four full-face tunnel boring machines, and extensive surface and portal facilities, all of which would require very large early expenditures for equipment and machinery and long delays before starting machine operations. As a result, the Board recommended that the program be simplified, recognizing that limited funding would not permit early tunneling operations unless a scaled-down, more efficient approach were developed.

With Congress funding the program at levels less than called for in the DOE cost and schedule baseline for fiscal year 1992, the DOE decided to delay the ESF final design and associated engineering studies. Instead, emphasis was placed on surface-based testing activities, including trenching and drilling. Deep dry-drilling in the unsaturated zones of the geologic block was started with the LM-300 drill rig, beginning hole UZ 16 in March 1992. However, slow progress in drilling with this rig and its high operating costs have required a reassessment of the scope of the dry-drilling program. Program funding for fiscal year 1993 also is less than requested. (See Chapter 1 discussion of congressional activities.)

To complete site-characterization activities and be able to apply for a repository construction license by 2001, the DOE has deferred excavation of the geologic block and planned for an accelerated schedule in later fiscal years that would require many simultaneous activities. The program now calls for tunnel boring to begin in October 1994, with access to the main test level by June 1995, and possible access to the Calico Hills unit by early 1996. This schedule, however, assumes receipt of the requested annual budgets. The Board is concerned that this deferment could possibly result in a reduction in the time available to evaluate test results and form conclusions regarding site suitability.

In meetings and discussions throughout 1992, the Board has continued to emphasize the importance of early access to the underground. The Board believes this is necessary to expose potential disqualifying conditions and to permit the timely initiation of long-term experiments. Given the current tight schedule (1998, waste receipt; 2001, license application; 2010, repository operation), if underground access is not provided as soon as possible, long-term testing in the repository horizon, such as heater tests, will not be in place soon enough to validate models essential to determine site suitability.

The Board has suggested that (1) construction of the ESF begin by early fiscal year 1994 with the operation of a single tunnel boring machine; (2) the DOE establish specific targets for exploration — early targets should address the issue of site suitability; (3) tunnel size (diameter) be no greater than functionally required for early access and exploration of the geologic block; (4) surface support facilities be greatly simplified; and (5) simple, functional portals be used in lieu of permanent structures.

The DOE's revised ESF configuration developed from the alternatives study now calls for a large increase in tunnel lengths, permitting exploration across the repository block, through most of the rock types, and across the major potential fault zones. This increased underground access should allow scientists to transfer portions of the testing planned for the surface-based, deep, dry-drilling program to the underground drifts and ramps. This was pointed out earlier by the Board during its April 7-8, 1992, meeting in Dallas, Texas.

The Board sees progress in the development of the ESF program. For example, the DOE has decided to start underground access with only one tunnel boring machine, to develop a simple, functional portal; and to use, where possible, temporary surface facilities. But the Board remains concerned about a number of issues, including the excavation of overly large diameter tunnels and the acquisition of tunnel boring machines. It is important that management and contracting procedures and incentives lead to efficient tunneling with respect to cost and schedule.

Repository conceptual design

The Board has emphasized the need to address ESF issues *within the framework of the conceptual design for the repository system*. The extent of the interrelationship between the ESF and the repository system became very clear at the Board-sponsored meeting on repository design and thermal-loading strategies that took place in October 1991. Because the thermal-loading strategy chosen for the repository will affect all components of the spent fuel and high-level waste management system — including repository costs and the need for a second repository — the DOE is now evaluating a number of strategies for their potential effects on the system. At the Board's July 1992 meeting, the DOE reviewed work it had recently undertaken to evaluate alternative thermal-loading strategies and waste emplacement concepts, including drift emplacement of large waste packages.

At a DOE-sponsored workshop in August 1992 on repository thermal-loading strategies, high and low thermal-loading concepts were defined. Both concepts have desirable features and the associated technical uncertainties. (See Chapter 1 discussion of the thermal-loading workshop.) The high thermal-loading strategy offers very large cost efficiencies, requires a smaller area of the geologic block to emplace the high-level waste, and possibly would be less complex to understand and predict with confidence. The low thermal-loading strategy could draw on the data and experience of other countries where that strategy is the baseline. However, this strategy requires long-term ageing of the spent fuel and the need for a much larger area in the geologic block for waste emplacement, or for a second repository.

Before the DOE can reliably predict the evaporation-condensation-convection processes postulated for either of the thermal strategies, however, more data are needed. Data needed to characterize the site for either thermal-loading strategy can be obtained only by conducting high temperature testing in welded tuff of the proposed repository geologic formation. The DOE's estimate of the duration of testing required to obtain definitive data is four to six years. This is one reason why beginning excavation as soon as possible is crucial if such testing is to be carried out in the ESF.

The DOE also has begun to consider alternative waste package emplacement concepts for the proposed repository, including drift emplacement of large waste packages. At the August 1992 DOE workshop, Board members reviewed early results of analyses that indicate that drift emplacement of large waste packages offers the advantage of reduced near-field rock temperatures when compared to the borehole emplacement concept. The possibility of drift emplacement of large waste packages in a proposed repository may require changes in the ESF testing program.

Conclusions

Exploratory studies facility development

1. The DOE has reoriented the site-characterization program for fiscal year 1993 to place major emphasis on access to the underground.

2. The Board supports recent DOE efforts to re-evaluate testing priorities, to scale down the dry-drilling program, and to transfer appropriate testing to the underground drifts of the ESF, which has been expanded from the very limited ESF proposed in the *Site Characterization Plan*.

3. The Board welcomes several recent program decisions by the DOE. The Board remains concerned about the large tunnel size planned for the exploratory studies facility, the acquisition of tunnel boring machines, and the DOE's allocation of its reduced funding. However, these issues were discussed at the Board's November 4–5, 1992, meeting and may be included in discussions in an upcoming report on this meeting.

Repository Conceptual Design

1. The DOE's decision on a thermal-loading strategy could have a significant impact on repository costs, the determination of site suitability, and on the need for a second repository. The DOE is therefore examining alternative thermal-loading strategies and design concepts for the proposed repository, including alternative waste package emplacement concepts.

2. The key data needed to reliably predict the evaporation-condensation-convection processes that are part of the various thermal-loading strategies can be obtained by conducting long-term heater tests in the repository geologic block. The DOE suggests this testing will take four to six years. A study plan is needed describing these tests, the anticipated results, and the time required to achieve those results.

3. It must be pointed out that testing in similar rock to get a better understanding of thermal-loading phenomena will not alleviate the need to test in the repository geologic block as part of site characterization.

The Engineered Barrier System

Introduction and Background

As the result of a decision made by President Ronald Reagan in 1985, high-level reprocessing wastes from defense-related activities also will be disposed of in the repository that is planned for commercial spent nuclear fuel.

The total radioactivity of the nation's defense high-level wastes from reprocessing is much smaller than the total radioactivity of the nation's commercial spent nuclear fuel. The Board therefore considered it appropriate to focus its attention in its early years on overall site characterization, transportation, and packaging issues. However, although a potentially small contributor to the mined geologic repository program, defense high-level wastes have their own set of repository-related issues and should not be considered a negligible contributor. Thus, the Board decided the time was appropriate to look into the issues related to defense high-level wastes and to consider their potential effects on the nation's system for managing the disposal of spent fuel and high-level waste.

Defense high-level wastes are located at three DOE facilities: Savannah River near Augusta, Georgia; the Hanford Site near Richland, Washington, and the Idaho National Engineering Laboratory (INEL) near Idaho Falls, Idaho. The Board's Panel on the Engineered Barrier System held public meetings in Augusta on February 10, 1992; in Richland on May 11, 1992; and in Idaho Falls on May 13, 1992. Board members and staff toured the respective nearby DOE facility on the day following each public meeting.

The following discussion reflects the Board's first look at the issues related to the disposal of defense high-level waste from reprocessing (referred to simply as defense high-level waste or high-level waste for the balance of this section). Also discussed below are the DOE's current efforts in conceptual waste package design and its lack of research efforts to obtain data on the long-term performance of waste package materials.

Defense High-Level Wastes

Defense high-level wastes are mostly in liquid form, stored in large underground tanks. Although it may appear useful to discuss high-level liquid waste in terms of gallons, it is more convenient to discuss it in terms of its radioactivity level, which is measured in curies (Ci).[2] This allows a meaningful comparison with the spent fuel that will be going into a repository.

At the end of 1990, the combined inventory of defense high-level waste at the Savannah River and Hanford sites and at INEL was approximately one billion Ci. This figure is projected to fall gradually since the rate of radioactive decay of existing waste will be greater than the rate of radioactivity added due to new waste. In contrast, the nation's inventory of civilian reactor spent fuel was approximately 23 billion Ci at the end of 1990. Even assuming no future orders of new nuclear power plants, the inventory of civilian reactor spent fuel is projected to grow to a peak of approximately 41 billion Ci by the end of 2014, and then gradually decline.

Comparison of defense high-level waste and spent fuel on a radioactivity basis, although convenient, is misleading. This is because the radionuclide compositions of the high-level waste and spent fuel are significantly different. Unlike spent fuel, high-level waste has had most of its uranium and plutonium removed during the defense reprocessing step, leaving radionuclides with shorter half-lives.[3] As a result, defense high-level waste loses its radioactivity more quickly in its early years than does spent nuclear fuel.[4]

The responsibility for defense high-level waste is divided between two organizational components of the DOE. The DOE Office of Environmental Restoration and Waste Management is responsible for

2 *Radioactivity is the spontaneous emission of radiation from the nucleus of an atom. Radioisotopes of elements lose particles and energy through this process of radioactive decay. The activity of a radioactive material is expressed in terms of the number of nuclear disintegrations occurring in a unit of time. A common unit of activity is the curie (Ci). One curie equals 3.7×10^{10} disintegrations per second. In common usage, a curie is the quantity of radioactive material that has the activity of one curie.*

3 *The time required for a radioactive substance to lose 50 percent of its activity by decay.*

4 *For example, the activity of 1,000 Ci of five-year-old Savannah River reprocessing waste will decay to only 0.02 Ci after 995 years, whereas the activity of 1,000 Ci of five-year-old PWR spent fuel will decay to 3 Ci after 995 years (DOE 1987a).*

preparing the waste for disposal and storing the prepared waste on site until repositories are ready to accept it. The DOE Office of Civilian Radioactive Waste Management (OCRWM) is responsible for transporting the canisters of prepared waste off site, giving it final preparation for transportation and disposal (e.g., overpacking if necessary), and undertaking its ultimate disposal in a geologic repository.

The Savannah River Site

By the end of 1990, more than 560 million Ci (approximately 34 million gallons) of high-level wastes had accumulated at the Savannah River Site as a result of the previous 35-plus years of defense reprocessing operations there. When created, the wastes were principally aqueous and acidic and contained dissolved solids. Subsequent neutralization and evaporation have resulted in precipitated solids and a concentrated liquid containing dissolved solids. The wastes are stored in 51 large tanks.

The DOE has nearly completed construction of the facilities at Savannah River necessary to process the high-level wastes stored there. These facilities will process the wastes stored in the 51 tanks to produce two solid "products": a low-level "saltstone" waste that will be permanently disposed of on site in above-ground concrete vaults, and canisters of vitrified high-level wastes that will be disposed of in a mined geologic repository. Omitting some of the front-end feed preparation steps, the vitrification process consists of mixing a glass frit with a water slurry of high-level waste, feeding the mixture at approximately one gallon per minute into an electrically heated glass melter that operates at approximately 1,150°C, pouring enough molten glass into each canister to occupy approximately 90 percent of the canister's volume, cleaning the canister's exterior, and sealing the canister (by resistance welding a plug).

The vitrification facility is scheduled to begin production runs making vitrified high-level waste in 1994, and it is projected that more than 7,000 canisters of vitrified waste will be produced during the subsequent 30 years. Sealed canisters will be stored on site until a repository is ready to take them. Each canister will contain approximately 1,700 kilograms of vitrified waste, which will have a maximum radioactivity of 230,000 Ci and a maximum decay heat rate of 730 watts. The 304L stainless steel canisters are 61 centimeters (two ft) in outside diameter and 300 centimeters (almost ten ft) in length. They have a wall thickness of one centimeter (about ⅜ in). The empty weight of a canister is 450 kilograms. Because the one-centimeter walls do not provide adequate shielding, radiation-protection shielding (e.g., casks or overpacks) will be required for shipping, handling, storage, and probably disposal.

Based on information obtained at the public meeting in Augusta and the subsequent tour of the Savannah River waste vitrification facility, Board members have four concerns as discussed below.

1. From a regulatory compliance standpoint, is the methodology the DOE plans to use to determine the radionuclide composition of the vitrified waste in each canister sufficiently accurate?

To comply with present repository regulations,[5] it is necessary to have an accurate estimate of the types and amounts of radionuclides in each canister. The DOE plans to sample the molten glass stream pouring into the canister at a frequency of only one sample per approximately 120 canisters. Even at the maximum planned production rate, this is a sampling frequency of no more than once every three-and-a-half months. No other samples downstream of

5 *Particularly NRC regulation 10 CFR 60. Paragraph 113(a)(1)(ii)(B) of this regulation provides, "The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction as may be approved or specified by the [Nuclear Regulatory] Commission; provided that this requirement does not apply to any radionuclide which is released at a rate less than 0.1 percent of the calculated total release limit." To determine the radionuclide inventory at 1,000 years after permanent closure, it is necessary to know the radionuclide composition of the waste form in each canister at some point in time (e.g., at the time the canister is filled). This, together with already known nuclear decay processes and rates, is used to calculate the radionuclide inventory at any future time.*

the glass melter are planned, and no regular samples of the molten glass within the melter are planned.

Even with the planned extensive upstream feed blending to achieve a measure of uniformity of the feed, estimates of waste compositions based only on a single sample per 120 canisters would be inadequate. However, there is a 5,000-gallon melter feed tank, which is an agitated tank immediately upstream of the melter and which contains enough waste-frit-water slurry to make a four-canister batch of vitrified waste. The planned DOE methodology is to sample each batch of slurry in the melter feed tank, measure the sample's chemical and radionuclide composition, and use the resultant data to estimate the glass and radionuclide composition of the four canisters of vitrified waste produced from that batch of slurry.

Even assuming perfect melter feed tank sampling and laboratory analysis, the Board is concerned that this methodology may not be accurate enough for compliance purposes for reasons such as the following. (1) Larger, denser particles and agglomerates will settle out preferentially if the agitation of the melter feed tank is temporarily lost. When agitation is resumed, total resuspension of settled materials can not be guaranteed. At a minimum, resampling of the melter feed tank contents would be required. (2) Accumulation of sediments in the melter feed tank and in lines leading to the glass melter is probably inevitable. One would expect the effect of the accumulation on radionuclide composition to be insignificant, unless and until the accumulation becomes sufficiently large that portions begin to slough off, possibly contaminating the current melter contents with material of an earlier, different composition. (3) The radionuclide inventory may be different at times in the melter and the melter feed tank. For example, the inventory of semivolatile radionuclides may be low early in the life of a melter due to partial volatilization. (4) The melter contents are unlikely to be completely homogeneous; it is known, for example, that noble metals tend to move toward the bottom of the molten glass pool and that a crust tends to form at the top of the pool.

The Board recommends that the DOE perform a study to estimate the differences between vitrified waste radionuclide compositions predicted on the basis of melter feed tank sampling and actual vitrified waste radionuclide compositions. The study should examine all factors that could lead to differences in the radionuclide compositions of the melter feed tank contents and of the vitrified waste. The DOE should ensure that one of the side results of the study is the degree of accuracy in radionuclide composition necessary to show that regulatory requirements (e.g., 10 CFR 60.113) will be met.

2. There appear to be no plans for direct measurements (other than visual inspection) of the integrity of canister closures (welds).

After cooling, filled canisters will be closed by welding a plug into the top of the canister using upset resistance welding. During this process, a plug is mechanically forced into the canister while electricity provides the heat for welding. During the visit to Savannah River, the Board was informed that the DOE plans to carry out only a simple remote visual inspection of each completed weld. A simple visual inspection alone is insufficient, in the Board's opinion, for high confidence in the short- and long-term performance of the canister closure. Without such high confidence, the utility of the canister as a barrier in the repository's multibarrier system is questionable.

Overpacking, that is, inserting the canister in a larger container, closing the larger container with a suitable method such as welding, then examining the outer container's closure with inspection methods that merit high confidence, is a way of bypassing the issue of confidence in the inner canister's closure. The DOE apparently decided long ago to overpack defense high-level waste canisters prior to their transportation and disposal. The Board believes this decision was based principally on uncertainties about the long-term mechanical performance of canisters due to thermally induced stresses associated with glass-pouring operations.

The fact that the canisters will be overpacked should not be used as an excuse to abandon the canisters as one of the barriers in a multibarrier system. The DOE should develop and implement suitable nondestructive inspection methods to confirm canister closure integrity, so that the canisters may receive full consideration as one of several barriers.

3. There appear to be no provisions for reworking filled canisters that fail to meet specifications.

As far as the Board has been able to ascertain, the facilities at Savannah River do not include the capability to rework canisters of vitrified waste that do not meet specifications. The Board is concerned that, as a result, there will be irresistible pressure to declare marginal canisters passable. The DOE must develop and implement a plan for reworking filled canisters that fail specifications. There is no technical requirement that facilities for reworking failed canisters be located at the Savannah River Site. If they are located elsewhere, however, the DOE must provide the capability for their safe packaging and movement to the rework locations.

Glass melters have limited lifetimes — two to three years or less. Portions of the spent melters (e.g., the refractory lining) will probably be so contaminated with high-level waste that, even after cleaning, they will require repository disposal. Although space to store spent melters is provided at the vitrification facility, the Board knows of no plans to address the ultimate disposition of the spent melters.

4. There appears to be no defined link between OCRWM's specifications for the canisters of vitrified waste and the current regulations that apply to repository disposal (i.e., 10 CFR 60). Also, the specifications lack flexibility.

Specifications that the vitrified defense high-level waste produced at Savannah River must meet to be "accepted" by OCRWM for transportation to a repository and disposal therein are contained in a document aptly titled *Waste Acceptance Preliminary Specifications...* (WAPS) (DOE 1989). This document was developed by OCRWM and, after consideration of comments by the DOE Office of Environmental Restoration and Waste Management, approved by senior executives from both offices. The document currently is undergoing revisions. The following comments are based on the latest (DOE 1991) draft of the revision made available to the Board.

a. The Board believes it commendable that the revised draft document no longer applies to just Savannah River, but to any location that may produce vitrified high-level waste for repository disposal (e.g., Hanford and West Valley, as well as Savannah River).

b. The draft revised document is limited to borosilicate glass. Any other type of solidified high-level waste to be disposed of in a repository, such as glass-ceramic, glasses other than borosilicate glass, calcines, crystalline forms, etc., will apparently require additional WAPS-like documents.

c. The revised draft document requires that the amounts of each radionuclide present be reported only on a "waste type" basis, where a "waste type" consists of that set of canisters of vitrified waste produced from vitrification facility waste feed that remains "relatively constant in composition and properties for an extended period of time." (Items in quotes are from the April 1991 draft.) By itself, this requirement is insufficient because:

- Even if the waste feed remains "relatively constant...," one or more canisters of vitrified waste of each "waste type" could contain significantly different amounts of radionuclides than other canisters of the same "waste type" due to such things as changes in frit-to-waste ratios and differences in composition of the feed to the melter and of the melter inventory. Furthermore, the terms "relatively constant" and "extended period" are undefined.

- For actual emplacement of the vitrified waste, it will be necessary to know the thermal output of *each* canister with reasonable accuracy to implement whatever repository thermal-loading strategy is ultimately chosen. The thermal output of a canister of vitrified waste may be calculated easily if the amount of each radionuclide in the canister's waste is known. But the requirement given above does not provide this information, since it is on a "waste type" basis rather than an individual canister basis.

- This requirement takes away the flexibility of splitting "waste types" among repositories. This is a significant shortcoming only if a "waste type" could consist of many hundreds of canisters or more. (More than one repository will be required because the NWPA effectively restricts the first repository to a maximum of 70,000 metric tons of heavy metal, which is less than the amount of heavy metal contained in the spent fuel that will be generated, even if no additional reactors are built.)

d. The draft revised document specifies that the leach rates of lithium, sodium, and boron from vitrified waste be less than the leach rates of lithium, sodium, and boron from a standard borosilicate glass called "EA glass." The leach rates are determined by a recently developed product consistency test (PCT), which is essentially a one-week leach of crushed glass by pure water at 90°C. Although it is possible that the leach rate specification in the draft revised document is equivalent to (or better than) the NRC's requirement [10 CFR 60.113(a)(1)(ii)(B)], this is neither established nor referred to in the draft revised document. The DOE needs to determine and report the relationship between the specifications in the draft revised document and the NRC requirements.

For the purposes of meeting the release-rate limit of 10 CFR 60.113 (one part in 100,000 per year), it seems that the DOE has assigned a role only to the vitrified waste form. Other engineered barrier system elements (e.g., filler, canister, overpack, backfill, etc.) do not seem to have been assigned a role in meeting the limit. This could result in overly stringent glass specifications. It also could preclude the selection of waste forms other than glass that — alone or in combination with other engineered barrier system elements — could meet or even exceed the regulatory requirements.

The Hanford Site

Hanford's inventory of high-level waste consists of approximately 220 million Ci in tanks and 170 million Ci of cesium and strontium radioisotopes in capsules. The tank wastes are contained in single- and double-shell tanks. There are approximately 40 million gallons of high-level waste in 149 single-shell tanks that range from 55,000 to one million gallons in capacity. The single-shell tanks were built between 1943 and 1964. There are approximately 20 million gallons of high-level waste in 28 double-shell tanks that range from 1 to 1.1 million gallons in capacity. The double-shell tanks were built between 1968 and 1986 and are made of carbon steel. To minimize corrosion, the tank contents are alkaline. Essentially no new waste has been added to the single-shell tanks since 1980.

Much of the free water in the single-shell tanks has evaporated, resulting in "saltcake" (a hard, crystalline material that is difficult to penetrate and mobilize) and sludge. These nonhomogeneous semi-solid/solid materials are difficult to sample and may well be difficult to retrieve. DOE personnel are concerned about their ability to retrieve material safely from the single-shell tanks, and "in-place" disposal of the single-shell tanks and their contents is being seriously considered.

Over 99 percent of the single-shell tank waste consists of nonradioactive components, chiefly sodium nitrate (approximately 60%) and water (approximately 20%); the remaining approximately 20 percent consists mostly of other simple inorganic sodium salts. A major program is under way to obtain samples to characterize each tank's contents.

In contrast to the single-shell tanks, the contents of the double-shell tanks are almost totally liquid with small amounts of suspended solids, sludges, and crusts. There is a greater variation of gross chemical composition among the double-shell tank wastes, however, because they originate from different parts of the various reprocessing stages.

Hanford's disposal plans for its inventory of high-level reprocessing wastes are as follows.

- Double-shell tank waste: Pretreat (by processes to be developed) into two streams: (1) a low-radioactivity stream to be disposed of on site by mixing with cement, flyash, etc., to form a "grout" and (2) a high-radioactivity stream to be vitrified for disposal in a repository.

- Single-shell tank waste: Same as double-shell tank waste or dispose of on site.

- Cesium/strontium capsules: Overpack and send to repository. (But if this is not satisfactory, blend with the double-shell tank waste high-radioactivity stream and vitrify. The criteria for determining whether overpacking is satisfactory are unknown.)

The vitrified waste canisters to be used at Hanford would be of the same dimensions and materials as those to be used at Savannah River.

Hanford personnel have not decided on the degree of pretreatment of the tank wastes. If *no* pretreatment is done, *more than 200,000* canisters of vitrified waste will result. (This is a much higher figure than the Board has seen or heard in the past. For example, the DOE *Draft Mission Plan Amendment* estimates that a total of about 17,750 canisters of defense high-level waste *from all locations* will require repository disposal.) Pretreatment to remove nonradioactive, water-soluble salts (e.g., sodium nitrate) would still result in more than 40,000 canisters of glass. And if pretreatment were to consist of removal of both nonradioactive, water-soluble salts and selected radionuclides (presumably short half-life radionuclides that would be mixed in with the grout for on-site disposal), only 10,000-15,000 canisters of glass would result.

Although the estimate of canister numbers does not have to be precise, it should be reasonably close to permit adequate planning for repository space and design. The DOE should immediately initiate a brief systems study to ascertain the potential impact of the number of canisters (given the fixed total amount of radioactivity to be disposed of) on repository design and costs, as well as total waste management system costs. The Secretary of Energy must take particular care to ensure that the study is a true systems study not burdened with artificial DOE organizational constraints.

Hanford has a major, long-term (and expensive) program under way to develop pretreatment technologies for reducing the number of canisters that would go into a repository. Hanford personnel justify their pretreatment technologies development program by their *assumption* that the cost of disposing of their high-level waste in a repository is approximately proportional to the number of canisters of Hanford waste needing disposal. Although there are some published studies about the allocation of repository costs between civilian and defense waste, we are unaware of studies supporting this assumption over the wide range of canister numbers communicated to the Board. The results of the aforementioned systems study should also be very helpful to Hanford personnel in determining DOE costs of various pretreatment levels.

In contrast to Savannah River's vitrification plant, which is virtually constructed, ground has just been broken at Hanford for the vitrification facility, and a target date of 1999 has been established for the start of hot operations. Essentially, the glass-making part of the Hanford vitrification plant will be the same as the Savannah River plant's, thus allowing Hanford to benefit from experience gained at Savannah River, if Savannah River maintains its current schedule.

Unlike Savannah River, there is no "official" WAPS document for Hanford providing the specifications that the glass and containers must meet for acceptance by a repository. Hanford personnel used the 1989 WAPS document for guidance until its draft replacement became available in 1991. And, as already mentioned, this replacement document will apply to both Hanford and Savannah River once it has been approved.

Finally, for comparison with spent fuel, the DOE uses the equivalency of one-half ton of heavy metal for each canister of vitrified defense high-level waste in many, if not all, of its current planning documents. This equivalency is highly questionable because of the considerably different radionuclide compositions of high-level waste and spent fuel. In any case, the equivalency depends on unstated (and possibly no longer valid) assumptions regarding factors that include waste loading, waste radioactivity, and waste age. Use of the equivalency should be avoided, unless absolutely necessary, and the equivalency should be more precisely determined and published for each defense site's wastes, with a careful and complete statement of the assumptions underlying the calculations.

Idaho National Engineering Laboratory

A principal mission of INEL has been to reprocess spent nuclear fuel from naval reactors. On April 29, 1992, the Secretary of Energy announced that reprocessing at INEL would be phased out. According to INEL personnel, spent naval fuel will continue to be sent to INEL for storage, but eventually will go to a repository. Naval fuel comes in a metallic, very highly enriched form, in contrast to commercial light-water reactor fuel, which comes in an oxide, low-enriched form. Unlike Hanford reprocessing waste, which is neutralized and stored for long periods in carbon steel tanks, INEL reprocessing waste is first stored temporarily in eleven 300,000-gallon stainless steel tanks in its original acidic form, then converted to a solid waste by fluidized bed calcining. The INEL tanks are contained in individual, underground concrete vaults. The solid waste (calcine) is stored on site in vertical, cylindrical stainless steel bins. The bins are contained in concrete "bin sets" (silos). There are seven bin sets, and a bin set may contain up to seven bins. The bins are air-cooled and are designed so that the heat generated by radioactive decay of the calcine will result in a maximum temperature at the centerline of the calcine in the bin of no greater than 500°C. The DOE projects a bin life of up to 500 years.

Approximately 7,500 cubic meters (approximately two million gallons) of reprocessing wastes still remain in the stainless steel tanks. INEL intends to calcine it all. INEL believes that when allowances for downtime for maintenance and other purposes are taken into account, this will require about five years. The calciner was built in 1982 to replace an earlier one. The current calciner is kerosene-fueled, five-ft diameter, and operates at approximately 500°C. The calciner's nominal capacity is 3,000 gallons per day of liquid reprocessing waste.

Like Hanford, INEL has an aggressive technology development program to get its high-level waste (calcine) into a form suitable for repository disposal. Vitrification of a water slurry of the calcine — essentially the route being followed by Savannah River and Hanford — is being examined but is not the route currently preferred by INEL. The currently preferred route is INEL's glass-ceramic process, in which the major steps are (1) retrieving the aged calcine from the bins and heating it to nominally 600°C to drive off residual gases and (2) hot pressing a mixture of degassed calcine and additives at about 1,000°C to produce glass-ceramic logs of a size appropriate for loading into canisters somewhat larger (with diameters of 15 ft x 26 in) than the nominal size proposed for use by Hanford and Savannah River.

A portion of the INEL development program is aimed at finding the optimum amount and composition of additives to achieve high waste loading and low leachability. Currently, INEL personnel are working in the range of 25–30 percent (total mixture dry basis) of additives such as silica-aluminosilicates, apatite-aluminosilicates, etc. They see the potential for waste loadings more than twice that achievable by vitrification, and leach rates lower than the glass waste form.

In addition, like Hanford, INEL is examining pretreatment concepts that would result in splitting the high-level calcine waste into two streams: waste with a higher radioactivity level that would go to the repository, and waste with a lower radioactivity level that would be disposed of on site.

There are other high-level wastes at INEL that probably will end up in a repository. Examples include the Three Mile Island-2 core, spent naval reactor fuel, and Ft. St. Vrain (a gas-cooled reactor) spent fuel. No information about any planning or technology development activities for transforming/packing these other wastes into items that would be acceptable for repository disposal was obtained during the Board's visit to INEL.

Also, the Board has been informed that Hanford and INEL reprocessing wastes fall under the Resource Conservation and Recovery Act (RCRA). This means they are considered a mixed waste, with both chemical and radioactive hazards. The DOE should determine as soon as possible whether disposal of Hanford and INEL wastes at repositories will mean that the repositories would have to meet RCRA requirements, and, if so, what the significance of this is. The Board is aware of the WIPP experience with mixed waste.

Waste Package Design

Waste package plan

The DOE is designing and developing waste packages for spent fuel and high-level waste according to the *Yucca Mountain Project Waste Package Plan* (DOE 1990). The Board understands that the current *Waste Package Plan* document is being revised and thinks the following comments should be considered during the revision process.

1. The current *Waste Package Plan* can be (and has been) interpreted so that the waste package need only meet minimal regulatory requirements. The Board believes that public confidence considerations require that the waste package design should substantially exceed minimal requirements.

2. The current *Waste Package Plan* places too much emphasis on the waste package design and emplacement mode contained in the *Site Characterization Plan (SCP)* (DOE 1988), giving the impression that this is the preferred waste package design.

3. The current *Waste Package Plan* implies that prediction of behaviors of materials beyond 50–100 years is outside the current state of the art. Although this may hold for many newer, high-alloy materials, it is not accurate with regard to many common iron- or copper-based materials, for which potentially useful data exist — from both natural analogues and archaeological sources.

Waste package conceptual designs (spent fuel)

In accordance with the *Waste Package Plan*, the DOE has been generating conceptual waste package designs for spent fuel since the fall of 1991. The DOE was scheduled to begin conducting detailed engineering evaluations of the conceptual designs in the fall of 1992, with the goal of narrowing the designs to two candidate designs by mid-1996. According to the DOE's schedule, this would be reduced to a single design by the time of application for a license in 2001.

A variety of conceptual designs are being considered, including borehole and in-drift emplacement, thin-walled and thick-walled, self-shielded and non-self-shielded, corrosion-resistant and corrosion-allowance materials, and small and large packages. Examples of the conceptual designs that the DOE is considering are shown in Table 2.1. Except for the SCP waste package design, all of the designs in Table 2.1 are robust, long-lived designs that are amenable to drift as well as borehole emplacement.

As evidenced by its past recommendations, the Board is very concerned that full consideration be given to robust, long-lived waste package concepts. Thus, the Board is encouraged to see that such concepts are being included. However, it is very important at this early, prescreening stage that no concepts be omitted — for the simple reason that it will be difficult to consider concepts later that are not considered now. One family of the concepts that appears in danger of being omitted consists of waste

Table 2.1 – Examples of Conceptual Waste Package Designs Under Consideration

Name	Capacity (MTIHM)[1]	Diameter (feet)	Gross Weight (tons)	Outer Wall Material	Outer Wall Thickness (inches)	Self-Shielded
SCP	~ 3	2.3	~ 8	304L SS[2]	0.375	No
SCP with Overpack	~ 3	3	~ 18	Steel	3	No
Moderate-Capacity	~ 15	5.5	~ 45	Steel	3	No
Self-Shielded	~ 5	5.25	~ 80	Steel	12	Yes

[1] Metric tons of initial heavy metal

[2] Stainless Steel

Sources: Presentations to the Board by D. Stahl and H. A. Benton on May 11, 1992, and July 7, 1992, respectively.

packages that are both high-capacity and self-shielded. Such waste packages could have diameters greater than seven feet and gross weights greater than 120 tons. Most important, this family of waste packages is the only one that realistically offers the potential use of multipurpose casks[6] — that is, casks that could be filled, permanently closed, and stored at the reactor, and then shipped directly to the repository or some intermediate location. If the DOE were to omit high-capacity, self-shielded waste packages now, the option of a true multipurpose cask would effectively be foreclosed.

Thus, the Board strongly recommends that high-capacity, self-shielded waste package designs — including designs compatible with multipurpose cask concepts — be included in the set of waste package conceptual designs now being developed.

Waste Package Research

The Board remains concerned about the small amount of waste package research that was carried out in fiscal 1992. Only a very small amount of laboratory work on gathering data on oxidation (in air) of spent fuel and dissolution (leaching) of spent fuel was carried out. Very limited laboratory efforts on waste package materials were undertaken in fiscal year 1992. This is particularly critical if modern metals or alloys (such as titanium, Alloy 825, or even stainless steel) are to be used as the primary parts of waste packages. Long-term experimental data are needed to predict the behavior of such materials with reasonable confidence. (As of this writing, the Board has been informed that planning is underway for the initiations of two new, small research projects on waste package materials at Lawrence Livermore National Laboratory during fiscal year 1993. The Board hopes that these projects represent the beginning of a program to obtain long-term experimental data on candidate waste package materials.)

Conclusions

1. The relationship between the leach rate specification in the April 1991 draft revised WAPS document for vitrified wastes and the current regulatory requirements that the repository must meet (particularly the one-part-in-100,000-per-year release-rate limit of 10 CFR 60.113) does not appear to have been established and documented for wastes that will be governed by the document.

2. The numbers of Hanford canisters OCRWM is using for repository planning purposes are *vastly smaller* than the potential number of canisters that Hanford staff have indicated to the Board they may actually produce.

3. The methodology planned for use at Savannah River to estimate the radionuclide composition of filled canisters may not be adequate to demonstrate compliance under current standards.

4. The Board believes that waste package designs should not only meet regulatory requirements, but that public confidence considerations require that the design exceed them.

5. The current *Waste Package Plan* places too much emphasis on the waste package design contained in the *Site Characterization Plan*.

6. Long-term experimental data obtained for repository relevant conditions are needed to predict with reasonable confidence the behavior of modern metals and alloys that could be used in the repository.

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6 *Numerous multipurpose concepts under numerous labels are being examined by various parties. The labels include "multipurpose cask," "multipurpose container," "multi-element sealed canister," "universal cask," and "universal container," among others. The Board is using the label "multipurpose cask" as a generic one to embrace all similar concepts regardless of label. The use of the label "multipurpose cask" by the Board should not be construed as an endorsement or lack thereof of any specific concept. The Board is very interested in the overall multipurpose cask idea and has that idea high on its agenda for future examination.*

Recommendations

The Board makes the following recommendations.

1. The DOE should establish and document for defense wastes the relationship between the requirements of the draft Waste Acceptance Preliminary Specifications document and the regulatory requirements of 10 CFR 60.

2. A study should be initiated to assess the impact of the projected number of canisters of defense waste — projections range from 15,000 to 200,000 — on repository design and cost, as well as on total waste management system costs.

3. The DOE should perform a study to determine if the planned methodology for estimating the radionuclide composition of filled defense waste canisters is adequate for compliance purposes.

4. The Board strongly recommends that high-capacity, self-shielded waste package designs — including designs compatible with multipurpose cask concepts — be included in the set of waste package conceptual designs now being developed.

Risk and Performance Analysis

Introduction

Early determination of whether the Yucca Mountain site is a suitable location for a permanent repository of the nation's high-level radioactive waste has been a recurrent theme in the Board's reports. In 1991, the Board was informed that the DOE had initiated a formal evaluation of suitability of the Yucca Mountain site. The DOE also informed us that it was completing a total systems performance assessment of the proposed repository. Although these are separate efforts, site-suitability evaluation and performance assessment both serve as the primary tools by which the results of ongoing investigations at Yucca Mountain can be used to determine priorities in, and progress toward, assessing its suitability and eventual licensability.

On April 7-8, 1992, the Nuclear Waste Technical Review Board held a meeting in Dallas, Texas, primarily devoted to the recently completed, DOE-supported, Early Site Suitability Evaluation (ESSE) and the Total System Performance Assessment (TSPA) studies. Presentations were made by the DOE and its contractors, the state of Nevada, and members of the ESSE External Peer Review Panel. What follows is a discussion of these studies, including background on early site suitability evaluation and performance assessment, and a description of the critical technical issues, assumptions, and conclusions. Comments also are provided on how the studies can be used, and future efforts improved.

Early Site Suitability Evaluation — Background and Process

The purpose of early site-suitability evaluation during site characterization is to provide the DOE with an early technical assessment of the suitability or unsuitability of Yucca Mountain to serve as the location of a high-level radioactive waste repository. The framework for this technical assessment is 10 CFR 960, General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories.

The first effort at site-suitability evaluation was undertaken and then published in 1986 as part of the Environmental Assessment (EA), when several sites, including Yucca Mountain, were examined. In the beginning of 1991, the Office of Civilian Radioactive Waste Management decided on a general approach to site-suitability evaluation, including the determination that 10 CFR 960, primarily proposed as a means of discriminating among several candidate sites, would be applicable for use when only one site was being considered. The actual technical evaluation for the ESSE was carried out by a DOE contractor in the spring and summer of 1991. In the fall, the draft ESSE was subjected to an external peer review and subsequently modified. The evaluation report (SAIC 1992a) accompanied by the external peer review (SAIC 1992b) was issued for public comment and review on February 21, 1992. The DOE indicated that at the end of the comment period (June 15, 1992), it would consider and respond to all public comments and then "determine appropriate actions with respect to future plans for evaluating the Yucca

Mountain site.”[7] • The DOE states that currently the ESSE is only a contractor’s report and does not represent any official position.

The ESSE makes use of the set of 10 CFR 960 pre- and postclosure, qualifying and disqualifying conditions (guidelines) to assess site suitability or unsuitability. The evaluation is presented as a finding of “unsuitability,” “lower level (certainty of) suitability,” or “higher level (certainty of) suitability” for each condition.

Disqualifying conditions tend to be more specific and are meant to be more easily assessed, so that any obvious unsuitability can be detected early. The qualifying conditions are usually more general in character and require more information. The presence of any single disqualifying condition or the absence of any single qualifying condition results in the site being found unsuitable. An ultimate finding of suitability for the site, however, requires not only that *none* of the disqualifying conditions be present, but also that a higher level suitability finding be made on the presence of *each* of the qualifying condition.

The core team that evaluated the ESSE consisted of 16 scientists and engineers from the national laboratories, the U.S. Geological Survey (USGS), and other DOE contractors. Although there was some overlap, each member had lead responsibility for a specific technical area. The core team was directed to consider all available site data and information. After this information was reviewed and discussed, the entire core team voted on each qualifying or disqualifying condition. Core team members had the option of abstaining if they felt they lacked sufficient knowledge in a particular area. The core team conclusion with respect to a particular condition was controlled by the lowest level indicated by any single member for that condition. Thus, if 15 members thought that the preclosure tectonics disqualifying condition was absent at a higher level of certainty and one member held that its absence could only be described at a lower level of certainty, the core team and ESSE conclusion for that disqualifying condition would be that there was support for only a lower level of suitability. Another team of DOE contractors and a 14-member, contractor-appointed External Peer Review Panel of university professors and private consultants not otherwise connected with the Yucca Mountain site-characterization program reviewed the core team’s conclusions. The external peer review comments and the replies and modifications by the core team were published, resulting in a volume twice as large as the original ESSE.

Early Site Suitability Evaluation — Geohydrology and Tectonics Specifics

At the Board’s Dallas meeting, special attention was given to two specific areas, geohydrology and tectonics. ESSE core team members gave summaries of the deliberations and reasoning that went into the conclusions in these areas, and two members of the External Peer Review Panel gave their perspective. According to the ESSE, the technical issues in geohydrology that need to be resolved for site suitability are the possibilities for sustained flow and the expected ground-water travel time. The former is concerned with the occurrence of preferential pathways capable of sustaining sufficient ground-water flow to affect waste containment and isolation. This could result in the site not meeting the geohydrology qualifying conditions. The latter, related to the geohydrology disqualifying condition, concentrates on the presence of characteristics that could prevent the site from satisfying the requirement that the ground-water travel time to the accessible environment be greater than 1,000 years.

The key issue in the unsaturated zone is the existence of preferential fast paths (fractures, faults) for the flow of water and their potential effects on waste isolation. Locating these paths and their possible activation, and determining the role of the non-welded tuff horizons below and above the repository in impeding the downward flow of water, were deemed to be important program objectives. With respect to the saturated zone, much discussion

7 *The DOE has received comments on the ESSE and is presently evaluating them.*

was devoted to the steep hydraulic gradient that begins less than one kilometer north of the proposed repository site. The water table to the north of the steep gradient is some 300 meters higher than that beneath the repository site. Current interpretation is that the steep gradient is caused by either a dam (geologically caused permeability contrast) or a drain (buried fault zone) which provides access to the deep Paleozoic carbonate aquifer beneath Yucca Mountain. The core team pointed out that there are other steep gradients near Yucca Mountain and that this gradient would have little or no expected adverse effect on waste containment and isolation.[8]

Ambiguities associated with calculating expected ground-water travel times were described. A case was made for using a stochastic rather than a deterministic approach in calculating travel times. Although the ESSE concludes that the ground-water travel time is likely to be greater than 1,000 years, it also indicates that all calculations are highly dependent upon assumptions. Under certain conditions, such as high percolation flux (see discussion below in section on TSPA), calculated travel times may be less than 1,000 years. The ESSE establishes the need to gather much site-specific information before these issues can be fully resolved. As a result, it concludes that the presence of the qualifying condition and the absence of the disqualifying condition can be supported only at a lower level.

The tectonics discussion was limited to the postclosure disqualifying condition, which concentrates on whether it is "expected" that fault movement or other ground motion causing the loss of waste isolation is "likely to occur." The evaluation of this condition has changed since the EA in 1986, when the absence of this condition was only supported at the lower level. In the current ESSE, this condition has been upgraded to a higher level finding.

Mapping, trenching, and other surface-based excavation were cited as indicating decreasing rates of activity along faults in the area and the lack of evidence for Holocene (and perhaps Quaternary) movement along the Ghost Dance Fault, which crosses the proposed repository site. Primary activity appears to be on the principal north-south tending faults such as the Paintbrush Canyon Fault. The core team argued that earthquake ground motion would not be a problem because the wavelengths of this motion are expected to be much larger than the dimensions of the engineered barrier and design measures could be undertaken to accommodate this motion safely. It was also maintained that the existence of heavy, precariously balanced boulders on steep slopes at Yucca Mountain, which, based on surface weathering, apparently have not moved over hundreds — perhaps thousands — of years, argues against the occurrence of very severe ground motion during that same time period.[9] Finally, the core team indicated that because fault movement and very severe ground motion are not expected within the repository boundary, neither is any significant earthquake-induced change in the local hydrologic regime.

Early Site Suitability Evaluation — Conclusions and Recommendations

The final conclusions of the ESSE are that 13 of the 17 disqualifying conditions are not present and new information is unlikely to change these conclusions (higher level of suitability), and that the remaining 4 of the 17 disqualifying conditions are not likely to be present, but further information is required (lower level of suitability). It was further concluded that 13 of 32 qualifying conditions are present and new information is unlikely to change these conclusions (higher level of suitability), and the remaining 19 of 32 conditions are likely to be present, but further information is needed (lower level of suitability). The core team originally recommended that three additional qualifying conditions were present at a higher level, but the External Peer Review Team recommended downgrading them to the lower level. The

8 *A member of the External Peer Review Panel, however, did point out that a worst-case scenario for this hydraulic gradient, that could have an adverse impact, would be the existence of a small "drain" going through, and bringing water to, the unsaturated zone in the area of the repository.*

9 *The Board heard a presentation on this topic at its July 1992 meeting in Denver.*

core team concluded that the available information continues to support the 1986 EA findings that the site is suitable for characterization.

Perhaps of greater interest are the areas of investigation that the ESSE identified as needing additional information most critical to the evaluation of suitability. These include the effects of climate change, the effects of tectonic disturbance, the potential for and consequences of fast flow paths, and the source term for gaseous release. The ESSE recommends that a systematic prioritization of proposed tests be carried out.

Although External Peer Review Panel members had individual comments and suggestions, eight of the earth scientists on the panel issued a consensus statement. They reported a strong need to prioritize the tests and a greater need to integrate the different technical disciplines. Three integrated topics of particular concern were

- the evaluation of fast pathways in the unsaturated zone;
- the study of the steep hydraulic gradient north of the site; and
- the effects of thermal loading.

These earth scientists also stated their belief that there will be substantial residual uncertainty in many aspects of site suitability that will not be amenable to quantification using standard statistical methods, but will have to be evaluated by expert panels or peer review.

Early Site Suitability Evaluation — Board Comments

1. The ESSE represents a useful and relatively unbiased summary of what is known and not known about Yucca Mountain. It should be used as one input in reassessing priorities among the numerous studies that are part of site characterization. (See the comment below following the discussion of total system performance assessment.)

2. Many disciplines were represented by only one person on the core and peer review teams. For the core team, this could lead to a very narrowly based finding on issues related to that discipline. Although core team members could make use of the expertise of other scientists, a better way should be found to bring at least several people from each discipline into the decision-making process.

3. The requirement that the core team be unanimous when reaching a "higher" level finding results in the level of finding on any single condition being determined by the member with the single "lowest" (most conservative) finding. Thus, in spite of a conscious effort to reach unanimity, the panel is "held hostage" to the single lowest rating. Theoretically, any single individual reaching a finding of unsuitability on any single condition could effect a core team decision of unsuitability with respect to that condition *and*, according to 10 CFR 960, with respect to the site in general. This could make it difficult for the DOE to reach a finding that Yucca Mountain, or any site, is suitable for development of a repository. On the other hand, this also could lead to undue pressure on individuals not to "rock the boat" and express true concerns. The process would be better served in the future if there were a less stringent requirement than unanimity.

4. The small number of choices (unsuitability, lower level suitability, and higher level suitability) creates a problem. It would be very useful if, in early site-suitability evaluation, the choice could be expanded to include at least one that is "neutral," that is, makes no conclusion about suitability or unsuitability. It would simply reflect a lack of information or an equivocal set of information.

5. Perhaps the most vexing problem is the way the core team dealt with the gaseous releases (^{14}C). There is no specific qualifying or disqualifying condition for gaseous releases. This issue is covered under the general postclosure systems requirement qualifying condition. The ESSE states that there is a "significant probability, perhaps greater than 10 percent, of exceeding the [1985 EPA] limits for cumulative release of ^{14}C." If true, this could be a violation of the EPA criteria for the proposed repository. The core team's conclusion that the postclosure systems guideline is likely to

be met (lower level of suitability) is puzzling. The team indicates that this problem is one of an inappropriate regulation and is subject to an engineering fix. Calculations on the release of ^{14}C may vary (see discussion of the TSPA below), but the ESSE seems to be skirting the site-suitability guidelines (10 CFR 960) by saying that a part of the 1985 EPA standard (40 CFR 191) is inappropriate. The appropriateness of the standard should be addressed through processes outside early site-suitability evaluation. [10]

This also was noted by a representative of the state of Nevada in his comments at the Dallas meeting. The one External Peer Review Panel member who discussed this issue concluded that "little confidence can be associated with a finding of even low-level suitability under current, strict regulatory constraints and the present understanding of gaseous migration." Given that there was no neutral option, it appears that the core team members had to stretch the meaning of low-level suitability.

Total System Performance Assessment — Background

TSPA, as applied to the Yucca Mountain site, is the principal method to evaluate the ability of the proposed repository system to contain and isolate radioactive waste. In contrast to the performance assessment of an individual element, such as the waste package or ground-water transport, the emphasis is on the behavior of the *repository system* as a whole, including both engineered and natural barriers.[11] Overall performance has usually been measured against the 1985 EPA standard (40 CFR 191) for the cumulative release of radionuclides over 10,000 years, and it is the primary means by which repository safety and licensability (as defined in 10 CFR 60) will be judged. The recently enacted Comprehensive National Energy Policy Act (described in Chapter 1) has initiated a process by which the EPA standard and the NRC licensing regulations may be significantly changed. Such changes may include, but are not necessarily limited to, replacement of the cumulative release criterion and modification of the way future human intrusion is addressed. The discussion in this chapter is based on the 1985 EPA standard and does not take possible regulatory changes into account.

The first effort at total system performance was a limited, semi-quantitative effort (based on some previous studies by Sandia National Laboratories) that appeared as part of the 1986 Environmental Assessment.[12] During the past few years, the DOE also has used estimates of cumulative release as a figure of merit in studies such as the ESF Alternatives Study, the Calico Hills Risk-Benefit Analysis, and the study produced by the Test Prioritization Task Force. Limited performance assessment studies also were carried out for the ESSE.

In addition to the DOE and its contractors, the NRC in 1990 and the Electric Power Research Institute in 1990 and 1992 carried out total system performance assessments whose stated purpose was more to perfect and demonstrate capability and methodology than to judge the safety of Yucca Mountain as a repository site.

The Board, starting with its first report, has urged the DOE repeatedly to adopt a strategy of iterative performance assessment, which not only would help determine compliance with the overall standard, but also would help the DOE assess progress and priorities in a very complex program. In that light, the Board was looking forward to the DOE presentation

10 *The recently enacted Comprehensive National Energy Policy Act (described in Chapter 1) has initiated such a process. A revised EPA standard based upon maximum effective annual dose to individual members of the public may eliminate regulatory concerns about the release of gaseous* ^{14}C *from the proposed repository.*

11 *Total System Performance Assessment can also refer to the total waste management system, including transportation, interim storage, and the repository. In this discussion, it refers to the postclosure performance of the repository system alone.*

12 *Discussions of past performance assessments at Yucca Mountain can be found in the presentation by Felton Bingham to the NWTRB Panel on Risk & Performance Analysis on May 20, 1991, and in the section on the evaluation of the postclosure system guideline in the Early Site Suitability Evaluation.*

on recently completed TSPAs, made at the April 1992 Board meeting in Dallas.

Total System Performance Assessment — Introduction

TSPA, as applied to the proposed repository, is a measure of the repository's ability to contain and isolate harmful radionuclides. It provides a measure of the *risk* (the likelihood of adverse consequences) posed by the repository to humans and the environment. This risk can be thought of as being a function of three factors (Kaplan and Garrick 1981; Helton 1991).

1. Possible future events and processes, such as climate change, human intrusion, or earthquakes, that could affect the repository. Combinations of events and processes including the nominal case, which assumes no future changes in the natural and human environment, are called *scenarios*.

2. The probabilities of the different scenarios occurring during the lifetime of the repository

3. The consequences of each scenario

Following the 1985 EPA standard (40 CFR 191) and NRC regulations (10 CFR 60), consequences are characterized as radioactive releases to the accessible environment. ! 13 • To be able to predict the releases, the effects of different scenarios on the waste package, repository, and aqueous (and gaseous) flow and radionuclide transport to the accessible environment have to be modeled. The kind and amount of radionuclides released from the engineered barrier system (waste package plus repository) and available for flow and transport during a given scenario are called the *source term*. The consequences of the different scenarios, including the probabilities of occurrence, are combined in such a manner as to be comparable to the EPA standard using a *complementary cumulative distribution function* (CCDF), that is, a graph or curve that shows the probabilities of exceeding different levels of radionuclide release, normalized to fractions and multiples of the EPA limit. Predicting releases is associated with many different kinds of uncertainties, including those associated with the probability of a given scenario occurring, with the extrapolation of data, and with the use of different conceptual and computational models. Use of a CCDF allows the incorporation of much, but not necessarily all, of these uncertainties. Multiple CCDFs can be calculated to show some of these uncertainties. A particularly powerful use of the CCDF is to be able to hold certain assumptions fixed (e.g., volcanism will occur) while seeing the effect of these assumptions on the predicted release. Such sensitivity tests allow factors that may or may not affect the repository risk assessment to be identified.

Total System Performance Assessment — SNL and PNL Studies

The DOE presented two recent TSPAs to the Board: one by the Sandia National Laboratories (SNL) and the other by the Pacific Northwest Laboratory (PNL). These studies have both areas of commonality and of difference.!14•

In terms of scope, both TSPAs evaluate the base (nominal) case, human intrusion, and volcanism scenarios. In addition, Pacific Northwest's TSPA looks at the effects of a tectonically induced rise in the water table beneath Yucca Mountain. Both TSPAs consider aqueous and gaseous releases from the repository. PNL assumes the presence of waste in the form of spent fuel and defense high-level waste glass, while SNL assumes only the presence of spent fuel. For the most part, SNL and PNL analysts use a common geologic and hydrologic data set, but there are some differences in how these data are applied. In general, SNL's approach emphasizes many computations, using *abstracted*, or simplified, models, while PNL emphasizes fewer calculations using

13 The accessible environment is currently defined as the subsurface rock and water five kilometers or more from the repository boundary and the land surface, surface waters, and atmosphere at any location, including that directly above the repository.

14 These descriptions of the SNL and PNL TSPAs are based on the presentations at the Board's April 7–8, 1992, meeting, the review of draft reports, and additional discussions with individual scientists and engineers.

more complex models. Finally, both TSPAs use CCDFs to produce results in the form of the cumulative release of radionuclides from the repository. The PNL report also estimates doses to individuals, assuming the releases calculated by both PNL and SNL.[15]

Following is a discussion of some of the key assumptions and models used and their effects on the TSPA results.

1. *Source term*. Both studies assume a waste inventory of 10 radionuclides[16] including gaseous ^{14}C. Ground water, the driving force for container failure, is assumed to come in contact with the waste packages by two means: (1) The *flow-through* mode occurs in an assumed locally wet part of the repository where water, flowing in fractures, seeps into the containers entraining radionuclides, which then move with the flowing water. (2) The *wet-continuous* mode occurs when the air gap surrounding the container is filled with rubble and the radionuclides are assumed to diffuse out of the failed containers through the wet rock.

Container failure rates also are assumed. Neither TSPA gives credit to the cladding or the container to slow releases once the container fails. The onset of radionuclide release for the base case is treated differently in the two studies and varies from 300 to 2,000 years after closure. This onset time apparently is controlled by the assumed thermal loading and the implied time at which the rock near the waste containers becomes cool enough to permit the presence of water. When the temperature near the waste package is above boiling, it is assumed that water won't come in contact with the container.[17] As indicated previously, PNL also considers releases from defense high-level waste glass. In this case, it is assumed that some of the radionuclides found in spent fuel (carbon, iodine, and cesium) are removed as a result of reprocessing and vitrification.

Of particular importance in both studies is the fact that the transport of radionuclides by colloids or by organic complexing is not considered. Recent studies (e.g., see Bates et al. 1992) indicate that these could be significant with respect to the transport of *actinides* (elements with atomic numbers of 89 to 103), such as plutonium and americium.

2. *Percolation flux*. Percolation flux is a measure of the rate at which water flows downward through the unsaturated zone to the saturated zone. It is a function of precipitation, evapotranspiration, and rock permeability. Percolation flux is important when estimating radionuclide release because it determines (1) the amount of water available to transport the radionuclides and (2) whether sufficient water is available to sustain the more rapidly moving flow of waters through rock fractures (see below). PNL assumes five equally probable fluxes ranging from 0.0 to 0.5 mm per year, while SNL assumes a distribution extending out to 39 mm per year to capture a wide range of possible future climate changes. This distribution is heavily weighted to the lower values such that the mean flux is 1.0 mm per year. Although distributions allow for the incorporation of uncertainty into input parameters, in this case the lack of accompanying sensitivity tests assuming different fluxes limits insight into the effects of percolation flux on the release of radionuclides.

3. *Hydrogeologic and geochemical data set*. As indicated above, both studies use a common data set. Although many of the assumed properties of the tuffaceous rocks are based on measurements and interpretations of existing data, some arbitrary assumptions, such as those relating to the hydrologic properties of fractured rock, have been made. Be-

15 The individual dose criterion is presently being reassessed (see Chapter 1 discussion of the 1992 Comprehensive National Energy Policy Act). Concern about this criterion in the 1985 EPA standard (40 CFR 191) was one of the reasons the federal court remanded the regulation. PNL's estimates are not discussed in this report; however, PNL does point out that the calculations are highly dependent on the assumed dilution properties of the aquifer.

16 A larger suite of radionuclides is used by SNL in its calculations for the human intrusion and volcanism scenarios.

17 The effects of different thermal-loading strategies on the hydrologic regime near the proposed repository are discussed in some detail in the Board's fifth report.

cause of a lack of data in the carbonate aquifer (see below), parameters measured in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) are used. SNL emphasizes an expert elicitation technique that derives probabilistic distributions of the different parameters, while PNL emphasizes single-valued parameters.

With respect to the retardation of radionuclide transport, it is assumed that americium, plutonium, and tin would be completely sorbed;[18] technetium, carbon, and iodine would not be sorbed at all; and uranium, neptunium, selenium, and cesium would be partially sorbed. The combination of assumptions regarding source term and retardation often determine the extent to which different radionuclides are projected to reach the accessible environment.

4. *Unsaturated zone flow*. Most of the computations are carried out using the *equivalent continuum model* (ECM), which assumes that the flow properties of the fractured rock can be approximated by assuming a porous medium with gross properties chosen to reflect both the slower movement of water through the unfractured rock matrix and its faster movement through fractures.[19] The SNL uses a series of one-dimensional stochastic calculations, while the PNL employs two-dimensional deterministic calculations. PNL models the Ghost Dance Fault (which cuts through the proposed repository site) as having an order of magnitude higher fracture density and, therefore, higher permeability than the adjacent rock strata. SNL analysts point out that it is not possible to simulate the fault in their one-dimensional analysis.[20] The SNL study, however, also includes parallel computations using a *weeps model*, which allows for the independent flow of water though a set of random, discrete fractures. This is meant to simulate the existence of fracture zones that could permit the rapid, concentrated flow of water. Some argue that this model, which assumes the existence of a number of faults, would have a more adverse impact on radionuclide release than if the model had assumed the existence of the Ghost Dance Fault alone.

In the SNL study, both the ECM model, in combination with high percolation fluxes that allow fracture flow, and the weeps model result in releases of water-born radionuclides to the accessible environment because of the relatively short travel time of water to the saturated zone. In the PNL study, the assumed percolation flux in the base case is low, and, consequently, the travel time through the unsaturated zone is so long that no radionuclides are projected to reach the saturated zone and, therefore, the accessible environment, during the 10,000-year repository lifetime.

5. *Saturated zone flow*. The saturated zone below the proposed repository at Yucca Mountain consists of two parts, an upper zone (or aquifer) of volcanic tuff units and a lower zone (or aquifer) in carbonate rock. Calculations are performed assuming (1) average properties for the saturated zone as a whole (all SNL scenarios except for human intrusion) and (2) separate properties for the different rock types (the SNL human intrusion scenario and all PNL scenarios). When treated separately, travel times are estimated to be much longer in the tuff than in the carbonate rock. A better understanding of groundwater flow in the parts of the saturated zone in which radionuclide transport can occur, including the effects of possible fast paths, would help define the efficacy of this part of the geologic barrier.[21]

6. *Gaseous releases*. Problems associated with the possible release of gaseous ^{14}C have been discussed by the Board beginning with its first report. The importance of gaseous releases with respect to demonstrating compliance with the 1985 EPA standard is pointed out in the previous section on the ESSE. Difficulties associated with estimating the true level of

18 *Sorption is the deposition or uptake of radionuclides (or other species) from gas or solution by geologic materials such as volcanic tuff.*

19 *The Board's fifth report contains a discussion of the different computational models used to describe the flow of water in unsaturated fractured media.*

20 *The SNL study does include two-dimensional flow calculations, some of which simulate the presence of the Ghost Dance Fault. These, however, are not incorporated into the CCDF.*

21 *As discussed in the Board's third report, the DOE's Calico Hills Risk-Benefit Analysis concluded that the saturated zone made a substantial contribution to waste isolation.*

release are shown in the SNL and PNL studies and their resultant conclusions. In the SNL TSPA, calculations are based on a separate study on gaseous flow by Ross, Amter, and Lu (1992). The methodology is different from that used for aqueous releases in that a two-dimensional, rather than a one-dimensional, analysis is used. Similarly, for aqueous releases, all the rock above the repository is assumed to possess one set of properties, while for gaseous releases a more detailed stratigraphy is used, including the presence of the nonwelded unit of the Paintbrush Tuff. This thin, relatively unfractured layer is assumed to retard the upward flow of gas.[22] Releases of gaseous ^{14}C dominate the CCDFs produced by SNL. In fact, using the equivalent continuum model of unsaturated zone ground-water flow leads to a slight exceedance of the EPA standard. This occurs because, in the equivalent continuum model, water is not restricted to discrete fractures as in the weeps model of unsaturated flow and a larger number of waste containers are allowed to come in contact with water, fail, and leak gaseous ^{14}C. In this case, because of the relatively short travel times of gaseous ^{14}C to the surface, assumptions about the source term (including the extent of container failure) have a large impact on estimated releases to the accessible environment.

The PNL study uses a simpler model of rock properties overlying the repository. The model includes neither the nonwelded unit of the Paintbrush Tuff nor the Ghost Dance Fault. Gaseous ^{14}C makes a much smaller contribution to the computed CCDF. This is primarily due to an assumed gas permeability of the rocks overlying the repository some *three orders of magnitude* less than that assumed in the SNL study. Clearly, this and other factors, such as uncertainty in its source term and the possible retardation and removal of significant ^{14}C by reactions with moisture and carbonates (Codell and Murphy 1992), make estimating the extent of the ^{14}C release one area where additional work is needed.

7. *Human intrusion*. Two scenarios of human intrusion are considered in the studies. Both involve inadvertent drilling into the repository some time in the future. The first is one in which the driller brings either some portion of the contents of a waste container, and/or the contaminated rock around it, to the surface. The second is one where drilling penetrates a container and continues down to the saturated zone, forming a direct pathway for radioactive waste. The tuffaceous and carbonate portions of the saturated zone are considered separately. Both the SNL and PNL studies conclude that the scenario whereby the drill hits the container, bringing the waste directly to the surface, causes the largest release of radionuclides. The SNL study shows the importance of the assumed frequency of drilling.

8. *Volcanism*. Both studies examine a scenario whereby volcanism could lead to the formation of a *dike* (a vertical, wall-like intrusion of igneous rock cutting across the preexisting rock strata) disrupting the repository and bringing radioactive waste to the surface. Although the SNL study relies on site-specific data and the PNL on generic information for many of its input parameters, the estimated releases are not dissimilar. Both studies assume that the likelihood of volcanism during the 10,000-year lifetime of the repository is on the order of 10^{-4}. It is interesting to note that even if the likelihood of volcanism is assumed to be 1.0, the *conditional* CCDF, which reflects the probability that a dike could disrupt the repository and bring waste to the surface, suggests releases still less than the 1985 EPA standard.[23]

9. *Tectonically induced rise in the water table*. The possibility of a large rise in the water table beneath Yucca Mountain due to earthquakes and other tectonic forces has been a topic of interest in recent years. The PNL chose to include this scenario, basing its analysis on work performed by EPRI (1990). The PNL assigns different probabilities to the postulated rises in the water table that range up to 100 meters above its present level. While this places the satu-

22 *The nonwelded unit of the Paintbrush Tuff also may play an important role in reducing aqueous releases in that it can slow the rate at which surface water percolates from the surface down to the repository horizon.*

23 *The Board discussed volcanism in its fourth report, encouraging the use of a probabilistic approach and highlighting the need to emphasize studies that determine the vulnerabilities of the repository to volcanic activity.*

rated zone a lot closer to the repository than it is now, there is no calculated release of radionuclides due to the very long travel time of ground water calculated by the PNL in the unsaturated zone above the water table. It would have been useful if the PNL had carried out a sensitivity test that allowed the water table, as some have proposed,[24] to reach the repository itself and had evaluated the consequences of such a scenario.

Total System Performance Assessment — Summary

1. Both the SNL and PNL point out that their TSPAs are primarily tests of methodology, modeling, data adequacy, and integrative abilities. The presenters explained that because the calculations are not based on a comprehensive set of analyses, many of the models need to be validated, and because site-specific data are lacking in many areas, the results of the studies cannot be used in licensing as a baseline measure of repository acceptability. The presenters did indicate, however, that neither study found any reason not to continue with site characterization.

2. The release of gaseous ^{14}C dominates the SNL-computed total system CCDF. As indicated above, use of the ECM model alone shows a slight exceedance of the 1985 EPA standard. In the integrated CCDF used to represent repository performance from all scenarios, this exceedance is avoided (just barely) because the ECM model is only assigned a weight of 50 percent. The SNL argues that in this case, as in many others, the emphasis is not on best estimates of repository performance but rather more on the use of bounding models and assumptions.

3. The PNL-computed total system CCDF does not exceed the 1985 EPA standard. Different scenarios control it at different levels of radioactive release. At the low releases (highest probability), the dominant scenario is that of human intrusion where contaminated rock is brought to the surface. At a somewhat higher level of release, the dominant scenario is the release of gaseous ^{14}C. At the next highest level of release, the dominant scenarios are those whereby human intrusion brings waste directly to the surface or to the saturated zone. At the highest level of release (the EPA limit), the dominant scenario is volcanism. The probabilities of this release, however, are orders of magnitude below that allowed in the 1985 EPA standard.

4. Both studies point out that future TSPAs will need additional data, clarified assumptions, and better models. Some specific information requirements include a firm design and emplacement concept, statistically meaningful hydrologic properties for all stratigraphic units, and geochemical data that take thermal changes into account.

5. The DOE presented a schedule for implementing iterative performance assessment. Six additional TSPAs are scheduled up to the planned license submittal in 2001. The next iteration should be completed by June 1993. In this next iteration, the DOE plans to emphasize those aspects that will provide insights about the ESF design, surface-based testing, thermal loading, site suitability, and issue resolution.

Total System Performance Assessment — Board Comments

1. The DOE is to be commended for completing the two total system performance assessments presented to the Board. They represent a substantial increase in the number of studies available that strive to portray the whole repository system in light of its ability to contain and isolate radioactive waste from the accessible environment.

2. This should, however, be only the first step in a process by which iterative performance assessment can serve as a primary tool for judging program progress, assessing program priorities, and, eventually, determining compliance with the appropriate regulations.

24 *Flooding of the repository by means of a tectonically induced rise in the water table was originally proposed by Szymanski (1989). It was the subject of a recent report by a special panel of the National Academy of Sciences (National Research Council 1992) and is discussed in Chapter 1.*

3. The DOE should solicit reviews from outside groups such as the NRC, the state of Nevada, and the electric utility industry as to the quality and completeness of the TSPAs and the lessons that may be learned from them.

4. Sensitivity tests were conducted only for selected parts of the SNL and PNL studies. More are needed. Sensitivity tests provide useful insight into which scenarios, assumptions, models, and data are important to waste isolation.

5. Future total system performance assessments need to be as *transparent* as possible; that is, those interested must be able to understand what was done, how it was done, what were the results, and what is and is not important. A fully transparent TSPA can turn what might appear to many (including the educated citizen) to be a complicated exercise in mathematics and statistics into an understandable evaluation of the proposed repository's ability to contain and isolate radioactive waste.

6. Based on Sandia's and Pacific Northwest's TSPAs (and the ESSE and other relevant and available studies), the DOE should reassess its site characterization priorities. A spreadsheet model for reassessing priorities was presented to the Board at its April 1992 meeting in Dallas, and a DOE Convergence Task Group was described at the Board's July 1992 meeting in Denver. The first test of such programs should be a reassessment of priorities.[25] Of critical importance is the identification and definition of those data most needed for assessing site suitability.

Recommendation

Based on Sandia's and Pacific Northwest's total system performance assessments, the Early Site Suitability Evaluation, and other relevant and available studies, the DOE should provide a *timely* reassessment of its priorities among the numerous studies that are part of site-characterization plans. Of critical importance is the definition of those data most needed for assessing site suitability.

25 Board members saw some initial results of priority reassessment in a brief presentation on the spreadsheet model at the November 4-5, 1992, meeting of the Panel on Structural Geology & Geoengineering.

Chapter 3

NWTRB Visit to Selected Countries Insights into the U.S. Nuclear Waste Management Program

Introduction

Since the members of the Nuclear Waste Technical Review Board first convened in March 1989, the Board has been committed to learning about the spent fuel disposal programs of other countries for primarily two reasons: (1) to increase the Board members' knowledge and understanding of the problems facing those determined to find safe ways to dispose of nuclear waste and (2) to determine if those working in the U.S. program might be able to learn from the work under way in other countries to meet the challenge of spent fuel and high-level waste management.

To date, the Board as a whole has visited and met with experts in spent fuel and high-level waste management programs in five foreign countries. In 1990, the Board visited Sweden and Germany. This trip was followed by a visit to Canada in 1991. In 1992, the Board met with officials in Finland and Switzerland to assess the progress being made in their programs and to determine if additional insights could be gained for application to the U.S. program. Also, as discussed in Chapter 1, the Board's Panel on the Engineered Barrier System visited Japan in 1992. The Board hopes to continue these visits in 1993 with trips to Belgium, France, and the United Kingdom.

The Board members have found the opportunity to meet with officials and to visit the nuclear waste facilities in other countries very enlightening and informative. There is no substitute for meeting and talking in person about the important issues facing us all as we undertake the often contentious and complex challenge of nuclear waste disposal. The Board members wish to take this opportunity to thank all people involved in each country for helping to ensure the success of the Board's visits.

Although it is difficult to compare the approach and experience taken by those managing programs in other countries to the current situation in the United States, the Board believes it is important to make the effort. Such efforts help ensure that the best knowledge and expertise available in the world today have been consulted in addressing the technical, as well as the nontechnical, aspects of nuclear waste disposal.

In June of this year the Board visited with officials in Finland and Switzerland to discuss their research and site-characterization programs. The Board also took this opportunity to visit research facilities, disposal sites, and sites under study in these countries for the disposal of spent fuel, high-level waste, as well as intermediate- and low-level wastes. Following these brief, but information-filled visits, Board members collectively made a number of observations about the foreign programs it has visited in recent years. Their observations have led to some tentative conclusions about other approaches that have potential application to the U.S. program. These observations and conclusions are discussed in the following pages.

Some observations are not new. In previous Board reports, especially the third and fourth reports, the

Board commented on insights gained from evaluating other countries' programs. Board members expressed their concerns then about some aspects of the U.S. program they consider problematic.

It is important to reiterate how complicated it can be to compare approaches to nuclear waste management that have evolved within very different historical, cultural, and institutional frameworks. Although, there are some similarities among the programs, there are also some obvious differences between the U.S. approach and those being taken in Canada, Finland, Germany, Sweden, and Switzerland:

- The United States is the only country where federal *law* requires the federal government to enter into contracts with the nuclear utilities to accept waste for disposal *by a certain date*, but where responsibility for interim storage is assigned primarily to individual utilities.

- The United States is the only country that does not have an integrated and widely accepted plan for long-term interim storage of all spent fuel and high-level waste.

- Besides Germany, the United States is the only country that plans to have a repository operating before 2020.

- Besides Finland, the United States is the only country currently without a research and development (R&D) program at an underground facility where work on repository-related scientific and technical uncertainties is being conducted.[1]

- Besides Germany, the United States is the only country characterizing a specific site for potential repository construction.

- The United States is the only country evaluating a repository in an unsaturated zone (above the water table).

- Besides Germany, the United States is the only country of those visited to date by the Board, that does not plan to rely heavily on the engineered barrier system for long-term waste isolation.

- Besides Germany, the United States is the only country considering emplacing high-level waste and spent fuel at above-boiling temperatures.

To help the reader gain a quick overview, some key components of programs in countries visited by the Board and the U.S. program are compared in Table 3.1.

The following discussion concludes with several suggestions which, if pursued by U.S. officials, could ease — and perhaps eliminate — some of the pressures that are constricting the U.S. program.

1 *Finland's geology is similar to Sweden, Canada, and Switzerland, and it has been able to participate in and benefit from research performed at the URL at Pinawa, Manitoba, Canada; the Äspö hard rock laboratory, Simpevarp, Sweden; the Stripa mine near Kopparberg, Sweden; and the URL laboratory at Grimsel Pass, Switzerland.*

Table 3.1 – Comparison of Key Program Components for Selected Countries

	Approximate Metric Tons of Spent Fuel Projected by Year 2000	Current Thermal-Loading Strategy	Geologic Environment	Projected Waste Package Lifetime	Investi-gating Specific Site	Underground Research Facilities in Operation	Estimated Minimum Fuel Ageing Requirements	Target Date for Repository Operation
Canada	*27,000*[1]	*Below Boiling*	*Granite Saturated*[2]	*At least 500 years, but intent is much longer*	*No*	*1986*	*Decades*	*Not before 2025*
Finland	*1,300*	*Below Boiling*	*Crystalline Rock Saturated*	*At least 10,000 years*	*No*	*None, but has built underground facility for intermediate-level waste*[3]	*40 years*	*2020*
Germany[4]	*8,950*	*Above Boiling*	*Salt Saturated*	*500-1,000 years*[5]	*Yes*	*1967*	*None*	*2008 (tentative)*
Sweden	*4,400*	*Below Boiling*	*Granite Saturated*	*1,000,000 years*[6]	*No*	*1990*	*40 years*	*2020*
Switzerland	*2,000*	*Below Boiling*	*Crystalline Rock Sedimentary Rock Saturated*	*100,000 years*[7]	*No*	*1983*	*40 years*[8]	*After 2020*
United States[9]	*40,000*	*Above Boiling for 300–1,000 years, then Below Boiling*	*Tuffaceous Rock Unsaturated*	*300–1,000 years*	*Yes*	*1996–97 (projected)*	*10 years*	*2010*

[1] *Because it is not enriched uranium and has a lower burnup, the Canadian (CANDU) heavy water reactors generate a considerably larger amount of spent fuel per kilowatt hour of electricity than light-water reactors do in the U.S.*

[2] *"Saturated" denotes a repository built in water-saturated rock below the ground-water table.*

[3] *The designation "intermediate-level waste" is not used in the United States but in Europe is used to describe waste that requires some radiation shielding, but no cooling.*

[4] *Based on information provided prior to reunification and applicable only to West Germany.*

[5] *For spent fuel, not high-level waste. The Germans are researching the potential of a triple-purpose cask for storage, transport, and disposal of spent fuel.*

[6] *Although the Swedes and the Finns are looking at similar designs, the Swedes recently published their view that a copper canister will remain intact for at least a million years, by which time the wastes will have ceased to be dangerous.*

[7] *Includes waste package and bentonite buffer.*

[8] *All spent fuel in Switzerland is reprocessed. The resulting high-level waste is being stored for 40 years.*

[9] *Based on U.S. DOE 1988 Site Characterization Plan, which is undergoing revisions at present.*

Observations

Deep Geologic Disposal and Public Mistrust

Observation 1: The current scientific and technical consensus in the United States, and in all countries the Board has visited, is that deep underground disposal is the best option. The public, however, remains mistrustful of underground disposal and of things related to nuclear waste.

Although alternatives to underground disposal have been examined by various countries over the years, in all countries with nuclear disposal programs, deep underground disposal in a mined geologic repository is the preferred option.[2] Canisters of vitrified high-level waste or spent fuel[3] • enclosed in durable containers would be buried in a deep geologic formation and surrounded by multiple engineered and natural barriers. The geologic and hydrologic conditions (e.g., saturated vs. unsaturated) in which the waste would be buried varies dramatically from country to country, depending on the climate and geology of the region and the sites under investigation. A variety of reasons have been offered by those governments favoring mined geologic disposal, but the basic rationale seems to be the belief that underground burial will provide the greatest degree of waste isolation at the most reasonable cost.

Programs in Switzerland and Finland have much in common. The Swiss have decided that all nuclear wastes will be disposed of in mined geologic repositories because of the high population density in Switzerland. Although the Swiss have not yet chosen a geologic medium, they have set safety conditions that require a repository to be designed so that it can be sealed at any time within a few years. It also must be possible to dispense with safety and surveillance measures once it is sealed. The current strategy in Finland is to dispose of the waste in crystalline rock. Given the very small amount of waste to be disposed of, the limited resources, and, in Switzerland's case, the very limited number of suitable sites, both Finland and Switzerland have policies endorsing multinational or bilateral cooperation in the disposal of high-level waste and spent fuel.[4] Both countries would like to purchase or share in the development of space for their small amounts of waste in a repository located in another country. Recognizing that a cooperative effort is unlikely given the current political attitudes concerning nuclear matters, they are actively moving toward developing their own repositories.

In 1979, the Germans decided to study the possibility of disposing of spent fuel directly in addition to reprocessing it. Permanent disposal in Germany means the waste will not be retrieved. Research on spent fuel disposal involves looking at the emplacement of triple-purpose casks in tunnels of a repository mined in a salt dome.[5] Salt, behaving somewhat like a liquid plastic, would naturally flow to fill the mined cavities, eventually sealing off the containers completely. In Germany, site-characterization work is under way at the Gorleben site, which is a salt dome located in north central Germany.

Following years of work, discussion, and political considerations, the Swedish government in 1984 approved the KBS-3 method as feasible for the safe final disposal of spent nuclear fuel. Using this method, the spent fuel would be encapsulated prior to disposal in cylindrical canisters made of copper and filled with lead. Recent studies now indicate that the preferred alternative is copper on a steel canister (SKB 1992). Swedish research suggests such

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2 *Some alternatives that have been suggested include encapsulation in the ice cap of the Antarctic, shuttling or rocketing waste into outer space, deep-well injection, rock melting, and subseabed disposal. Of all these options, subseabed disposal is the only option, other than deep geologic disposal, that still has some supporters. But as the general political climate in most countries is against subseabed disposal, this option is currently not being pursued seriously.*

3 *The terms "canister" and "container" are used interchangeably in this section. "Cask" usually refers to a container used for storage, transport, and perhaps disposal. "Canister" is generally used in other countries where the term "container" would be used in the United States. Also, for purposes of this report, spent nuclear fuel means irradiated fuel elements not intended for further use in a nuclear reactor. High-level waste is the waste stream resulting from the first cycle of fuel reprocessing.*

4 *Federal law for both countries, but Switzerland especially seems to favor this option.*

5 *A salt dome is a geologic structure produced by the upward movement of a mass of salt from a mother salt bed (Lau 1987)*

a container could be expected to remain intact in Sweden's geologic setting for at least one million years, and probably longer (SKB 1991). The storage chamber would be built at a depth of 500 meters in granite, with canisters placed in vertical holes drilled in a series of tunnels. Each canister would be surrounded by a backfill consisting of hard-packed, bentonite clay, which, when it came in contact with ground water, would expand and seal the space surrounding the canisters. The waste canisters could be reached and retrieved in the future, although this would be a difficult undertaking.[6]

Canada currently is revisiting its decision to pursue the *concept* of deep geologic disposal of spent fuel in granitic rock. In 1977, two government agencies recommended focusing on deep geologic disposal in the granitic rock of the Canadian Shield. Then, in 1977/1978, after citizen concern about siting significantly impeded R&D, the decision was made to decouple siting from R&D. Consequently, since the early 1980s the Canadian approach has been to seek public consensus on the best way — from a political *and* technical perspective — to dispose of high-level waste. The Canadians are using an environmental assessment review process to evaluate the potential environmental, social, and economic consequences associated with the concept of deep geologic disposal in granite.

In the United States, discussion of underground disposal of radioactive waste has gone on for many years, going back to the mid-1950s when the United States began exploring the option of disposing of the radioactive waste in salt. The United States is currently characterizing a potential repository site in the tuffaceous rock[7] at Yucca Mountain, Nevada, to determine if it would be suitable to bury waste in a repository excavated approximately 300 meters below the surface of the mountain. The repository, at its deepest point, would be approximately 150 meters above the water table; at its shallowest, approximately 300 meters. The spent fuel would be encased in thin-walled, metal containers, and the defense high-level waste from reprocessing[8] would be vitrified in thin-walled metal canisters with thin-walled metal overpacks. These would be placed in boreholes excavated in the floors of tunnels. The repository would remain open for 50 years following initial emplacement to permit retrieval of the waste packages.[9]

Although the technical and scientific communities in the countries visited by the Board have, for the most part, concluded that underground burial is the best option, public support is tenuous. Surveys conducted in the state of Nevada, for example, reveal that the public sees nuclear facilities as presenting risks that are unknown and dreaded. When asked to describe the thoughts that came to mind when presented with the phrase, "underground high-level nuclear waste repository," 79.4 percent of the respondents said their thoughts were very negative (Flynn et al. 1992). The survey concludes that trust in repository management and the public's *perception* of risk are the dominant contributors to public opposition in Nevada to a potential repository. The study also concludes that repository program managers must increase trust and reduce perceived risk, not only for Nevadans, but for all. Fears have been heightened in recent years around the world by a number of issues: the occurrence of accidents (Three-Mile Island, Chernobyl); news reports on environmental and health hazards posed by past mismanagement of radioactive waste at U.S. and Soviet defense installations; and reports on reactor accidents that could occur at any time (e.g., in Russia, and in Eastern European reactors). Thus, as the technical minds move ahead, often with sound technical solutions to difficult disposal problems, a skeptical public may not be "willing" to accept those solutions.

6 *Retrievability is not required by regulation, but it has not been ruled out.*

7 *A rock composed of compacted volcanic ash.*

8 *Of the countries we have visited to date only the United States has high-level wastes resulting from reprocessing for defense-related activities.*

9 *DOE Site Characterization Plan (1988). This plan currently is being modified.*

The Canadians are attempting to address these kinds of concerns through their public environmental assessment review process (EARP). Whether this process will result in the public reaching a solution that presents an acceptable level of risk remains to be seen. Interestingly, after hearing from the public through an exhaustive public hearing and comment process, the panel conducting this review asked the technical community to restate its rationale for deep burial of the waste, including the implications of such a decision for future generations. It also asked that the view the current generation should have of its responsibility to future generations be clarified. The same panel wants plans to be developed for retrieving the nuclear waste from a sealed and decommissioned disposal vault given possible emergency or other circumstances. The plan should include cost estimates and a description of how retrieval could be facilitated by the design of a repository vault (Federal Environmental Assessment Review Panel 1992).

As the Canadian EARP process demonstrates, whether or not to retrieve the waste is an issue in discussions of the underground disposal option. Where countries have made a decision not to retrieve the waste, that decision seems to stem from cost considerations and from a desire to solve the problem now and not pass it on to future generations. Despite the technological difficulties and high costs associated with waste retrieval, public concerns may persist about the risks involved in burying radioactive waste without having a way to retrieve it.[10]

Conclusion: Unless public perception about the risks associated with nuclear power and the waste it generates can be addressed, efforts to site a permanent repository for burying such waste will continue to meet with opposition.

Responsibility for Managing, Storing, and Disposing of Spent Fuel and High-Level Waste

Observation 2: In contrast to the U.S. and German programs, the producers of nuclear waste in the other countries visited by the Board are responsible for the safe management of their nuclear waste, including in most cases, planning and financing the strategy, and executing all R&D, interim storage, transportation, and final disposal activities.[11]

In Finland, Switzerland, and Sweden, the nuclear waste producers are responsible under national law for all radioactive materials resulting from the operation of nuclear reactors. As producers, the utilities are responsible for the safe management and disposal of spent fuel and high-level waste, including designing and operating the facilities as well as financing their operation. Thus, spent fuel interim storage and transport and all R&D work related to spent fuel and waste management are essentially the utilities' responsibility. In Canada, fiscal and management responsibility for the storage and disposal of spent fuel is shared by a federal crown corporation and the nuclear utilities. In Germany, the federal government finances and runs the program and then is reimbursed by the nuclear utilities.[12]

In several of the countries, the utilities have established a corporation, whose exclusive job it is to manage the waste from the utilities. In Finland, for example, the utilities (of which there are two) manage their own waste storage, transportation, and disposal programs. They have established a joint research program (YJT) to coordinate the R&D aspects of their work. The Finnish government acts as regulator, ensuring that the program is carried out safely. Each year the utilities pay money into a state nuclear waste management fund. To ensure that financial liability is not underestimated, the utilities are required to present cost estimates each year for the future management of the waste. The costs are estimated assuming that nuclear power production

10 In addition, since the potential future value of spent fuel is not yet known, some argue that the retrieval option should be kept open.

11 Another exception is Japan, where the federal government is also responsible for waste disposal. Members of the Board's Panel on the Engineered Barrier System visited Japan in September 1992, but the panel focused primarily on Japan's plans for EBS development, so remarks are limited in this report to that topic.

12 General discussion is under way in Germany, however, about the possibility of transferring responsibility for the waste program to the nuclear utilities.

will stop at the end of the year under consideration. For the outstanding liability (i.e., the estimated future costs not yet covered by contributions paid into the fund), the licensee must furnish securities as a protection against insolvency.

In Switzerland in 1972, the nuclear utilities, together with the Swiss Confederation (central government), which is responsible for radioactive waste resulting from medicine, industry and research, jointly established a private institution called the Swiss National Cooperative for the Disposal of Nuclear Waste (NAGRA). NAGRA is responsible for final disposal of high-level radioactive waste and related work. The utilities retain responsibility for spent fuel reprocessing, transport, waste conditioning, and interim storage. The costs are born directly by the utilities, with the Swiss Confederation making a minor contribution. A fund has been established within each utility to finance the spent fuel and nuclear waste disposal program.

In Canada, responsibility for radioactive waste management rests with the producer. As such, Canadian utilities are responsible for the management, storage, and transport of their spent fuel. A large proportion of Canada's nuclear energy production takes place in Ontario. In 1987, that province's government and the federal government issued a joint statement that established the Canadian Nuclear Fuel Waste Management Program. The statement provides for Ontario Hydro, the utility, to assume responsibility for the management of spent fuel, including research into interim storage options and transportation. Responsibility for R&D on immobilization and disposal of high-level waste was assigned to the Atomic Energy of Canada Limited (AECL), a federal crown corporation that conducts research on nuclear energy. The federal government, through an appropriation to AECL, and Ontario Hydro jointly pay for and manage the programs.

In Germany, the responsibility for high-level waste and spent fuel disposal rests primarily with the federal government. Under the auspices of the Federal Ministry for Environmental Protection and Reactor Safety (BMU), the federal government manages all siting, and site-specific R&D, characterization, and construction work for nuclear waste disposal facilities. The program is run by the Federal Institute for Radiation Protection (BfS), which falls under BMU's purview. Each year the BfS drafts its fiscal budget, which must be approved by the federal government. Once approved, the nuclear utilities are obliged to reimburse the federal government. As there is no equivalent to the U.S. Nuclear Regulatory Commission (NRC) in Germany, the state governments issue the licenses, acting in the name of the federal government. The federal government supervises this process, however, to ensure that the states are in compliance with federal law. If the federal authorities determine the state is not in compliance, the federal government can overrule the state. The utilities transport, condition, and dispose of the spent fuel and waste.[13]

In the United States, a federal statute (the Nuclear Waste Policy Act) passed in 1982 required the U.S. DOE to enter into contracts with the utilities. The utilities pay for disposal through fees collected from their ratepayers, but the responsibility for disposal was turned over to the federal government. The U.S. DOE manages the spent fuel and defense high-level waste program, and the DOE must take title to spent fuel for disposal no later than January 31, 1998. U.S. utilities, have been assigned the responsibility of providing for interim storage. The NRC is responsible for licensing the facility.

In deciding to place management of the final disposal of spent fuel with a government agency, the U.S. Congress effectively removed the U.S. utilities from decisions affecting the R&D, siting, construction, and operation of a permanent repository.[14] Although, the utilities in other countries may not be

13 *This description of the German program is based on information available prior to reunification. There currently is discussion of the utilities assuming full responsibility for financing, building, and operating waste disposal sites. Reunification also has increased competition for funds throughout the government, resulting in greater scrutiny of current expenditures.*

14 *The Edison Electric Institute (EEI) and the Electric Power Research Institute (EPRI), both funded by the utilities, comment and/or conduct research on the decision-making process of the U.S. waste management program.*

directly responsible for the day-to-day management of their R&D, siting, site-characterization, design, and construction programs for a repository, in all cases except Germany they are responsible for the successful management of their waste. Consequently, the utilities in these countries appear to have more responsibility for developing the system for long-term management of spent fuel and high-level waste than do U.S. utilities.[15]

In most of the countries visited, the company or organization responsible for their R&D program must submit annual reports to the appropriate government authority detailing the amounts and reasons for all expenditures of funds. The approach taken by the governments in these countries is that the responsible organizations are accountable, not only from a safety perspective but also from a financial perspective. Consequently, the tendency is either to set budgetary limits within which the utility or organization must operate or to scrutinize closely the expenditure of funds. For example, the budget for the Swedish Nuclear Fuel and Waste Management Company (SKB) in Sweden is published on an annual basis.

This organizational framework also affects the decision-making process and financial review of each country's waste program. In most of the countries visited, both decision making and financial review are one step removed from the legislative body governing the country. The organization reviewing the budget in most cases is not the parliament or its equivalent, but rather the equivalent of a U.S. federal department. In contrast, the U.S. DOE presents its annual budget to the U.S. Congress. The DOE makes its strongest case for the funding it requests and hopes that the U.S. Congress and the current administration will see fit to fund it accordingly.

Conclusion: There may be a tendency toward greater managerial and financial accountability when those responsible for financing the operation of nuclear power plants and generating spent nuclear fuel and high-level waste also are responsible for disposing of it. In the U.S. system this would mean requiring the nuclear utilities to share more direct responsibility and liability for managing and disposing of their spent fuel.

Size and Scope of Nuclear Waste Management and R&D Programs

Observation 3: The U.S. program employs a significantly greater number of people in its R&D program than any other countries visited, and the costs of running its program are higher.

Finland has a very small nuclear spent fuel and waste management program. Approximately ten people, employed with two government agencies, the Ministry of Trade and Industry (KTM) and the Finnish Centre for Radiation and Nuclear Safety (STUK), run the program for the government. Currently, approximately ten people work at Industrial Power Co. (TVO), the utility responsible for the spent fuel disposal program; they are supplemented by roughly 20 to 50 in-house consultants each year depending on the work to be accomplished. Because of limited resources, the Finns have sought opportunities for international cooperation to expand their access to R&D expertise, to make the most of their financial resources, and to save money on expensive experiments.[16] The Finns have spent roughly 30 million markkaa (US $6.7 million) per year on their entire spent fuel and high-level waste management program, including preliminary site investigations at five sites from 1987 to 1992. The work consisted of airborne surveys, deep and shallow drillings, surface and borehole measurements and sampling, in-situ measurements and laboratory tests, and computer-aided modeling and evaluation work.[17]

The Swiss program is larger than the Finnish program, but does not approach the size of the U.S.

15 The U.S. utilities are responsible for managing their low and intermediate level wastes.

16 For example, the Finns participated in and found the research at the Stripa mine in Sweden to be very beneficial to their program. Also, the Finns recently established a joint project with SKB in Sweden to participate in research at the Äspö hard rock laboratory, enabling them to join in full-scale testing and to expand their R&D base.

17 Based on information provided to the Board during its June 1992 visit to Finland and in follow-up conversations with and information provided by Timo Äikäs, Chief of Georesearch, Nuclear Waste Management, TVO, Helsinki, Finland.

program. The actual R&D, site-characterization, and disposal work is done by NAGRA, a nonprofit institution responsible for final disposal of nuclear waste and all related work. The Swiss federal government created NAGRA, which is controlled by a six-person Board consisting of representatives from each of the utilities and a representative from the federal office of public health. Currently, the utilities make annual contributions to NAGRA based on their thermal power production. During the past few years, NAGRA's budget has fluctuated from 50 to 100 million Swiss francs (US $40-80 million) per year, but as site-investigation work at the low-level waste site increases, NAGRA anticipates that costs will rise. The first phase of work from the surface (seismic measurements and five deep boreholes) has cost approximately 60 million Swiss francs (US $46 million); the total cost of site characterization including exploratory tunneling is estimated at approximately 180 Swiss francs (US $144 million).

To perform *all* R&D work, NAGRA employs approximately 80-90 people full time, 50 of whom are project managers with the rest providing support. NAGRA relies on approximately 300 person-years of consulting work per year to supplement the full-time staff. With this staff and budget, NAGRA runs the Grimsel Underground Research Laboratory (URL) and all site-investigation and development work for low-level waste, intermediate-level waste, high-level waste, and spent fuel repositories.[18]

In Sweden, the SKB is responsible for all handling, transportation, storage, and permanent disposal of low- and intermediate-level waste and spent nuclear fuel. SKB also is responsible for the planning and construction of all facilities, and pertinent R&D work. SKB employs approximately 60 people full time, with 20 of those people working full time in R&D. SKB also retained the services of approximately 70 consulting organizations or 600 people during 1991. Of those, approximately 250-300 people were retained to help with R&D work. SKB's total R&D costs for 1991 amounted to Swedish kronen 183 million (US $31 million). This includes the cost of all R&D, construction, and investigations at the Äspö hard rock laboratory, studies on alternative systems, and demonstration and siting work.[19]

It is more difficult to estimate the size and scope of the German and Canadian programs because, as in the U.S. program, the number of people involved spans a number of organizations in different parts of the country. In contrast to the United States, however, a substantial majority of R&D work in both countries takes place at one or two locations. In Germany, part of the research and development on high-level waste and spent fuel disposal is conducted under the auspices of the GSF-IfT, which reports to the Ministry for Research and Technology.[20] It employs 220 people, 155 of whom run the R&D program and 65 of whom operate the Asse research facility. The annual budget of GSF-IfT has been 40 million German marks (US $28 million) per year, but is currently being reassessed due to overall constraints placed on Germany's federal budget as a result of the costs accompanying reunification.[21] The BfS, which runs the Gorleben site-characterization project, licensing and maintenance of the Konrad mine, and now manages the Morsleben facility (in former East Germany), will spend a total of approximately 550 million German marks (US $368.5 million) to sink the project's shafts. It has been estimated that the Gorleben site-investigation project, which has grown more expensive due to complications from an aquifer overlying the salt dome and brine intrusion where shafts are being sunk, will approach a total cost of approximately 3.35 billion German marks (US $2.2 billion) (Berg and Debski 1992).

In Canada, the majority of research on spent fuel disposal is carried out at the AECL laboratory in Pinawa, Manitoba. Approximately $45 million Canadian (US $36 million) a year is spent on R&D.

18 Based on information provided to the Board during its June 1992 visit to Switzerland and follow-up conversations with Charles McCombie, Director, Science and Technology, and NAGRA staff, NAGRA, September-October 1992.

19 SKB 1991 and information provided by Torsten Eng, Manager for International Relations, SKB, September-October 1992.

20 Company for Radiation and Environmental Research/Institute for Underground Storage (GSF-IfT)

21 Information provided by Klaus Kühn, Director, GSF-IfT in October 1992.

Although AECL employs more than 3,000 people at its research laboratories, 250 of these work on spent fuel disposal R&D programs.[22]

In the United States, research currently is spread among more than ten major organizations around the country, including several DOE national laboratories and the United States Geological Survey. The DOE also recently has awarded a management and operations (M&O) contract to integrate and coordinate all ongoing activities. The total number of people involved, including those working for the M&O contractor, DOE headquarters, the national laboratories and the Yucca Mountain Site Characterization Project Office and its contractors totals almost 2,000. The Congress recently appropriated approximately $375 million for the DOE's Office of Civilian Radioactive Waste Management to continue its program in fiscal year 1993. This includes $224.7 million, which the Yucca Mountain project received for its site-investigation program. The U.S. DOE currently projects it will cost approximately $6 billion for the site-characterization phase at the Yucca Mountain site.[23, 24]

Most of the countries visited by the Board are operating R&D programs comparable to the U.S. program. However, the size of the U.S. program is larger, and the costs of running the program are clearly higher. The U.S. DOE is spending more per year on R&D than any other country visited by the Board including Germany, where R&D actually includes underground site-characterization work at Gorleben and where a politicized program has led to work stoppage and its attendant costs.[25]

Why the size and cost of R&D programs in the countries visited by the Board are smaller than in the U.S. program is not entirely clear. At first glance one might think it is because the United States has considerably more spent nuclear fuel and high-level waste and must put more resources into disposal. This is not the case, however. Canada, which will produce a comparable volume of waste,[26] runs a considerably smaller and less expensive R&D program that includes the use of an underground research laboratory in Pinawa, Manitoba. Given our knowledge of the various programs, we suggest that there are a variety of possible reasons for smaller R&D programs in the countries visited by the Board, including

- the tendency in some countries to establish research priorities and cost controls *before* designing their R&D programs;
- the absence of a federal research establishment and infrastructure the size of that found in the United States, which requires considerable funding;
- the absence of detailed and prescriptive regulations similar to those found in the United States, which require extensive R&D work to license a repository;
- availability of fewer experts in some countries, which in turn dictates a smaller program;
- the absence of a very tight schedule and not yet having a specific site to characterize, both of which demand increased resources;[27] and

22 *Information provided by Barbara Gray, Acting Director, Environmental Review Office, AECL, October 1992*

23 *This includes research and development work, surface and underground exploration, and payments to the state of Nevada and other affected parties.*

24 *Presentations made by Carl Gertz, Director, Yucca Mountain Site Characterization Project Office, before the NWTRB, July 1991 - October 1992.*

25 *Intervenors have opposed site-characterization work at Gorleben on several occasions. Also, $6 billion German marks (US $3.9 billion) were spent on the design and ground preparation for the Wackersdorf reprocessing facility, only to stop work before construction began. In the United States, the WIPP facility is built and ready to test waste disposal, but it has been opposed by intervenors (See Chapter 1 discussion). According to Secretary James Watkins in testimony before Congress, it costs $14 million a month to keep the WIPP site open and staffed.*

26 *Because it is not enriched uranium and has a lower burnup, the Canadian (CANDU) heavy water reactors generate a considerably larger amount of spent fuel per kilowatt hour of electricity than light-water reactors do in the U.S. However, while the volume of waste is greater, each ton of spent CANDU fuel has a lower thermal and radioactive output than does U.S. fuel.*

- the ability to benefit from others' R&D work and to borrow technologies from the United States and others.[28]

Conclusion: The U.S. R&D program is larger in size and more costly than the R&D programs of other countries. Yet, most countries are conducting research in line with their program goals. The size of the U.S. program may in part be a result of the large level of funding required to support the current U.S. federal and contractor research establishment, and the need to accelerate the expenditure of funds to meet a very demanding schedule in characterizing the Yucca Mountain site. Whether the United States will realize greater benefits in its program as a result of the greater expenditure of funds and human resources remains to be seen.

Interim Storage

Observation 4: Regardless of their policies for spent fuel and high-level radioactive waste management, all of the countries visited by the Board, as well as the United States, currently are storing fuel in spent fuel pools, in dry cask storage, or at reprocessing facilities; and they will most likely continue to do so for decades to come.

Waste management strategies in Canada, Finland, Germany, Sweden, and Switzerland include either ageing fuel for a certain number of years and/or reprocessing the fuel prior to emplacement in a repository. The Finns are storing the waste from TVO reactors in KPA-store (water pools) at Olkiluoto. National Power Co. (IVO), the company in Finland that operates reactors of a modified Russian design was, until recently, sending its fuel to the Soviet Union for reprocessing. Since the Soviet Union's demise, it is not clear if the fuel will continue to be reprocessed in Russia. If not, it most likely will be included in the disposal plans for the other Finnish spent fuel.[29]

Spent fuel in Switzerland is stored in storage pools at nuclear power plants, then transported to England and France for reprocessing. A central interim storage facility will be built at Würenlingen, Switzerland, by a private company called ZWILAG. In 1989 the local community agreed to host the facility and will manage it together with the nuclear utilities. The facility will receive and store the high-level waste from reprocessing from the time it returns to Switzerland until it can be disposed of permanently. The general license for the facility must be approved by the Swiss parliament, expected in 1994. Thereafter, further applications will be made for construction and operating permits. Spent fuel and high-level waste will be stored in casks in dry storage. The first stage of operations will address the storage needs of all existing Swiss nuclear power plants for the next 25 years.

The Swedes have built and are operating a central interim storage facility (CLAB) as part of their plans to age their spent fuel for at least 40 years prior to emplacing it in a permanent repository. All spent fuel is shipped to the CLAB facility via a specially designed transport vehicle and a ship, the M/S Sigyn. The pools can hold about 3,000 metric tons, but CLAB currently is undergoing expansion because the total amount of spent fuel produced by Swedish utilities now is projected to be 7,800 metric tons.

German utilities are storing spent fuel at reactor sites from five to seven years to reduce peak heat loads. A method called "compact storage" is used to maximize the number of fuel rods that can be safely stored. Then, the fuel is shipped to either France or Great Britain for reprocessing into vitrified high-level waste. The reprocessed waste from France will be shipped back to Germany in November 1994. The exact date the waste will be shipped back from Great Britain has yet to be determined.

In Canada, spent fuel is stored either at reactor sites in pools or in dry storage in concrete canisters with steel lined containers. There are no current plans for a monitored retrievable storage (MRS) facility. Should one become necessary or desirable, however,

27 *Exception: In Germany, site-characterization work is under way at Gorleben.*

28 *Canadians, Finns, Swedes, and Swiss are all investigating the potential to dispose of spent fuel in crystalline bedrock.*

29 *OECD (1992) and conversations with Finnish program personnel during June 1992 Board trip.*

it would probably be built at an existing reactor site in Ontario.

The DOE would like to build a MRS facility, where some of the spent fuel from U.S. reactors would be stored beginning in 1998 until a repository is ready to receive the waste. The United States is seeking a locality, state, tribe, or territory to host the facility. However, the process is taking longer than originally anticipated, and a location has not as yet been found. Even if a site were found soon, the MRS facility would have to be licensed by the U.S. Nuclear Regulatory Commission, which at a *minimum* would take several years.

Because of constraints on the facility, the MRS does not provide a long-term solution to spent fuel storage. U.S. federal law links construction of an MRS facility to the construction of a first repository requiring that a license for repository construction be issued before construction of a MRS can begin. Federal law also established a 10,000-metric-ton-capacity limit for the MRS facility, which represents approximately five years' worth of spent fuel from all U.S. commercial reactors.[30] Without a change in federal law, the MRS, even if sited, could not begin to hold all of the waste accumulating at commercial reactors, nor would it be of much practical use if it were not available until a few years before a permanent repository was opened. For perhaps the next decade, then, U.S. commercial reactors lacking adequate on-site storage for the life of the reactor will need to plan for expanded on-site storage of their spent fuel.

In programs in other countries, a greater effort is being made to plan and integrate interim packaging and storage methods into the overall waste management system. Sweden has a well-integrated system for managing the fuel. It includes storing spent fuel on an interim basis at CLAB. The Swiss send the fuel out for reprocessing and are seeking final approval to build the ZWILAG facility to store the high-level waste when it returns. The Finns are storing their waste in KPA-store pools. The Germans are currently either storing their spent fuel in pools, or in central dry-storage facilities, while awaiting reprocessing or direct disposal in a permanent repository. The Canadians are storing their spent fuel either in spent fuel pools or in concrete casks containing stainless steel canisters. In addition, a prototype "integrated canister" made of concrete is being evaluated for possible use by Canadian utilities as a dual-purpose transportation and dry-storage cask.

In contrast, most U.S. utilities are storing their fuel in spent fuel pools, and, in a growing number of instances, are seeking to supplement pool storage with on-site dry storage systems.[31] Plans for on-site storage have not yet been integrated into the overall spent fuel and waste management system to the same extent that they have in most of the countries visited by the Board. The variety of dry storage systems in the United States is likely to increase as utilities run out of pool space, and no MRS facility or repository exists to receive the waste.

Another large difference between the U.S. program and the others is the emphasis in the United States on meeting the legislatively mandated 1998 deadline for the beginning of repository operations and acceptance of spent fuel by the DOE. This date is integral in the agreements reached between the DOE and U.S. commercial nuclear utilities because it drives the schedule the DOE has set to fulfill its obligation. Unfortunately, slippage in the schedule already has taken place and has contributed to the appearance that the DOE cannot meet its goals. Interestingly enough, this perception may have been fostered by the utilities themselves, who are pressing the federal government to remove the waste from their reactor sites by 1998. This is not the case in the countries visited by the Board. Except in Germany, the nuclear utilities are heavily involved in, if not

30 *Since U.S. reactors generate approximately 2,000 metric tons of spent fuel per year, an MRS facility with a 10,000-metric-ton limit could hold only approximately five years' worth of spent fuel from all U.S. commercial reactors. There are currently 111 reactors licensed to operate in 33 states in the U.S. (Nuclear Regulatory Commission 1992).*

31 *Currently the U.S. NRC has granted four licenses for on-site dry storage systems and four more applications for licenses are pending. Four cask designs have been certified for on-site storage, two cask designs are under review for approval in site-specific licenses, and four cask designs await certification of compliance under subpart L 10 CFR 72.*

primarily responsible for, managing and storing the spent nuclear fuel and high-level waste. Long-term interim storage is a planned component of the spent fuel and high-level waste management strategy in those countries, so a negative stigma is not associated with centralized or at-reactor storage. Also, specific deadlines for receipt, storage, and disposal of the waste do not exist.

Conclusion: Spent nuclear fuel and high-level waste will continue to be stored at a centralized facility or at reactor sites until decisions are made about the permanent disposal of that waste. In contrast to the U.S. program, however, other programs visited by the Board do not view long-term, interim storage as reflecting a failure to meet program goals. Indeed, interim storage of all fuel is acknowledged as fact and is incorporated into long-term plans for managing spent fuel and wastes. Interim storage plans in all of the countries visited seem to be well coordinated and integrated into the total waste management system.

Schedule for Design and Construction of a Repository

Observation 5: Most countries visited by the Board to date have established schedules for the siting, design, and construction of a permanent repository. In contrast to the U.S. program, however, their schedules are less rigid, and there does not seem to be the same amount of pressure to meet a specific starting date for repository operation that exists in the U.S. program.

In Finland, Sweden, and Germany, schedules have been established for the design and construction of a permanent repository. The Finns and Swedes intend to begin emplacing waste in a repository sometime between 2020-2030. *If* the Gorleben site is ruled acceptable, Germany wants to have a facility operational by 2008. Practically speaking, the Canadians have dispensed with all schedules for building a repository since they are revisiting the concept of deep geologic disposal as part of their environmental assessment review process. Currently, Environment Canada, one of the principal federal departments responsible for overseeing nuclear waste disposal, is scheduled to make a final determination on the acceptability of AECL's concept for nuclear spent fuel and waste disposal sometime during 1995/1996.

The Swiss indicate, that, should a multinational disposal option not be available, they will select candidate sites by the turn of the century and begin construction of a high-level waste facility sometime *after* 2020.[32]

In contrast, U.S. federal statute authorizes the DOE to enter into contracts with the utilities, and also requires the DOE to begin taking title to the utilities' spent fuel for disposal no later than January 31, 1998. The DOE contract with the utilities provides for acceptance of the waste upon commencement of "facility" operations, be it a repository or some other facility. To uphold statutory obligations, the U.S. Secretary of Energy has established administrative deadlines to site a MRS as soon as possible, to submit a repository license application by 2001, secure license approval and begin construction by 2003, and complete construction of the repository so that is it ready to receive waste by 2010 (DOE 1987b). Exactly how the courts would interpret the DOE's obligations in the event a repository or facility is not available to receive the spent fuel in 1998 is unclear.

The more relaxed approach being taken by the programs in other countries visited may be explained in part by their approach to managing waste. In all of the other countries visited, except Germany, the decision was made to age the spent fuel for a minimum of 40 years.[33] These countries are planning to store spent fuel and have set a goal for developing a permanent place to bury the waste by approximately 2020 or later.

32 *Of note, none of the above dates or schedules are prescribed in law.*

33 *Canada, Finland, Sweden, and Switzerland are faced with emplacing their waste in saturated rock below the water table. Because all countries visited, except Germany, have repository designs requiring temperatures to remain below boiling, ageing is an important component in the system. The rationale in ageing the waste for 40 or more years is to lower the thermal output of the fuel. This will help retard corrosion of the container, enhance the properties of the backfill (bentonite), and minimize the opening of fractures or the propagation of existing fractures to greater depth.*

Reprocessing and on-site storage have been part of the Swiss and German strategies for a number of years as well. The Finns and Canadians also are storing their spent fuel at reactor sites as part of their long-term waste management strategy. Should a centralized storage facility become necessary in Canada, it also would be located at one of the reactors, and the fuel could be stored there for up to perhaps 100 years. The Swedes established a fund like the U.S. nuclear waste fund and have built and operate a central interim storage facility (CLAB), to which the utilities' spent fuel is transported by ship.

In contrast, the U.S. DOE is pressing ahead to begin receipt of spent fuel by 1998 as required in the NWPA of 1982. The DOE wants to site and build a MRS facility to fulfill its obligation. Yet, the majority of U.S. nuclear utilities do not begin to run out of space in their pools until around 2010 (MRS Commission 1989). Interestingly, the U.S. NRC issued a ruling on September 18, 1990, stating that spent fuel can be stored safely at reactor sites, in pools, or in dry storage for at least 30 years beyond the licensed life for operation at the reactor (including the term of revised or renewed licenses). Assuming a reactor life of 40 years, plus license extensions, waste could be safely stored at a reactor site for roughly 100 years (10 CFR 51). From a safety or technical perspective, then, there may not be a need to have a finished repository by the year 2010. It also may not be necessary from a safety and technical perspective to site and build a MRS facility by 1998. However, the potential political and legal consequences of not meeting current deadlines may present more compelling reasons to at least try to achieve both goals.

Due to the provisions of the NWPA of 1982 and in the face of political and legal consequences, the DOE has been obliged to establish very demanding and unrealistic schedules. When a schedule is not realized, the U.S. DOE is criticized, the program is reorganized or reevaluated,[34] and the cycle repeats itself. This has led to the perception that the DOE is failing to meet program goals, even though the schedule may have little bearing on the nature of the technical and scientific work under way. In addition, tight schedules have created pressure on those involved in site-characterization work to establish deadlines that are difficult, if not impossible, to meet and could jeopardize the high scientific and technical standards of the program (National Research Council 1990).

Conclusion: The need felt by the U.S. DOE to establish an overly demanding schedule (currently 2001, licensing; 2010 repository operation) to meet a legistlative deadline (set in the NWPA as 1998) is likely to persist; and program credibility may continue to suffer because the DOE may not be able to meet the deadlines. The Board believes that the effort to rush to meet overly demanding schedules could affect the quality of the technical and scientific work being undertaken as part of developing a program to manage and dispose of spent fuel and high-level waste.

Engineered Barrier System and Underground Research

Observation 6: Except for Finland, all of the countries visited to date by the Board are performing underground research in the media they are proposing for repository development. All of the countries visited to date by the Board are studying or developing a long-lived engineered barrier system to work together with their respective media to isolate the radionuclides from the environment.

In research under way in Finland, Switzerland, Canada, and Sweden, experts are placing very high emphasis on different components of the engineered barrier system to contain the waste. This is because of the inherent uncertainties associated with predicting the long-term behavior of the climatological and geologic environment. If Canada decides to build an underground repository, it would most likely be built in crystalline rock; the nature of Finnish geology means a repository will probably be built in crystalline bedrock; and in Sweden, crystalline bedrock also is being studied. Faced with very few places to put a repository at all, the Swiss eventually will explore crystalline or sedimentary rock. Suitable sites in this rock type are located below the water table, and water may come in contact with the engineered barriers. Should waste containers be breached

34 This cycle is often precipitated by the appointment of a new Secretary of Energy or new OCRWM director.

(e.g., through corrosion), the most likely pathway for nongaseous radionuclides to the accessible environment is ground water. To address this concern, the research programs in these countries are examining ways to design a system of more robust, long-lived engineered barriers that will contain the radioactive wastes for very long periods of time.

In Sweden, underground studies have been made of the near-field environment, and of buffer and backfill materials. The most current plan continues to place primary emphasis on the container, which would consist of copper over a steel canister. These canisters would be placed in vertical holes bored in drift floors (one canister per hole), and the holes would be backfilled with a bentonite clay buffer. SKB officials estimate that this system would retard radionuclide movement for at least one million years.

The Finns also are placing primary emphasis on the container. The waste package is a similar version of the Swedish concept. Fabricated by an "advanced cold process" (ACP), it consists of steel for strength and copper for corrosion protection. The steel "slides" into a copper shell, and the copper shell is welded by an electron beam. Scientists assert the process is simple and fast. Moreover, the container life is projected to be at least 10,000 years. The Finns envision emplacing 1,200 such containers in the repository in bedrock at a depth of somewhere between 300 to 800 meters. Bentonite would be used as backfill, and a temperature of less than 100°C would be maintained. The possibility for enlarging the repository would remain (Raiko and Salo 1992).

As in Sweden and Finland, the Canadians have researched corrosion-resistant containers, including copper and titanium. Glass beads would be compacted around the used fuel bundles and fed into spaces between the fuel and the container shell to provide internal support against underground pressures. The containers would be emplaced at temperatures up to 100°C. Scientists also are researching the extent to which used fuel is a stable waste form and can itself serve as a barrier. The radioactive materials remain in ceramic fuel pellet form. These pellets are easily sealed inside zirconium alloy tubes that may provide an additional barrier against water penetration. Backfill and buffer materials are being studied, with particular emphasis on a mixture of bentonite and sand to slow ground-water intrusion.

Although the Swiss are placing emphasis on all aspects of the engineered barrier system, they are placing primary reliance on a buffer material consisting of a highly compacted layer of bentonite. The current system for their reprocessed waste includes a leach-resistant glass matrix, a stainless steel canister, a thick steel overpack, and the layer of highly compacted bentonite. The bentonite buffer will be prefabricated in circular, log-like forms and stacked within the repository tunnels. The total thickness of bentonite around each container would be about 1.4 meters. The Swiss waste packages will be designed to withstand conditions for a minimum lifetime of 1,000 years. The bentonite is expected to retard radionuclide movement for about 100,000 years.[35]

The Japanese do not currently have a policy explicitly stating that they plan to place high reliance on the EBS, but they have very complex geology. Consequently, they are evaluating a massive engineered barrier system consisting of a canister with foot-thick carbon steel walls surrounded by three-foot thick bentonite.[36]

Of all programs visited thus far, only the Germans are placing primary reliance for waste isolation on the natural barrier. The Germans are researching the emplacement of spent fuel in triple-purpose casks in tunnels of a repository excavated in a salt dome.[37] The casks would be designed to remain "tight" for 500 years. High-level waste would be vitrified and emplaced in salt. The Germans have not been as concerned with container corrosion because high temperatures (but no greater than 200°C) would increase the plasticity of salt, causing it to creep and encapsulate the waste beyond 500 years.

35 In presentation before the Board by Ian G. McKinley, R&D Coordinator, NAGRA in June 1992.

36 Information provided members of the Panel on the Engineered Barrier System during visit to Japan, September 1992.

37 Triple-purpose casks are casks used for storage, transport, and disposal.

Despite the early stages of their program development, all of the programs visited by the Board to date have been performing and sharing in underground research for a number of years in the media they are proposing for a repository.[38] Finland has had the experience of constructing an intermediate-level waste facility in crystalline bedrock and has benefited from other underground research studying their geology. Each country is evaluating a multiple barrier system that will help safely isolate the radionuclides for potentially thousands of years. Even the Germans, who also have been conducting underground research and who intend to rely heavily on the natural properties of salt to entomb high-level waste, are performing underground studies at the Asse Mine on the use of a triple-purpose cask system for the disposal of spent fuel. Their intent is to contain the radionuclides in the cask for at least 500 years.

The United States is characterizing tuffaceous rock in the Nevada desert. The current U.S. baseline plans call for the disposal of relatively young fuel (e.g., as young as only 10 years out of the reactor) in thin-walled containers in a repository approximately 300 meters below the surface of the mountain. The U.S. baseline plan for waste isolation evolved incrementally over time, and will continue to do so, according to the DOE. Current siting guidelines state, “the engineered barriers will be designed to complement the natural barriers, which provide the primary means for waste isolation” (10 CFR 960.3-1-5). According to the baseline plan, above-boiling temperatures would be created in the immediate vicinity of the waste package for approximately 300 to 1,000 years, followed by below-boiling temperatures. This would, in theory, create an early hot/dry environment for the waste packages. The above-boiling temperatures would drive away any moisture that might otherwise reach the containers. This should prevent, or greatly retard, aqueous corrosion of the containers for at least 300 years.[39]

Even though the U.S. Congress has mandated the characterization of a specific site, the U.S. DOE has *not* yet excavated underground at the Yucca Mountain site to examine and test the geology, faulting, and fracture flow conditions of the rock being characterized.[40] Not surprisingly, in discussions with Board members and staff, representatives from other countries have indicated that once their programs began underground research, new information was uncovered about the geology and hydrology that was not known prior to the investigations. They emphasized the need to begin underground studies in conjunction with surface studies as soon as possible. Although little underground research exists on tuffaceous rock in the unsaturated zone, such as that which is found at the Yucca Mountain site, the U.S. program base plan continues to place primary reliance on natural barriers.

Conclusion: Given the uncertainties that are likely to exist at any site being characterized for its suitability as a possible permanent repository, the countries visited by the Board are studying the potential contribution of a multibarrier system to help isolate radionuclides from the environment. An important component of the multibarrier system is the engineered barrier system. In contrast to the U.S. program, most other countries have devoted considerable resources from the outset of their programs to research development of the engineered barrier system.

Licensing Approaches

Observation 7: In Finland, Switzerland, Canada, Sweden, and Germany, the regulations to license a repository are less prescriptive than the U.S. regulations. All of these countries currently have a more flexible approach than the United States does to licensing a permanent underground repository.

In Switzerland, the regulator, the Nuclear Safety Inspectorate (HSK) of the Federal Office of Energy has set overall safety standards. Then, NAGRA, the or-

38 *Canada has the URL; Sweden has built the hard rock laboratory Äspö and conducted extensive research at the Stripa mine in collaboration with other countries; Germany is currently conducting research at the Asse mine and also is performing underground site-characterization work at Gorleben; and the Swiss have built and are operating an underground research laboratory at Grimsel Pass.*

39 *How the rock will actually perform under these high temperature conditions has yet to be tested and validated.*

40 *The U.S. program has performed underground research in the past in tuff at G-tunnel on the Nevada Test Site, but this research has been discontinued.*

ganization responsible for designing a disposal system, designs a system to meet the safety standards. According to federal law, various licenses are required for the construction of a final repository, including a license for test drilling during site characterization; a general license, which must be approved by parliament; a construction license; an operation license; and a license for closing and sealing the repository.

The Swiss criteria for radiological protection are based on the recommendations of the International Commission of Radiation Protection (ICRP). The safety conditions that must be met are defined in R-21, a guidance document issued in October 1980 by the Federal Commission for Safety of Nuclear Installations (KSA) and the HSK. There are two objectives: (1) Radionuclides that escape into the biosphere must not at any time lead to individual doses exceeding 0.1 millisievert (mSv) or 10 millirem (mrem) per year. (2) A repository must be designed so that it can be sealed within a few years at any time. After it has been sealed, it must be possible to dispense with safety and surveillance measures. R-14, a further guidance document, addresses the conditioning and interim storage of radioactive wastes (Frank 1992).

The Finnish Centre for Radiation and Nuclear Safety (STUK) is responsible for the control of nuclear safety, including waste management. In 1991, STUK issued guidelines for the safety of nuclear power plants and a disposal facility for reactor waste. STUK also has participated extensively with other Nordic countries (Denmark, Iceland, Norway, and Sweden) in the development of Nordic criteria for the disposal of high-level radioactive waste. (The final version of this document should be published soon.) Although the Nordic guidelines expand on the STUK guidelines, the STUK guidelines are essentially as follows. The upper bound of the annual dose to any member of the public is 0.1 mSv (10 mrem). The upper bound of the annual dose to any member of the public arising from accident conditions caused by natural action or human action is 5 mSv (500 mrem). Disposal must be based on natural and engineered barriers, and engineered barriers must limit the migration of radioactive substances for at least 500 years. Natural barriers should then limit migration to the biosphere to a level in compliance with the dose requirements (Finish Centre for Radiation and Nuclear Safety 1991).

In its third and fourth reports, the Board discussed the licensing approaches of Sweden, Germany, and Canada. Essentially, Sweden's approach is similar to Finland's and Switzerland's. The fundamental radiation protection requirements are based on ICRP principles, including the principle of ALARA (as low as reasonably achievable), and on internationally accepted principles on the multibarrier system, safety assessment methodology, and quality assurance. A working group from the Nordic nuclear safety and radiation protection authorities, which included representatives from SKI, the agency with authority for licensing a repository, and SSI, Sweden's radiation protection authority, recommended criteria on final disposal of spent nuclear fuel. No further specific regulations dealing with spent fuel or high-level waste have been established, but SKI will develop criteria and issue regulations as part of the licensing process (Norrby 1992).

In contrast to the other countries visited by the Board to date, there is no single, separate licensing authority in Germany. Licensing and regulation of nuclear waste disposal facilities are shared between the states and the federal government, with the state(s) in practice issuing most licenses. The principles and basic requirements for the use of ionizing radiation are set forth in the Atomic Energy Act and the Radiation Protection Ordinance.

The Germans also have issued guidelines on the disposal of radioactive wastes based on ICRP principles and the application of the ALARA principle. Doses to the public from normal nuclear facility operations must not exceed 0.3 mSv (30 mrem) to the whole body per year and less than 0.9 mSv (90 mrem) to the thyroid per year for all reasonable scenarios. Doses to occupational workers for normal operations at nuclear facilities may not exceed 50 mSv (5 rem) per year, and doses to occupational radioactive waste workers may not exceed 5 mSv (500 mrem) per year from direct radiation, with no more than 0.5 mSv (50 mrem) per year from inhalation. The application process for repository construction requires the applicant to do a site-specific safety analysis, which includes calculation of an individual dose requirement for approximately 10,000 years. After

10,000 years, only total isolation capability has to be demonstrated.

In Canada, the Atomic Energy Control Board (AECB) is responsible for licensing a permanent repository. The AECB's approach would be to review a proposal to build a repository in the context of general criteria, which are not legally binding and are outlined in the AECB's guidance documents. This document includes some general principles and an individual protection principle. AECB criteria state that no facility should subject a person to a radiological risk greater than a one-in-a-million chance of serious health effects per year. The dose limit for nuclear workers is 50 mSv (5 rem) per year. The AECB has *ruled* that radiological risks to future generations should be no greater than those presently considered acceptable. Following closure of the disposal vault, no individual should receive an annual dose greater than 0.05 mSv (5 mrem) per year. This criterion must be satisfied for 10,000 years.

Currently in the United States, the construction, operation, and closure of a repository can be undertaken only if the repository is licensed by the NRC. The NRC, in 10 CFR 60, implements general environmental radiation protection standards issued by the EPA (40 CFR 191). The NRC also has specified detailed requirements that must be met for minimum waste package lifetime, for maximum release rates for each radionuclide from the engineered barriers, and for minimum ground-water travel time to the accessible environment. Finally, the DOE has issued its own requirements (10 CFR 960) for assessing whether a site is suitable for repository development or not.

The current licensing approach for the U.S. program on siting, designing, and constructing a first-of-a-kind-facility reflects a very different philosophy from that of the countries visited. In the United States, the approach has been to establish numerous, very specific requirements, which, if satisfied, would assure the public that the spent fuel has been safely disposed of for 10,000 years. In the European countries visited by the Board and in Canada, the approach has been to establish very general guidelines; put the burden of proof on the organization siting, designing, and constructing the facility; and then evaluate the ensuing work. At the heart of the approach taken by most of the countries visited by the Board is to use the best available technologies and the geology of the site eventually selected to isolate the radionuclides from the environment for as long as possible, and the longer this can be accomplished, the better. For example, the SKI in Sweden has stated its intent to *not* issue very detailed requirements but, instead, to undertake a *systems approach and require that the total system be safe and effective at present and for the long term.*[41] This approach allows considerable flexibility in the application of best available technologies to maximize the amount of time that such a repository could be deemed safe enough to isolate radionuclides.

Recently, a U.S. federal law was passed that may, over the course of the next few years, change the regulations that apply to the characterization and licensing of the proposed site at Yucca Mountain, Nevada. In October 1992, the "Comprehensive National Energy Policy Act" was signed into law. One section of this law amends the Nuclear Waste Policy Act of 1982 to direct the Administrator of the EPA to promulgate health-based standards that will apply specifically to the Yucca Mountain site. Before doing so, the EPA is directed to contract with the National Academy of Sciences to complete a study by December 31, 1993, that will provide recommendations to the EPA.[42]

To what extent this review will result in adopting the regulatory philosophy and approach taken by the other countries visited by the Board to date remains to be seen. Given the prescriptive nature of the U.S. regulatory framework, however, a change in several specific requirements within that framework may not result in the more flexible regulatory framework prevalent in the other countries visited by the Board.

41 *Memorandum to NWTRB from Sören Norrby, Director, Office of Nuclear Waste, SKI, on SKI's regulatory approach, October 1992.*

42 *See section of this report entitled "Congressional Activities" for further details.*

Conclusion: Although this may change, the current U.S. approach to licensing may make the process of demonstrating site suitability more difficult than the approach being used by the other countries visited by the Board. In contrast to the U.S. approach, their approach to licensing allows considerable flexibility in the application of best available technologies so as to maximize the amount of time a repository could safely isolate radionuclides from the environment.

Siting a Permanent Repository

Observation 8: The United States and Germany are the only countries to have narrowed the selection process to a single site for characterization as a possible location for a permanent repository.

None of the other countries visited to date by the Board, except Germany, has selected one site for investigation as location for a permanent repository. Canada has delayed indefinitely any decision to site a potential repository. Sweden is currently in its final research and preinvestigation phases of site selection and hopes to select a site sometime between 2000 and 2010; and construction would start sometime thereafter. The Swiss will select a site sometime after the year 2000 if an international disposal option does not become available. They have, however, not started the candidate site-selection process. In 1985, the Finns identified 100 feasible sites, based on geology and other relevant scientific information. In 1987, they narrowed the number of potential sites for a permanent repository to five. They hope to have selected a final site by the year 2000. Construction is expected to begin around the year 2010, with operations scheduled to begin in 2020.

These countries have decided to delay the challenge of selecting a final site and instead are either working to achieve public and political consensus, looking for an alternative disposal site outside the country, or working gradually toward narrowing the candidate sites through a process that appears to be technically and scientifically based. In some cases all three approaches are receiving attention.

Germany wants to build a repository at Gorleben, but has been repeatedly stalled by the state government of Lower Saxony, which has licensing authority for the Gorleben facility. The Gorleben site continues to engender controversy and political conflict. In addition, technical problems have arisen since the onset of underground exploration work. The most recent event is a problem of brine intrusion, which appeared during work on a second exploratory shaft.

In 1987, in the Nuclear Waste Policy Amendments Act, the United States narrowed its potential sites from three to one; a site at Yucca Mountain, Nevada, was identified by Congress as the single site for characterization. Current U.S. policy is to characterize the Yucca Mountain site and if it is determined suitable by the DOE, then the Secretary will recommend it to the U.S. President, who, in turn, would make a recommendation to the U.S. Congress. If the recommendation takes effect, then a license application is submitted to the NRC.

During the past five years, the Governor of the state of Nevada, his representatives, and others in the state have voiced strong opposition to the selection of the Yucca Mountain site because of the belief that site selection, which originally entailed the technical evaluation of three sites for a possible repository, has become a political, rather than technical/scientific, decision. An opinion often appearing in the Nevada press is that the U.S. Congress basically thrust the repository on one of the states with few votes in Congress.[43]

Based on the Board's experience so far, the most heated political opposition over radioactive waste disposal currently exists in the two countries that have actually selected a site for characterization, Germany and the United States.[44] Whether this level

43 The state of Nevada has the right to object to a positive recommendation by the NRC to a license application for the Yucca Mountain site, but the final decision rests with the U.S. President and Congress.

44 Lower Saxony, a state in Germany, has successfully stopped work at the Gorleben site. The state of Nevada has also intervened at several points in the site-characterization process at Yucca Mountain.

of opposition will arise in other countries as they get closer to choosing a single site is not clear. But given the contentious and emotional nature of all issues surrounding nuclear power and its resulting waste, it would not be surprising. Whether or not public opposition will slow — or eventually defeat the prospects of selecting a repository site — may depend, in part, on several factors, including

- the extent to which the siting process is perceived by the affected and the *general* public as being "fair," and
- the level of control those most affected have over the siting, construction, and operation of a repository.

Finally, the level of trust the population of a given country has in its government and in the nuclear industry, and the extent to which the future of nuclear power has become linked to solving the spent fuel and high-level waste disposal problem may also play important roles.

Conclusion: Based on the record to date, siting a permanent repository for the disposal of spent fuel and high-level waste will continue to generate controversy no matter what approach is taken. The success of a country's program may depend on the ability of that country to identify and adequately address those factors that most influence the public's perception of the siting process. Involving the public in non-technical, as well as technical, issues before selecting a site may increase a country's chances of successfully siting a repository. Although such efforts are unlikely to eliminate all obstacles, they may succeed in framing a dialogue that is based more on fact than on emotions.

Summary

In summary, the Nuclear Waste Technical Review Board would like to suggest that both Congress and the U.S. Secretary of Energy review the U.S. program with respect to specific approaches countries visited by the Board are taking in the design and implementation of their programs to manage the disposal of spent fuel and high-level radioactive waste. The objective of this review is not to undertake an extensive and/or expensive study, but to simply determine if specific approaches in other countries could benefit the U.S. program. In reviewing the programs of Canada, Finland, Germany, Sweden and Switzerland, the Board urges the U.S. program to consider the advantages and disadvantages of the following.

- A management approach in which existing schedules (e.g., for repository operation) are taken seriously but do not drive the scientific and technical goals of the program (e.g., selection of a waste package)
- The strengthened role that nuclear utilities might play to help ensure that the overall system of nuclear spent fuel and high-level waste management moves ahead in a cost-effective way
- Management approaches *and* program procedures for cost allocation and control that effectively minimize costs for overhead and infrastructure in the R&D components of the program
- The usefulness of well-integrated, long-term plans for the interim storage and disposal of *all* spent fuel and high-level waste, especially in light of the successful implementation and noncontroversial nature of the interim storage programs in some of the countries
- The success other countries have had in integrating research and development on both natural and engineered barriers