# FOURTH REPORT TO

# THE U.S. CONGRESS

AND

# THE U.S. SECRETARY OF ENERGY

FROM THE

## NUCLEAR WASTE TECHNICAL REVIEW BOARD

December 1991

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

December 10, 1991

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 *Fourth Report* 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 aspects 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 evaluating site-characterization activities at Yucca Mountain, Nevada, as well as repository design features that could influence spent fuel packaging and transport activities.

As a result of its most recent scientific and technical review of the DOE's civilian radioactive waste disposal program, the Board would like to make several recommendations that it believes will help the DOE in its efforts to characterize the Yucca Mountain site as well as to develop an efficient civilian radioactive waste disposal program.

In his November 1989, *Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program*, the Secretary of Energy outlined the DOE's intent to redirect the program toward early determination of site suitability. The Board believes, however, that a recent DOE decision to postpone underground excavation because of funding restrictions will delay the exploration of key geologic features necessary for the early assessment of site suitability. The Board also is concerned about the potential effects that postponing underground excavation and evaluation could have on achieving the major milestones of the repository development program, especially on meeting key program target dates, assuming that the site is found to be suitable.

In this report, the Board has suggested that the DOE consider some enhancements to its design approach and schedule for the construction of the exploratory studies facility, the key component to underground site characterization. The Board believes that these enhancements would help in achieving an earlier determination of site suitability, which will require *both* subsurface and surface-based site characterization. In this way, given adequate funding and the necessary permits, the DOE should be able to progress toward the major milestones of the program in a timely and efficient manner.

We thank you for this opportunity to serve the nation and Congress. As our work progresses, we hope to continue to assist you in furthering the goal of safe, efficient, and timely disposal of civilian high-level radioactive waste.

Sincerely,

Don U. Deere, Chairman

Clarence R. Allen

John E. Cantlon

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# Executive Summary

By the year 2000, the United States will have a projected 40,000 metric tons of spent nuclear fuel stored and awaiting disposal at some 70 sites around the country. By 2035, after all existing nuclear plants have completed 40 years of operation, there will be approximately 85,000 metric tons. This amount of spent fuel will continue to grow with the possible relicensing of existing power plants or construction of new facilities. In the Nuclear Waste Policy Act of 1982, Congress assigned to the Department of Energy (DOE) the responsibility of designing and developing a system to manage the disposal of this spent fuel plus approximately 8,000 metric tons of defense high-level waste from reprocessing.

In a 1987 amendment to the Nuclear Waste Policy Act, Congress designated a site at Yucca Mountain, Nevada, for characterization. The DOE is evaluating the site's suitability for potential development of a repository for the permanent disposal of spent fuel. In that same legislation, Congress created the Nuclear Waste Technical Review Board (the Board) to advise it and the Secretary of Energy on site characterization and on issues relating to the handling and transport of spent fuel.

## Board Activities During this Reporting Period

The Board publishes two reports each year, in the fall and in the spring. This is the Board's fourth report. It reviews the activities undertaken by the Board and its panels from February 1, 1991, to July 31, 1991.

During this reporting period, members attended two full Board meetings along with eight Board-sponsored panel meetings. Members met with the DOE and its contractors, as well as with representatives from the Environmental Protection Agency, the Nuclear Regulatory Commission, Nevada state and county governments, the United States Geological Survey, and the utilities. Members of the public and representatives of environmental and other organizations also attended some of the technical meetings. Board members attended a variety of technical exchanges, conferences, symposia, and workshops. In June, the Board spent one week visiting with scientists and government officials involved with Canadian efforts to design a program to dispose of spent nuclear fuel in the plutonic rocks of the Canadian Shield. The Board gained some insight during the visit to Canada and addresses pertinent issues related to its trip in Chapter 3.

On March 21, 1991, Dr. Don U. Deere, Chairman of the Board, testified before the Senate Committee on Energy and Natural Resources. In response to questions, Dr. Deere stated that, in the Board's view, the DOE is prepared to begin a progression of site-characterization activities as soon as it gains access to the site. The Board stressed its agreement that the DOE should proceed with its assessment of the Yucca Mountain site. The Board believes that there appear to be no scientific or technical reasons to abandon the site at this time; however, until site-characterization studies, particularly subsurface exploration, (including boreholes, shafts, and tunnels) have progressed sufficiently, it is conceivable that disqualifying conditions may be identified as the site is being characterized.

# Board Comments on the Site-Characterization Program at Yucca Mountain, Nevada

At the July 1991 Board meeting, Dr. John Bartlett, director of the Office of Civilian Radioactive Waste Management (OCRWM), reviewed the OCRWM fiscal year 1992 budget. He indicated that OCRWM program priorities and budget allocations were based on the Secretary of Energy's goals for the program: to initiate the receipt of spent fuel for interim storage at a monitored retrievable storage facility by 1998 and to commence disposal of the spent fuel at a permanent repository by the year 2010. Dr. Bartlett also suggested that schedules and future funding levels could cause the OCRWM to modify its program priorities.

Later, as a result of funding cuts (approximately $30 million) for fiscal year 1992, the DOE decided to postpone the scheduled construction of the underground exploratory studies facility (ESF) and to focus on surface-based testing. Funding for research into the development of an engineered barrier system (EBS) also was reduced.

The Board expressed its concerns about delays to underground site characterization and continuing funding reductions to the EBS testing program. In September 1991, Dr. Deere met with the Secretary of Energy, The Honorable James D. Watkins, to express the Board's concerns about a DOE decision to postpone the initiation of underground excavation. The Board believes that a delay in subsurface excavation and testing will delay the early determination of site suitability and — if the site proves suitable — may delay the proposed schedule for license application (2001) and repository development (2010).

At a subsequent meeting of the Panel on Structural Geology & Geoengineering, also in September, Dr. Deere made several suggestions for enhancing the design approach and schedule for construction of the ESF, which is the key component of underground site characterization. The Board believes that subsurface excavation is essential to early determination of site suitability. However, current DOE plans call for a phased development of the ESF beginning with extensive surface-based drilling and surface facility construction *prior* to underground excavation. In addition, citing reductions in funding levels, the DOE has since decided to further postpone the start of portal construction (openings to the underground) by at least one more year — until fiscal year 1994. The Board believes that some enhancements to the design approach and an acceleration in the present schedule for construction of the ESF would offer a variety of advantages. One important advantage would be an earlier determination of site suitability, which will require *both* subsurface and surface-based characterization of the Yucca Mountain site. (See Chapter 2, Section 1.)

The Board has suggested some enhancements to the DOE's final ESF design to bring it more in line with the requirements of an exploratory facility. The Board recommends, for example, that smaller diameter tunnels be considered for the ramps and exploratory tunnels (16- to 20-ft tunnels should suffice). The smaller tunnels would offer a variety of other advantages over 25-ft tunnels currently proposed for the main access tunnels. Furthermore, the development schedule does not reflect the needed emphasis on visual examination and evaluation of key underground geologic features. The underground exposure of faults, such as the Ghost Dance Fault, is critical to understanding the host rock's hydrogeologic framework and to assessing site suitability. Although surface-based drilling is valuable to support site-suitability studies, it will not provide all the required information about the many important geologic structural features in the host rock.

Recent budget cuts have affected the DOE's priorities for its site-characterization program. The Board does not concur with the DOE decision to postpone ESF design and construction. Since Board members believe it will delay an early determination of site suitability, they see the decision as a departure from the Secretary's November 1989 commitment to redirect the program to early determination of site suitability. The Board also remains concerned about continuing reductions in the engineered barrier system program. These decisions may well affect the program's proposed timetable. If the DOE is to meet its present

schedule, substantial funding increases will be needed for ESF design and construction for fiscal year 1993 and the following years. Furthermore, if sufficient and predictable long-term funding is not provided both for ESF construction and for the necessary site-characterization activities, Congress and the Secretary should anticipate slippages in the repository development schedule.

The Board has recommended that, in light of recent budget constraints, the DOE develop contingency plans for fiscal year 1993 and beyond that would enable it to proceed with the program even during times of budgetary uncertainty. Under such plans, underground exploration should be given high priority, not postponed. In this way, given adequate funding and the necessary permits, the DOE should be able to progress toward the major milestones of the program in a timely and efficient manner.

# Recommendations

The recommendations made in the Board's reports are intended to aid the DOE in its efforts to improve the technical and scientific work being conducted in its high-level waste management program. As a result of activities during the past six months, the Board makes the following recommendations, which are organized according to the Board's panel activities.

## Structural Geology and Geoengineering

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

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

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

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

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

## Hydrogeology and Geochemistry

The Board recommends that the DOE carry out sensitivity studies to determine how limitations in instrument accuracy could affect estimates of water flux and performance in the unsaturated zone. This infor-

mation should be used to refine testing strategies, determine the need for new instrumentation, and provide a realistic estimate of the DOE's ability to adequately characterize the unsaturated zone.

## Engineered Barrier System

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

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

## Environment and Public Health

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

## Risk and Performance Analysis

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

# Introduction

By the year 2000, the United States will have a projected 40,000 metric tons of spent fuel from civilian nuclear power plants to dispose of. By 2035, after all existing nuclear plants have completed 40 years of operation, there will be approximately 85,000 metric tons of spent fuel. The U.S. Department of Energy (DOE) has been assigned by Congress the responsibility for developing and implementing a system to manage the disposal of this spent fuel, plus approximately 8,000 metric tons of defense high-level waste from reprocessing. The DOE must find a place for a waste repository and design and construct facilities to contain the waste for thousands of years. A nationwide transportation system to safely convey the waste to the facilities also must be designed and implemented. Managing the nation's high-level radioactive waste is a major undertaking *and* a task of major importance — now and for the future. The successful completion of this program will require an unprecedented effort on the part of the DOE, as well as other federal and state agencies.

There currently is worldwide scientific consensus that a deep geologic repository is the best option for disposing of high-level radioactive waste. In 1987, Congress designated Yucca Mountain, Nevada, as the site to be characterized for its potential suitability for repository development. Should the site prove suitable and meet licensing criteria, an underground repository would be constructed. Current plans call for a repository consisting of more that 100 miles of tunnels excavated approximately 1,100 feet below the surface of Yucca Mountain. The repository would cover about two square miles.

The development of a geologic repository is a complex task. First, there are the scientific and technical challenges of designing aboveground and underground facilities to handle radioactive waste. Second, we must be sure that the waste will be contained safely for generations to come without significant releases of radionuclides to the accessible environment. Third, a safe and efficient system must be designed to manage the waste as it moves from power plant to final disposal. Such a major undertaking can only succeed if it has the support of the nation.

Congress clearly recognizes the complex nature of the technical and scientific issues that must be resolved before the United States can achieve safe, long-term disposal of its high-level radioactive waste. In the same 1987 legislation that designated the site at Yucca Mountain, Congress created the Nuclear Waste Technical Review Board (the Board) because Congress recognized the need to establish an independent source of expert advice on the scientific and technical aspects of the DOE's work. Since it is the only independent agency directly charged to provide expert advice to the Congress and the Secretary of Energy, the Board has a unique role in this national effort.

The Board currently has eight members, who work on a part-time basis. Primarily through meetings with representatives of the DOE, its contractors, the national laboratories, the state of Nevada, the utilities, and other agencies and organizations concerned with radioactive waste disposal, the Board reviews the DOE's work in the technical and scientific areas pertinent to high-level waste management. The Board submits full reports on its findings, conclusions, and recommendations twice a year. The Board's *First Report* was released in March 1990.

One of the Board's goals has been to promote better communication among the technical and scientific people involved in the waste management program. Board members also believe that interaction with experts involved in radioactive waste management programs in other countries is crucial. Although other programs are researching disposal in different geologic media, important research is underway from which the U.S. program can gain valuable insights. Therefore the Board has initiated contact and remained in touch with experts in programs in Canada, France, Germany, Sweden, and Switzerland.

To help keep the Board apprised of the public arena in which nuclear waste management technology is being developed, the Board solicits on a regular basis the views of the public and environmental organizations on a variety of issues. Members and staff attend relevant technical conferences, symposia, and workshops.

This fourth report summarizes the Board's activities from February 1, 1991, through July 31, 1991. Extensive background information on the dates and nature of the Board's meetings, meeting participants, the Board's panels and panel members, and DOE responses to previous recommendations have been included in the Appendices of this report.

All of the Board's reports are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

# Chapter 1
# Background

## A. Board Activities this Reporting Period

The Nuclear Waste Technical Review Board (the Board) addresses issues and makes recommendations in this report that have evolved as a result of activities undertaken by the Board and its panels primarily from February 1, 1991, to July 31, 1991. Some non-Board activities attended by Board members during this time also are reviewed. (See Part B, below.)

From February to July 1991, Board members attended 10 Board-sponsored meetings. A chronological list of the Board's activities (beginning January 1, 1990, and including those scheduled for the future) can be found in Appendix B. A list of the people who made presentations at Board- and panel-sponsored meetings has been included in Appendix C. These meetings are reviewed and the Board's recommendations are presented and discussed in Chapter 2.

In June, the Board spent a week visiting facilities and speaking with experts in the Canadian high-level waste disposal program. Insights gained during this trip can be found in Chapter 3, and background information on the Canadian program has been included in Appendix D.

The Department of Energy (DOE) has made a good-faith effort to respond to the recommendations made in Board reports. Appendix E of this report contains the DOE's responses to recommendations made in the Board's *Third Report*. Inclusion of the DOE's responses, however, does not necessarily infer Board concurrence.

## B. Other Issues

In addition to Board activities during this reporting period, Board members participated in other activities that deserve mention here. At its July Board meeting, Dr. John W. Bartlett, director of the DOE's Office of Civilian Radioactive Waste Management, commented extensively on the DOE's priorities and budget allocations for fiscal years 1992 and 1993. Because of their timeliness, this meeting and a later meeting of the Panel on Structural Geology & Geoengineering in September on the exploratory studies facility (ESF) design and construction schedule have been included in this report.

At the Board's request, the DOE briefed members on the use of analogues to support performance assessment modeling of the potential repository at Yucca Mountain.

Finally, some progress has been made recently in the conflict between the state of Nevada and the DOE on permits that are required by the state before the DOE can begin full-scale testing at the site at Yucca Mountain. Comments on these issues as well as a summary of pertinent information gained during the Board's August trip to the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, follow.

*Dr. Bartlett's Comments to the Board at its July Board Meeting*

On July 16, 1991, Dr. John W. Bartlett, director of the Office of Civilian Radioactive Waste Management (OCRWM), made a presentation to the Board on OCRWM program priorities and budget allocations for the coming year. Dr. Bartlett reviewed the status

of current program activities and updated the Board on the recently initiated surface-based testing activities at the Yucca Mountain site. Surface-disturbing activities have commenced at the site for the first time since 1986 as a result of the issuance of air quality and water injection permits by the state of Nevada.

Current OCRWM program priorities and budget allocations are based on the Secretary of Energy's goals for the program: to initiate the receipt of spent fuel for interim storage at a monitored retrievable storage (MRS) facility by 1998 and to commence disposal of the spent fuel at a permanent repository by the year 2010.

*Predisposal* activities are based on the goal of accepting spent fuel for storage by 1998 and the assumption that a nuclear waste negotiator will find a site for the MRS by the end of 1992. Although the negotiator will have the lead responsibility for siting an MRS, the OCRWM will provide the negotiator with technical information. The OCRWM's goal is to have a transportation system and all necessary infrastructure, protocols, and technologies in place to begin transporting spent fuel to an MRS by 1998. To meet this goal, the OCRWM will adopt a two-phase program, using existing technology initially, and beginning a longer term research and development program for advanced cask design.

Activities related to the *disposal* of spent fuel will emphasize data acquisition at the Yucca Mountain site for potential repository development. The highest priority in regard to disposal activities, according to Dr. Bartlett, is the acquisition, as soon as possible, of the data necessary for evaluating site suitability. Data obtained from site-characterization activities will be used later as a basis for repository and engineered barrier system (EBS) design.

Dr. Bartlett made note of several factors that could cause the OCRWM to modify its program priorities, schedules, and expenditures in the future. For example, the relative contributions of data obtained from surface versus underground activities to site-suitability evaluation, and the cost-benefit of sustaining the present ESF schedule will be evaluated. Dr. Bartlett said that because underground testing is relatively expensive, some consideration might be given to delaying the start of the portals (surface openings) for the exploratory studies facility (ESF) currently scheduled for November 1992. (The start of portals has since been postponed until fiscal year 1994.)

Dr. Bartlett also indicated that even though the OCRWM had agreed to provide additional funding for the development of an EBS, as recommended by the Board, current plans call for taking maximum advantage of spinoff information from siting activities, which, according to Dr. Bartlett, could reduce the funding resources available to develop and implement an EBS program. (Funding for this program also has been cut.)

During the question and answer period following Dr. Bartlett's presentation, Dr. Don U. Deere, Chairman of Board, commented that the Board would not favor a delay in the start of the ESF and urged that underground testing be undertaken as soon as possible. The Board also is concerned about continuing reductions in funding to the EBS program. (See a detailed discussion of these issues in Chapter 2, Sections 1 and 3.)

*Meeting on Natural Analogues*

In its *Second Report*, the Board recommended that the DOE consider investigating more extensively the use of analogues to support performance assessment for a potential repository at the Yucca Mountain site. On April 16 and 17, 1991, the Board held a meeting at which the DOE and its contractors were asked to present summaries of DOE past and present activities relating to the use of analogues to support performance assessment. The purpose of the meeting was to permit the Board to (1) broaden its appreciation for the potential use of analogues to support performance assessment, and (2) review the uses being made by the DOE of analogues as part of its site-characterization and performance assessment activities relating to Yucca Mountain. In addition to the presentations by the DOE, the Board heard presentations from individuals and groups who have particular qualifications or experience with the investigation of analogues. Presentations were made by individuals from academia, national laboratories, and

other federal entities, such as the Nuclear Regulatory Commission (NRC) and the U.S. Geological Survey. Many presenters discussed the use of analogues in repository development programs in other countries. Following the presentations, the Board and the presenters held a general round-table discussion and received comments from the audience.

The Board found that there was considerable consensus among the presenters that analogues can provide important and possibly unique insights on processes that might operate at a potential repository. Analogues should not be viewed narrowly as a means of obtaining parameter values or validating numerical models, but more broadly as a means to improve our understanding of hydrogeologic and geochemical processes that operate over long time periods and extended spatial scales. Performance assessments must depend on calculations made with models of these processes, but the validation of these models through direct observation at the proposed repository site is precluded by the time periods and spatial scales involved. Situations in which materials that may be used for engineered barriers, or radionuclides, have been subjected to environmental forces in similar hydrogeologic settings provide opportunities for indirect validation of these performance assessment models. In addition to providing a check on the models used in performance assessment, analogue studies may provide illustrations meaningful to the lay public of the behavior of materials and processes over time periods of thousands to millions of years.

Many of the presenters and some Board members expressed optimism for the potential of analogue studies to increase current understanding of processes for the transport and alteration of materials over long time periods. However, some members of the Board expressed pessimism that analogue studies would be helpful in understanding complex ground-water transport processes and in validating the numerical models for such processes.

Many examples of analogue studies relevant to the proposed repository at Yucca Mountain were presented to the Board. In one example, mineralization observed in Yucca Mountain drill holes permits the development of hypotheses on the geothermal environment that altered these minerals more than 10 million years ago. These hypotheses have implications for the extent to which the elevated temperatures projected for the repository may alter the physical and geochemical properties of the tuff strata at Yucca Mountain. These properties are critical for repository performance.

In another example, studies of mineral alteration and material degradation in active hydrothermal zones in New Zealand could provide insights on the performance of both engineered and geologic barriers at Yucca Mountain. In a third example, studies of the dissolution of basaltic glass have shown the importance of proximity to small fractures in determining which of several dissolution processes occur; such studies may be critical for understanding the dissolution processes that occur in the borosilicate glass used as a matrix for isolating defense wastes. Examples were discussed of the many cases of native metals preserved for millions of years in the geologic environment. These are valuable analogues for the metallic containers, which would be part of an engineered barrier system.

Examples of anthropogenic analogues also were presented to the Board. Instances at weapons-related sites, in which there have been significant migrations of plutonium, provide opportunities to test models and data relating to the transport of this important actinide. Investigations at the Nevada Test Site following a weapons test indicated migration of a fission product (ruthenium) not expected to migrate in ground water. More careful investigation of the models and geochemical data indicated a mechanism by which ruthenium could migrate in ground water, and that such a mechanism might apply to other fission products as well. This experience indicates how iteration between modeling and data collection in the field can result in improved predictive capability.

The Board found that the DOE has a number of analogue-related studies either underway or planned, and that the DOE has provided support to international analogue studies. However, important opportunities to obtain valuable information through analogue studies are not now being pursued by the DOE — or are in jeopardy due to budget constraints. As with the other site-characterization activities being undertaken by the DOE for Yucca Mountain, the DOE's support for analogue studies should be based

on priorities for which items of information are critical for determining site suitability and licensability. Such information needs should emerge from iteration of the DOE performance assessment for Yucca Mountain. Although the DOE has not yet completed its initial overall performance assessment for Yucca Mountain, the DOE's task force efforts of the past year have provided significant insights on information priorities that were not obvious at the time the Site Characterization Plan was produced. Analogue studies and performance assessment should be pursued with effective communication and close coordination among the scientific investigators carrying out the analogue studies and the performance and modeling teams.

In this context, the Board finds it appropriate to reiterate its recommendation from the *Second Report*, that the DOE consider investigating more extensively the use of analogues to support performance assessment for a potential repository at Yucca Mountain, not so much for obtaining parameter values or evaluating numerical models, but to provide a better understanding of long-term geologic processes.

*Status of Litigation Between the Department of Energy and the State of Nevada*

On August 16, 1990, three separate actions were argued before the U.S. Court of Appeals for the Ninth Circuit. The first action was a consolidation of two cases brought by the state of Nevada. In the *State of Nevada v. U.S. Department of Energy*, 9th Cir. No. 90-70004, Nevada contended that as a result of its submission to Congress of state legislative resolutions withholding consent to repository siting, the state had "disapproved" the Yucca Mountain site pursuant to the "notice of disapproval" provisions of the Nuclear Waste Policy Act (NWPA), as amended. The state further had enacted legislation banning the disposal of high-level nuclear waste in Nevada. In addition, the state challenged, on various constitutional grounds, the direction by Congress in the Nuclear Waste Policy Amendments Act of 1987 (NWPAA) that the Yucca Mountain site be studied. In the *State of Nevada v. Watkins*, 9th Cir. No. 86-7308, the state contended that the DOE had not obtained the requisite jurisdiction over the Yucca Mountain site to begin characterization. The second action (*State of Nevada v. Burford*, 9th Cir. No. 89-15272) involved Nevada's appeal of a U.S. District Court's dismissal on jurisdictional grounds of the state's challenge to the Bureau of Land Management's grant of a right-of-way on public lands to the DOE for the purpose of conducting site-characterization activities. The third action involved two separate cases, *County of Esmeralda, Nevada, v. U.S. Department of Energy*, 9th Cir. No. 89-70142, and *County of Inyo, California, v. U.S. Department of Energy*, 9th Cir. No. 89-70162 where the counties sought review of the Secretary of Energy's denials of their requests for "affected" status under subsection 2(31) of the NWPA.

On September 19, 1990, the Ninth Circuit Court of Appeals ruled that Nevada's purported disapproval of the Yucca Mountain site was premature under the terms of the NWPA and was thus without effect. The court further ruled that the NWPAA preempted Nevada's efforts to legislate against the site, and that Congress had acted within its authority under the "Property Clause" of the U.S. Constitution. Nevada petitioned the U.S. Supreme Court to review the Ninth Circuit's decision. On March 4, 1991, Nevada's petition was denied. Nevada subsequently requested reconsideration of its petition by the Supreme Court. That request was denied on June 17, 1991.

On November 19, 1990, the Ninth Circuit upheld the district court's dismissal of Nevada's lawsuit in the right-of-way action, finding that Nevada had failed to show how the state was injured by the Bureau of Land Management action in granting a right-of-way to the DOE. Nevada also petitioned the Supreme Court to review the Ninth Circuit's decision in this case. That petition was denied on May 20, 1991.

On February 20, 1991, the Ninth Circuit vacated the earlier denials of affected status by the Secretary of Energy in the "affected county" cases. Following this ruling, the Secretary granted affected status to Esmeralda and Inyo Counties. The Secretary also granted affected status to two other Nevada counties (Eureka and White Pine), and notified three other Nevada counties (Churchill, Lander, and Mineral) that they might wish to submit a request for consideration for an affected-status designation.

On March 14, 1991, two other cases involving challenges by the state of Nevada and others to DOE repository program actions were argued before the Ninth Circuit. The first (*State of Nevada v. Watkins*, 9th Cir. No. 85-7308) concerned challenges to the sufficiency of the DOE siting guidelines (10 C.F.R. Part 960). The second (*State of Nevada v. Watkins*, 9th Cir. No. 86-7309) involved Nevada's challenges to the sufficiency of the May 1986 Yucca Mountain Environmental Assessment. On July 17, 1991, the Ninth Circuit dismissed the guidelines lawsuit, ruling that the plain language of the NWPA precluded judicial review of the promulgation of the guidelines. On August 28, 1991, the Ninth circuit dismissed the environmental assessment lawsuit, ruling that the passage of the NWPAA, which directed the DOE to characterize only Yucca Mountain, had rendered the case moot. The state of Nevada was given 90 days from the date of decision in each of these cases to petition the Supreme Court to review the Ninth Circuit. No other DOE repository program-related cases are pending before the Ninth Circuit.

In January 1990, the DOE brought suit in the U.S. District Court against the state of Nevada seeking final action by the state on three permit applications: air quality (AQ), underground injection control (UIC), and water appropriation. The DOE had filed applications for these permits with various state agencies in connection with the site characterization of Yucca Mountain. The permits had been returned by the state agencies without action on the grounds that the site had been "disapproved" by the state. Subsequent to the September 1990 decision by the Ninth Circuit in the "notice of disapproval" case and the March 1991 declination by the Supreme Court to review that decision on appeal, the state was ordered by the district court to take final action on the AQ and UIC permit applications by July 17, 1991, and to hold a hearing on the status of the water appropriation application. The state issued the AQ permit on June 12, 1991, and the UIC permit on July 17, 1991. Furthermore, the Nevada state engineer scheduled a hearing on the DOE water appropriation application for September 24, 1991. At a July 17, 1991, status hearing in federal district court, that part of the case that pertained to the two permits that had been issued (AQ and UIC) was dismissed. The court has retained jurisdiction over the water appropriation permit situation. As this report goes to print, the application for the water appropriation permit is still being reviewed by the state.

*The Board's Trip to the Waste Isolation Pilot Plant*

On August 12 to 14, 1991, Board members visited the DOE Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. The WIPP is a research and development facility consisting of surface handling and research facilities, and 11 miles of tunnels that have been excavated in salt a half mile below the Earth's surface. If the site is approved, the DOE plans to use it for disposal of transuranic waste (clothing, equipment, machine parts, and some liquid waste contaminated during reprocessing of high-level radioactive waste at U.S. defense facilities).*

Although the DOE's research and repository development at the WIPP are not within the Board's charge, Board members wished to be briefed on the history, progress, and current status of the program and on its problems, as well as on the research currently underway. There are many similarities between the proposed disposal program at the WIPP and that being proposed for the potential site at Yucca Mountain, Nevada; there are also lessons to be learned from the experience gained at the WIPP site. For example, both this project and the disposal project proposed for Yucca Mountain will be required to demonstrate compliance with the Environmental Protection Agency standards in 40 CFR 191.

In addition to the visit to the site, Board members were briefed on the WIPP performance assessment studies, intended to demonstrate compliance with the EPA standards. Presentations on performance assessment were made by representatives of the Sandia National Laboratories and their consultants, who are participating in the performance assessment effort. Members of the team were very willing to relate

* Transuranic wastes are non-high-level wastes that contain significant amounts of long-lived, alpha-emitting radionuclides. These wastes require long-term isolation from the biosphere.

both the problems and successes associated with the WIPP performance assessment, along with insights they felt could be of use with respect to performance assessment at Yucca Mountain. Some important points made by the performance assessment team that have particular relevance to the Yucca Mountain program include:

- Performance assessment should start early and be iterative. Its lessons should be integrated into the program on an ongoing basis.

- Successful performance assessment can be best conducted in an efficient and integrated manner, using a centralized, coordinated group, ideally working under one roof.

- Because there are often not enough data to carry out all aspects of a performance assessment, expert judgment, through a structured elicitation, can be used to translate existing data into input for the performance assessment. The use of experts from outside the program was found to be particularly beneficial.

One other important point made by experts at the WIPP is that outside review has been very useful to the project. Many outside groups oversee the WIPP, and researchers believe they benefit especially from the constant, sometimes very critical, review of a peer panel that is made up of individuals outside of the program.

# Chapter 2
# Areas of Inquiry, Recommendations, and Future Board Activities

This chapter is organized primarily into sections according to the major interest areas of the Nuclear Waste Technical Review Board's (the Board) panels. Where the Board's investigation and research have progressed sufficiently since the previous report, recommendations are included. Some of the issues raised here, however, have not yet been examined thoroughly enough by the Board to warrant recommendations at this time. The Board intends to explore such issues further. The Board's planned future activities are summarized at the end of this chapter. (See Appendix B for a list of scheduled meetings.)

Briefly, the major areas of interest covered by the Board's panels can be broken down in the following way:

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

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

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

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

The *engineered barrier system* refers to the constructed, or engineered, components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. The Board believes it may be possible to improve confidence in the reliability of the repository to isolate waste from the accessible environment for the long term by relying on geologic barriers *in combination with* a more robust engineered barrier system.

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

various handling sites, storing it, and finally emplacing it in a repository.

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

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

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

*Quality assurance* refers to the oversight strategy that is built into a system to ensure the system's integrity. At this point in the repository program, quality assurance ensures the integrity of the technical and scientific data required for site selection and licensing. It also will help ensure the integrity of the design, construction, operation, and closure of the repository and its transportation and support systems. Quality control is composed of the auditable-specific requirements that must be met to ensure quality in the system.

Recommendations made in this chapter, while addressing activities of a variety of state and federal agencies, are intended to inform Congress and to aid the DOE in its efforts to improve the technical work being conducted as part of site characterization at the Yucca Mountain site, and to identify areas for possible improvement in the DOE's transportation program. The Board also identifies areas of future inquiry that may eventually affect the current legislative and regulatory framework.

# Section 1 — Structural Geology and Geoengineering

## Geoengineering

Before the Department of Energy (DOE) can develop a geologic repository for the permanent disposal of civilian spent fuel, it must first determine if a potential site is suitable and if future repository performance at that site will meet regulatory requirements. As a result, the DOE must determine if features are present at the Yucca Mountain site that could adversely affect repository performance over thousands of years. The DOE also must collect additional data on the site characteristics that will be necessary for repository design and eventual licensing.

During the past months, the DOE has completed extensive conceptual and preliminary design work on the exploratory studies facility (ESF), which is the key component of future underground site-characterization activities. However, recent budget cuts have resulted in a DOE decision to postpone the initiation of underground ramps and tunnels at the ESF until fiscal year 1994. Current plans call for a continuation of the surface-based testing program.

The Board, through its Panel on Structural Geology & Geoengineering (SG&G Panel), has been following closely the DOE's task force studies and the resulting revisions to the preliminary design of the ESF, as well as DOE decisions to delay the ESF design and development. On March 6 and 7, 1991, in Denver, Colorado, the DOE briefed the panel on the final results of three task force studies (Calico Hills Risk-Benefit Analysis; ESF Alternatives Study; and Test Prioritization Task). Also, an interim presentation was made on the Early Site Suitability Evaluation effort.

On March 26, 1991, in Dallas, Texas, the SG&G Panel held a joint meeting with the Board's Panel on Quality Assurance at which the DOE briefed the panels on quality assurance procedures as they apply to the engineering design process with specific emphasis on the conceptual and preliminary design phases of the ESF.

On June 25 to 27, 1991, in Denver, Colorado, a joint meeting of the SG&G Panel and the Board's Panel on Hydrogeology & Geochemistry was held at which the DOE briefed the panels on the proposed surface and subsurface testing of hydrogeologic characteristics and on rock mechanics.

On July 15, 1991, in Arlington, Virginia, the panel was briefed on the DOE's progress in revising the ESF preliminary design to incorporate the favorable features identified in the ESF alternatives analysis and the systems requirements document, a necessary precursor to the final design phase of the ESF. At the full Board meeting on July 16 and 17, 1991, Dr. Bartlett, director of the Office of Civilian Radioactive Waste Management (OCRWM), reviewed the fiscal year 1992 budget.

Finally, on September 18 and 19, 1991, in Las Vegas, Nevada, the panel was briefed on the Yucca Mountain Project Office's revised ESF preliminary design, the design approach, and the recommended schedule for construction. Although this last meeting did not fall within the Board's February to July 1991 reporting period, the Board decided that because of the meeting's importance, the information presented there should be included in this report.

The following sections summarize the issues the SG&G Panel has reviewed during the past months and presents the Board's thoughts on and some suggested changes to the DOE's site-characterization program. Of primary concern to the Board at this time are the ESF Title II (final) design approach and the construction schedule. However, the Test Prioritization Task Study and the proposed rock mechanics testing program also are discussed.

### A. The Approach and Schedule for the Construction of the ESF

The ESF design approach and schedule for construction have progressed essentially as outlined in the following paragraphs.

*Revised Title I Design of the ESF*

The ESF Title I (preliminary) design was revised during the spring and summer of 1991. The design incorporated both the favorable features of the highest ranked options of the recently completed ESF Alternatives Study and the recommendations of the Calico Hills Risk-Benefit Analysis to excavate exploratory tunnels into the Calico Hills unit. The revised ESF concept calls for mechanically excavating two ramps (i.e., tunnel declines) that would descend from the surface in Midway Valley, just to the east of Yucca Mountain, both to the proposed repository horizon and to a depth within the underlying Calico Hills unit. Exploratory tunnels would then be excavated across the block to intersect critical geologic features. This concept meets the Board's earlier recommendations for extensive horizontal exploration underground.

The revised Title I Design Summary Report was finished and approved in September 1991 by Dr. Bartlett. The report provides a comprehensive review and description of the preliminary design of the ESF, its interface with the proposed repository and surface facility, the basis for the design and design requirements, estimates of the construction costs and schedules, and the general strategies for conducting final design, construction, and operation of the ESF.

With the completion of the preliminary design phase, the DOE is now entering into the final design phase (ESF Title II), which will consist of refining the Title I design. As a result of its technical review, the Board would like to suggest that the DOE consider several changes to enhance the final design.

*Considerations for Enhancing the ESF Title II (Final) Design*

In its current form, the DOE's approach appears to emphasize equal construction and funding increments more than the early evaluation of key geologic features for assessing site suitability. The Board believes that several important changes to the ESF design approach and schedule for ESF construction would enhance the Title II (final) design and help the DOE redirect its program toward early determination of site suitability, which will require *both* subsurface and surface-based site characterization.

**Tunnel Diameter:** The Board recommends that smaller diameters be considered for the ramps and exploratory tunnels. Smaller tunnels would be more in line with the requirements of an exploratory facility than the 25-ft-diameter tunnels currently proposed for the main access tunnels. Sixteen- to 20-ft tunnels should suffice at this stage. Smaller diameters offer several advantages. They could reduce excavation volumes by up to 50 percent and lower ventilation requirements. Tunnel walls would be more stable thus decreasing structural support requirements. The extent of surface facilities and power requirements also could be reduced. The smaller diameter tunnels also call for the use of smaller tunnel-boring machines, which are not only less expensive but also more available in the marketplace. Finally, the increase in tunneling advance rates resulting from smaller tunnels would provide additional cost and schedule savings. The DOE's projected TBM advance rates of 50 ft per day are conservative. If more realistic rates are assumed, the number of tunnel-boring machines required could probably be reduced.

**Early Exploration of Ghost Dance Fault:** Of the various faults to be explored, the Ghost Dance Fault is considered to be of highest priority because it represents what most likely is a permeable zone cutting across the heart of the Yucca Mountain geologic block. This fault zone should be viewed and studied not only in the Topopah Spring welded tuff at repository level and in the underlying Calico Hills unit, as is currently planned, but also in one of the bedded or zeolitic tuff units that occur well above the repository level. A good target area for exploring the Ghost Dance Fault in this upper area would be where the fault crosses the contact of a welded tuff bed (considered normally to be fractured and permeable) with the underlying zeolitic or bedded unwelded tuff (believed to be less fractured and less permeable). Such exposures are critical to understanding the hydrogeologic framework of Yucca Mountain. Access could be gained through a ramp or by raise-boring off of one of the entrance ramps, or possibly through a short tunnel from the surface.

Although valuable to support site-suitability studies, surface-based drilling will not reveal all the important hydrogeologic characteristics of many important structural geologic features. Surface-based drilling

also will not reveal how faults affect the vadose water movement in the unsaturated zone (i.e., whether the faults act as barriers to flow along the contacts of the dipping beds, or as drains).

*Funding Cuts and Their Effects on ESF Design and Construction*

Under original funding projections for fiscal year 1992, the Title II (final) design was scheduled to begin in October 1991. Construction of the ramp portals (surface openings) to the underground portion of the ESF would begin in October 1992. As a result of recent funding cuts (approximately $30 million) for fiscal year 1992, however, the DOE has decided to delay the scheduled construction of the ESF. This means a delay in the start of portal construction by approximately one more year — probably not until fiscal year 1994.

The DOE's decision to delay ESF development in favor of surface-based testing is inconsistent with the Board's view that visual examination and evaluation of underground geologic features, such as the Ghost Dance Fault, should be early goals of site characterization. The decision also appears to be inconsistent with the Secretary of Energy's 1989 report to Congress, in which he expressed the DOE belief that an "iterative, scientific approach using both surface-based and underground tests . . . is the efficient, cost-effective, and timely way to conduct the scientific investigations" (DOE 1989). Delaying the construction of the ESF will delay access to the underground, which the Board believes is crucial to a comprehensive and more accurate evaluation of the suitability of Yucca Mountain for potential repository development.

The Board also is concerned about the potential impact of recent funding cuts on the overall repository program. If the DOE is to meet its present schedule (2001 for license application to the Nuclear Regulatory Commission; 2010 for operation of a repository, assuming that the site is found suitable), substantial funding increases will be needed for ESF design and construction for fiscal year 1993 and the following years. Furthermore, if sufficient and predictable long-term funding is not provided for both ESF construction and necessary site-characterization activities, Congress and the Secretary of Energy should anticipate slippages in the repository development schedule.

*Contingency Planning for Underground Work*

In light of budgetary uncertainty, the Board believes that the DOE should make contingency plans to enable significant progress on *both* subsurface and surface-based site characterization during fiscal year 1993 and beyond. Under such planning, underground excavation should be given high priority, not postponed. For example, the south portal could be designed and constructed early so that excavation of the south ramp by a TBM ( say of 20-ft diameter) could begin in late fiscal year 1993, or early fiscal year 1994. The ramp could turn into the north-south tunnel alignment at the candidate repository level in the form of a "J." Or it could extend completely through the repository level, continuing on up the ramp to the north portal in the form of a "U." Later, a second TBM could continue down into the Calico Hills unit from the repository level. Such an approach would provide considerable flexibility, thereby allowing adjustments to funding changes.

## B. The Test Prioritization Task (TPT) Study

The TPT study, covering both surface-based and underground site-suitability testing, had two primary objectives: to develop an explicit decision analysis method to facilitate prioritization of testing in the initial phase of site investigation, and to reprioritize — or terminate — testing at any time as new information justifies such action. This would ensure early investigation of significant, potentially adverse conditions and provide a method for deciding when to stop testing.

The TPT study consisted of a spreadsheet exercise based on available information, expert technical assessments, and management-level judgments on test values and impacts. More than 100 potential adverse or disqualifying conditions about the site were considered, derived primarily from 10 CFR 960 and 10 CFR 60. The conditions were then screened and consolidated into 32 "potential concerns," which were evaluated quantitatively and ranked in order of im-

portance. "Importance" was defined as "the product of expected consequences for waste isolation if the potential concern is present at the site with the probability that the potential concern is present." Importance can be interpreted as the expected value, assuming that perfect information is available about a potential concern's presence or absence, thus providing an upper bound on the value of a testing activity.

The TPT study reached several major conclusions. Three potential concerns make a greater contribution to radionuclide releases *than all others* by a wide margin: "gas flow" (i.e., predominantly $^{14}C$), "complex geology-gaseous," and "complex geology-aqueous." Among these three potential concerns, the highest expected contribution to curies released over 10,000 years is only *6 percent* of the EPA limit. The ratio of the most important to the least important concern is 10 trillion to 1, indicating that many concerns and associated testing programs are of little consequence to the issue of site suitability.

The tests of highest priority are those for gas flow above the repository and, possibly, tests that address complex geology related to aqueous-phase radionuclide releases, depending on management-level value judgments, which are required for weighing costs and benefits and for determining the potential for false alarms.

The Board agrees with the TPT study conclusions that a broader sampling should be made of management-level value judgments and possibly of expert technical assessments to provide a clear indication of need and priorities for early tests at Yucca Mountain. An additional phase to this study should be considered, based on the first-phase results plus simplified model calculations of performance assessment incorporating value judgments and assessments made by the larger sampling of management and technical experts. Consideration also should be given to including preclosure and other related issues to provide assessments and numerical results to support site-suitability evaluations.

The Board believes it unfortunate that the TPT study was not structured to include activities aimed at early detection of potentially unsuitable site conditions, in particular those associated with major underground geologic features.

## C. The Proposed Rock Mechanics Testing Program

The objectives of the rock mechanics testing program are to characterize the thermal and mechanical properties of the rock units, thus providing a basis for the design and construction of the repository and an understanding of the long-term thermal behavior and stability of the underground openings and waste package emplacement holes. The thermomechanical behavior of the rock also will have some effect on fracturing and permeability in the vicinity of the waste package emplacement holes.

This program appears to have a reasonable scope and appears to be compatible with the revised ESF layout. For example, it does not interfere with tunnel-boring machine progress, and it provides for the evaluation of thermomechanical characteristics of mechanically excavated openings of the type that may be used for the repository.

Much of the needed data on rock characteristics will come from careful observations of fracturing and deformation in the excavated openings that can be obtained through well-coordinated mapping and construction monitoring activities. Rather than concentrating tests only in one portion of the ESF, testing of rock characteristics should be done at several locations so as to sample a broad range of rock conditions.

To investigate many of the thermomechanical effects properly, sophisticated instrumentation using new technology will be required. This instrumentation should be tested in an underground environment over the expected range of temperatures prior to its full-scale use. The results of the G-tunnel tests of thermomechanical behavior of rock and fluid and gas flow conducted at Rainier Mesa in the 1980s were informative, but not definitive. The G-tunnel tests provided an initial shake-down of procedures and equipment, and provided experimenters with some experience in working underground, but the tests were terminated before the prototype testing

was advanced enough to be able to develop and evaluate revised testing strategies.

## D. Conclusions

*The Approach and Schedule for Constructing the ESF*

1. Because of the recent $30 million budget cut, the DOE has decided to postpone underground excavation. This will result in delays in characterizing the site and — should the site prove suitable — may delay the current schedule to license and operate a repository. Without substantial funding increases for ESF design and construction beginning in fiscal year 1993, Congress and the Secretary of Energy should anticipate a slippage of the key dates.

2. The Board believes that the current ESF design approach does not consider the many advantages to be gained by excavating smaller diameter tunnels. Advantages include reduced excavation volumes, increased wall stability, reduced surface-facility and power requirements, and schedule and cost savings. In addition, a smaller scale ESF would be more in line with the requirements of an exploratory facility.

3. In its present form, the DOE's approach appears to emphasize equal construction and funding increments more than early evaluation of site suitability. Underground access across key geologic features such as the Ghost Dance Fault is critical to understanding the hydrogeologic framework of Yucca Mountain. Surface-based drilling, although valuable to support site-suitability studies, will not reveal all the important hydrogeologic characteristics of the many important structural geologic features.

4. In spite of budgetary uncertainty, the DOE has not presented any contingency plans to enable it to proceed with subsurface and surface-based site characterization. Such plans should be developed. They should incorporate the early underground evaluation of key geologic features crucial to determining early site suitability. If funding expectations are not met, underground visual access to key geologic features should be made a priority, not postponed.

*The TPT and Proposed Rock Mechanic Studies*

1. The Board agrees with the TPT study recommendation that an additional phase to this study should be considered. It should be based on the first-phase results plus simplified model calculations of performance assessment that incorporate a larger sampling of management-level value judgments and possibly technical assessments. This will provide a clearer indication of the need for, and priorities of, tests to be conducted at Yucca Mountain. Consideration also should be given to expanding the scope of the TPT analysis to include preclosure or other related issues so that assessments and numerical results to support the site-suitability evaluations can be provided.

2. Sophisticated instrumentation using new technology will be required to investigate properly many of the thermomechanical effects. It is recommended that this instrumentation be tested in an underground environment over the expected range of temperatures, prior to its full-scale use.

## E. Recommendations

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

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

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

## Structural Geology (Tectonic Features and Processes)

In its first three reports, the Board discussed several topics related to tectonic features and processes. These topics primarily were concerned with earthquake hazard and included issues such as seismicity and faulting, seismic vulnerabilities and consequences, site-suitability considerations, and geologic licensing standards and criteria.

Also identified as an important issue and discussed in some detail in the *First Report* was the subject of volcanism. Subsequent reports delayed further discussion of volcanism until additional data and analysis become available. During the past six months, the Board has devoted most of its effort in the area of tectonic features and processes to the subject of volcanism.

Following is an update of the Board's views on volcanism. It is based primarily on a Board-sponsored meeting that included input from a number of groups including the DOE, the U.S. Nuclear Regulatory Commission (NRC), the U.S. Geological Survey (USGS), the Electric Power Research Institute, and the state of Nevada.

### A. General Progress

The Board is encouraged that significant progress has been made toward a resolution of the issues related to volcanic hazards at Yucca Mountain. Large differences of opinion between the DOE, the NRC, the state of Nevada, and some geologists at the USGS still exist, however. If momentum and funding continue, research now underway may narrow these differences to the point where a potential hazard can be reasonably assessed and perhaps generally agreed on. A probabilistic approach to the estimation of volcanic hazards is generally accepted, although a number of input parameters are critical and still subject to debate. The Board encourages the use of a structured probabilistic approach that not only can serve to provide useful estimates of volcanic hazard at Yucca Mountain, but can also help discriminate between those differences in input assumptions that have a significant impact upon volcanic hazard and those that do not.

One area where work has only just begun is the evaluation of the vulnerability of the proposed repository to different manifestations of volcanism and the resultant consequences with respect to public health and safety. The Board urges the DOE to place added emphasis on the evaluation of volcanic vulnerabilities and consequences. As with other natural hazards, the *occurrence* of natural phenomena alone should not be the only consideration. Other factors should be considered, such as the likelihood and magnitude of adverse consequences from these natural hazards and options for their avoidance through engineering design.

### B. Mode of Volcanism and the Age of the Most Recent Volcanic Activity

Major differences of opinion remain concerning (1) the age of the youngest volcanic activity at the Lathrop Wells cone, and (2) whether the activity has been polycyclic (multiple eruptions over tens of thousands of years at the same site but from separate sources at depth) or monogenetic (a single episode of eruptions from the same source closely spaced in time). Although the advanced field and laboratory techniques being used are very new and differences of interpretation by various investigators are to be expected, the Board hopes that these issues can be resolved within the next year or two. Both of these issues will have some effect on the probabilistic analysis of potentially disrupting volcanic events at Yucca Mountain itself; it tentatively appears, however, that this effect will not be great. Therefore, even if these issues cannot be resolved completely among

the experts, the Board believes it still may be possible to make a probabilistic assessment of volcanic hazards at the Yucca Mountain site that is reasonably robust.

## C. Structural Control of Volcanism

Other areas of disagreement concern questions like what precisely is the area over which volcanism could be expected to occur, and what structural trends may control individual eruptions. Some of these issues may never be resolved, inasmuch as they involve buried structures whose locations are obscure. The ability of individual structures to serve as volcanic conduits may be essentially unpredictable. Nevertheless, the Board is optimistic that reasonable and conservative assumptions can be made about structural control. This will at least allow realistic limits to be put on the credible range of these assumptions.

Some scientists have proposed that extensive new geophysical surveys could help define the underlying structural control of volcanic activity. It is the Board's view that the need for such surveys should be carefully evaluated on the basis of their potential contribution to the estimation of volcanic hazards at Yucca Mountain.

## D. Recommendations

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

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

# Section 2 — Hydrogeology and Geochemistry

In December 1989, members of the Panel on Hydrogeology & Geochemistry (HG&G Panel) met in Denver, Colorado, with representatives of the DOE and its contractors to discuss the surface-based program for characterizing the saturated and unsaturated zones at the proposed site at Yucca Mountain, Nevada. As a result of that meeting, the Board, in its *First Report* (NWTRB, March 1990), identified seven issues of concern: (1) recharge to the unsaturated zone; (2) measuring fluid flow potential; (3) hydrogeologic models; (4) moisture movement in the unsaturated zone; (5) thermal stability of zeolites; (6) the applicability of laboratory-measured Kd (sorption) values to the prediction of radionuclide transport at Yucca Mountain; and (7) suggested approaches to the study of radionuclide adsorption by tuff .

In its *Third Report* to Congress and the Secretary of Energy (NWTRB, May 1991), the Board addressed in some depth the measurement, modeling, and application of radionuclide sorption data (#6 and #7, above). Thermal stability of zeolites (#5, above) was addressed at a Board meeting on thermal loading scheduled for October 1991 and will be discussed in the Board's next report. The other issues of concern — recharge to the unsaturated zone, measuring fluid flow potential, hydrogeologic models, and moisture movement in the unsaturated zone — were the subjects of discussion at an HG&G Panel meeting on June 25 to 27, 1991, in Denver, Colorado. Taking the aforementioned 1989 meeting as a "benchmark," we can now proceed to discuss the progress observed on these important issues.

## A. Characterization of the Unsaturated Zone

The hydrogeologic issues raised by the Board in its *First Report* can be thought of as different aspects of one of the main challenges in characterizing Yucca Mountain, namely: describing the spatial and temporal distribution of water flow through the unsaturated zone. The ability to meet this challenge will play an important role in the determination of the suitability of Yucca Mountain as a site for a future high-level waste repository. In its *First Report* to Congress, the Board made specific recommendations to help the DOE meet this challenge. It reported that the program to understand infiltration (the downward entry of water into the rock or soil) was well planned, but should be expanded and accelerated (NWTRB, March 1990). In addition, the Board supported the continued use of $^{3}H$ and $^{36}Cl$ for the detection of modern recharge. (Recharge is the moisture that passes through the repository level, eventually reaching the saturated zone.) There has been much progress here, especially with $^{3}H$ studies. There also has been progress in characterizing the flux-related matrix properties by laboratory testing of samples obtained from boreholes, excavations, and surface outcrops. (Flux is the rate at which water flows across a given area.) A number of measurements have been taken including permeability, sorptivity, and porosity. Moisture characterization curves have been plotted that provide insight into shallow field conditions at Yucca Mountain.

Following is a discussion of ongoing issues and problems associated with the characterization of the unsaturated zone. Infiltration and the measurement of air discharge, problems with near-surface measurements, the use of fracture-flow models, and current strategies for experimental work are among the issues the Board is addressing in this report.

*Meteorology, Infiltration, and Air Discharge*

Instrumentation is now in place to obtain a good understanding of the regional meteorology, with particular emphasis on precipitation. The current understanding is that there are two distinct weather patterns, winter and summer, with over 50 percent of the precipitation occurring in winter as snow and rain. This information will be used to numerically simulate rainfall to provide input to the infiltration and flooding/runoff studies. Identification and mapping of the surface materials above the repository block have been completed. This surface will repre-

sent an upper flux boundary in the infiltration studies. In support of these studies, researchers have processed more than seven years' worth of data on soil water content. The data were collected using borehole neutron probes.

There currently is an improved understanding of moisture movement through Yucca Mountain. There is convincing evidence that borehole UZ-6S annually discharges into the air about 16 metric tons of water vapor. This would be the equivalent of about 1 millimeter of moisture infiltration (and presumably recharge) over a circle of rock approximately 75 meters in radius. It is important to determine whether such discharge takes place naturally through fractures as well, or whether such discharge is restricted to boreholes, such as UZ-6S, that penetrate cap rock. Because such discharge could reduce infiltration through the mountain, this issue should be addressed in future studies that have yet to be proposed. Aerial infrared studies might be useful to evaluate more precisely how much moisture is discharged naturally through fractures as well as through boreholes.

*Problems with Near-Surface Measurements*

The program design to monitor infiltration is extensive and heavily vested in sensitive and complex instrumentation. The question remains, however, whether these efforts will result eventually in the accurate determination of the water flux through the unsaturated zone. Consider the following problems:

1. One of the primary methods proposed to evaluate net infiltration is the water balance methodology. Researchers are aware that errors in each component of the water balance may be larger than the net infiltration. This effort cannot be depended on to provide accurate estimates of infiltration.

2. Even if infiltration could somehow be reasonably approximated, there is a difference between infiltration and the amount of recharge passing through the repository level. The amount of recharge is of special interest because it represents the water that would come into contact with the waste forms. Recharge is not likely to be determined accurately from a surface-based program alone (see discussion below of subsurface-based testing from the exploratory studies facility). This situation is complicated by evidence pointing to air discharge from borehole UZ-6S discussed previously. If fractures or fracture zones perform like boreholes, much of the downward movement of moisture may be returned to the atmosphere prior to reaching the repository horizon.

3. Measurement of the water flux at Yucca Mountain is complicated further by the existence of both matrix and fracture flow and by a variety of potential gradients that may drive flow in the system, including water potential, pneumatic potential, surface temperature, and geothermal. Most of the unsaturated zone instruments, however, have been developed to measure properties in unfractured, porous media, primarily unconsolidated sediments at shallow depths. Such instrumentation may not readily measure parameters in fractured rocks at the depths being considered. This point is emphasized below.

- Detailed monitoring of natural infiltration is proposed adjacent to the artificial infiltration control plot. Such studies include monitoring water potential with pressure transducer tensiometers and heat dissipation probes. Heat dissipation probe measurements are complicated by hysteresis, and additional research and prototype testing should be conducted. Both pressure transducers and heat dissipation probes have a limited range (~ 0.0 to – 0.5 MPa), which is probably much higher than the natural in-situ water potentials, except after precipitation events. Thermocouple psychrometers (range – 0.1 to – 7.5 MPa) should be installed in addition to tensiometers and heat dissipation probes to monitor water potentials in the drier range. To be able to apply Richards equation to quantify flux in the unsaturated zone, water retention functions should be measured, but no such mention of these measurements has been made in the DOE natural infiltration study plan.

- In-situ monitoring of the potential field in the unsaturated zone includes measurement of water potential (matric and osmotic potential) with psychrometers, measurement of pneumatic potential with transducers, and measurement of temperatures with thermistors. Osmotic potential is considered to be negligible. Although psychrometers

have been in use for over 30 years for shallow unsaturated zone monitoring, they have never been used at the proposed depth and time scales. Problems frequently associated with psychrometers include drift, general inability to recover psychrometers for recalibration, temperature gradient effects, and a generally limited life span. They are extremely fragile instruments. The study plan states that the measurement range of psychrometers extends from -0.1 to -7.5 MPa with 7 percent error in the wet end and 1 percent error in the dry end. The inability to measure potentials in the 0 to -0.1 MPa range may prove important because water retention curves from lithologies at Yucca Mountain show that the water content variations occur primarily in the 0 to -0.1 MPa range (Peters et al., 1984). In other words, water flux and, in particular, the wetting front depth may not be greatly affected by water potentials less than -0.1 MPa. Sensitivity analyses should be conducted to evaluate the effect of water potential variations greater than and less than -0.1 MPa on water-flux estimates. At present, there is no instrument capable of measuring water potentials in the 0 to -0.1 MPa range. Researchers in the program should evaluate other instruments, such as osmotic tensiometers, or attempt to develop new instrumentation to measure these matric potentials.

*Hydrologic Testing from Ramps and Drifts in the ESF*

In the above comments, surface-based testing in boreholes was emphasized. However, testing from the ramps and exploratory drifts excavated as part of the ESF also should be considered. Although planning is not complete, the DOE intends to place a series of enlargements and side drifts off the ramps to perform tests in the stratigraphic units located above the repository level. Most, if not all, of the testing is anticipated to be conducted away from the front of the advancing TBM used to excavate the ramp. The advantages of being able to test at several levels above the repository, without the access and interference problems that arise in a small shaft, are being recognized. Experimenters are in the process of submitting proposals or requests for testing in the revised facility, but the proposals and ideas have not been evaluated and combined into a test plan.

The ramps and drifts should provide the opportunity to view conditions in a given stratigraphic unit in the vicinity of faults as well as away from faults. Tests can then be conducted to evaluate the hydrologic and chemical characteristics in the vicinity of and away from such features. The exposures in the underground excavations will enable much more complete mapping than can be obtained from surface-based testing in boreholes. For example, a steeply dipping joint or fault near a borehole could affect test results in the borehole, without the feature being discovered. The Board believes that tests conducted from the ESF will provide very useful information in characterizing the unsaturated zone. The DOE should carefully consider this information in developing an integrated surface-based and subsurface-based testing program.

*Fracture-Flow Models*

Fracture-flow models have evolved to include more realistic interactions between fractures and the rock matrix. This flow model describes how these interactions affect both the depth of penetration of water in a fracture, the distribution of water in the welded and nonwelded tuff, and the transport of solutes. This flow model predicts that water penetrating deep into Yucca Mountain can be the result of discrete or short-term surface processes such as winter storms and/or rapid snow melt. The model may be used to explain the presence of deeply penetrating isotopes. However, the model at present considers only a single continuous joint in a lithologic unit and obviously is not yet capable of predictions in the complex repository block, which consists of both continuous and discontinuous joints in different lithologies. The next step would be to place this model in series with other layers having different joint and matrix properties.

*Strategies for Experimental Work*

In spite of the aforementioned problems involved with measuring in the unsaturated zone, the experimental tasks are properly conceived, and the work is being executed properly. The study plans that describe these experiments are generally very comprehensive. If there were a criticism, it would be that considerable overlap exists and that some of the

study plans may reflect the strengths of individual researchers rather than the most appropriate technique to resolve certain issues.

It also is important to remember that the regulations are structured such that the suitability and, ultimately, the licensability of Yucca Mountain as a waste disposal site will be based on a prediction of future performance. In that sense, the focus of the project is to develop this predictive capability; hence modeling becomes central. Experimental work can be structured to support the modeling effort in two ways: although there may be considerable overlap, experiments may be either designed primarily to help develop or confirm hypotheses contained in the conceptual model, or primarily to produce input data required for use in the models. Experiments that help develop or test hypotheses used in the conceptual model can be referred to as *model validation experiments*, while experiments designed to produce model input data can be referred to as *parameter experiments*. The experiments that are primarily for model validation include the air-flow studies through the mountain, water balance studies, some of the fluid potential measurements, and the isotope studies. While these experiments differ in many details, they have in common direct measurements of transport that serve as yardsticks to judge the adequacy of both the transport models being developed and the methods used to generate characterization data.

One major criticism is that this experimental work is being conducted independently of the modeling effort. What is missing is a strategy for using the experimental data being collected to validate the model, and in the case of the fracture model, a clear explanation of what characterization parameters are required.

## B. Conclusions

1. Since the Board last reviewed the characterization of the unsaturated zone (1989), progress has been made in several areas including laboratory testing of matrix properties and $^{3}H$ studies.

2. The discovery of air discharge through boreholes has the potential for reducing the infiltration of moisture through the mountain and eventually to the repository. Aerial infrared studies may be useful in determining precisely how (or if) moisture is being discharged naturally though fractures as well as through boreholes.

3. Because of the complexity associated with water movement through the unsaturated zone and limitations on the performance of existing instruments, it is not certain that measurements will be accurate or reliable enough to provide defensible estimates of flux in the unsaturated zone. The water balance methodology cannot be depended on to evaluate net infiltration. In addition, most of the unsaturated zone instrumentation has been developed to measure properties under conditions that are not all present at Yucca Mountain. Additional instrumentation, including the development of new instruments to measure matric potential, may be called for.

4. Hydrologic testing from the ESF should provide useful information in characterizing the unsaturated zone. The DOE should carefully consider this information in developing an integrated surface-based and subsurface-based testing program.

5. Fracture flow models, which have evolved over the past few years, may play an important role in explaining observations of deeply penetrating isotopes and ultimately flow through the unsaturated zone. Efforts should be made to more realistically model the complexity of the repository block.

6. A strategy should be developed to better match specific tests and experiments being planned with the conceptual models being considered and to determine how the data derived from these tests and experiments will be used to validate these models.

## C. Recommendation

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

# Section 3 — Engineered Barrier System

Since the creation of its Panel on the Engineered Barrier System in March 1990, the Board has evaluated the potential contribution of a long-lived engineered barrier system (EBS) to the confidence in a repository's performance. It is the Board's view that well-engineered structures fabricated under strict controls generally may be less variable and their properties more predictable than rock formations. Consequently, the use of an EBS designed to contain the radioactive waste for thousands of years — in conjunction with a well-characterized, suitable site — should materially improve confidence in the performance of a repository.

To better understand the issues involved with developing long-lived engineered barriers, the Board has initiated several activities. First, the Board has met with the DOE and its contractors to gain an understanding of the DOE's program to develop an engineered barrier system. The Board also requested that the DOE address the question, "Is it possible to develop an engineered barrier system that can be shown to have a reasonable degree of assurance of isolating radioactive wastes for 10,000 years" (NWTRB, November 1990).

Second, to gain a broad sense of the issues, the Board has encouraged the DOE to seek input from people and programs not connected with the DOE. The EBS workshop hosted by the DOE, which is discussed below, provided such input.

In addition, the Board also has investigated EBS programs in other countries. In May 1990, the Board traveled to Sweden and the Federal Republic of Germany to meet with experts in their respective high-level waste programs. Both countries are devoting considerable energy to the development of engineered barriers, including waste containers and casks that are being tested for use during transport as well as for storage and disposal. The Board reported on these programs in its *Third Report* to Congress and the Secretary of Energy (NWTRB, May 1991). In June 1991, the Board traveled to Canada to meet with experts in the Canadian program. Ontario Hydro, for example, is developing a concrete integrated container, which could serve multiple purposes.

In past reports, the Board has recommended that the DOE not foreclose efforts to study the potential contribution of a long-lived EBS (see NWTRB, November 1990 and May 1991). In June 1991, in response to a Board recommendation, the DOE's Yucca Mountain Site Characterization Project Office (YMPO) organized a workshop on EBS concepts in Denver, Colorado. A brief discussion of this workshop follows.

## A. The Engineered Barrier System Concepts Workshop

The DOE organized its workshop around three objectives: (1) to provide an opportunity for outside organizations to present their ideas on EBS design; (2) to provide a forum for the discussion of EBS concepts and their applicability to extended-life performance; and (3) to solicit opinions from experts outside the program regarding the technical feasibility of an extended-life EBS.

Presentations provided background information on (1) the role of engineered and natural systems; (2) the Lawrence Livermore National Laboratory systems engineering approach and selected examples of EBS concepts; (3) Board concerns with the EBS program and expectations for the workshop; and (4) a comparison of the U.S. perspective on extended life to that of the Swedish and Swiss programs.

Thirteen concepts were presented by 12 organizations outside the program, and 6 technical experts provided their assessments of the concepts and on extended-life and EBS developments in general. Among the more than 100 attendees were representatives from the Nuclear Regulatory Commission, the city of Las Vegas, Nye County, and the state of Nevada. The presentations stimulated technical discussion among both the independent experts and other experts in the audience. The Board expects that the DOE will use the results of the workshop to up-

date the Waste Package Plan and to help identify alternative EBS designs for future consideration.

Presentations at the workshop focused on the corrosion behavior of containment barriers, and their design and the materials used in construction were emphasized. It was concluded that the issues of oxidizing versus reducing environments, kinetic versus thermodynamic equilibrium, and localized versus uniform corrosion should not be oversimplified.

Other presentations were made on specific design concepts for waste packages. Several approaches that suggest modifying the surrounding near-field environment were discussed, including some that rely on geologic analogues; other approaches using an unmodified environment also were discussed. The waste package concepts included both metallic and nonmetallic containers, used singly or as multiple barriers. Concepts using internal fillers and external packing also were presented.

Despite the current lack of data on the new nonmetallic and composite materials, participants nevertheless encouraged the consideration of several container, filler, and packing materials. There was strong interest in concepts involving thick-walled, self-shielding designs, particularly if packaging could be performed at the utility's power plant or at interim storage facilities, thus simplifying operational considerations. It was suggested that the expected high initial package costs for such concepts would probably have to be offset by providing additional waste capacity within individual packages, thus reducing the number of packages required, and possibly reducing total operational costs.

Not all experts fully addressed the question put by the Board in its second report, "Is it possible to develop an engineered barrier system that can be shown to have a reasonable degree of assurance of isolating radioactive wastes for 10,000 years." Those who did so, however, believe it is feasible to develop such an EBS.

Several concepts received especially strong support by those present. They include

- use of multi-barrier system designs to reduce uncertainty;
- selection of combinations of canister materials/chemical environments that minimize corrosion thermodynamically;
- use of standard casks designed to minimize handling; work toward multipurpose casks for storage, transportation, and disposal;
- use of simple canister design configurations to simplify manufacture and closure;
- regulation of the water flow through the repository by providing drains and seals;
- use of heat pipes to control and reduce repository temperatures (and consequently the possibility of increasing the waste storage capacity of "warm" repositories); and
- use of self-shielding casks to reduce radiological risks during handling and transportation.

The Board strongly believes that the development of a long-lived EBS should be made a more important part of the DOE's program to design a civilian high-level radioactive waste management program. The Board was encouraged by the technical insight and enthusiasm exhibited by participants at the DOE June workshop. The momentum generated there should be extended. A follow-up meeting of workshop participants and others should be scheduled by the DOE to review and consolidate the resulting recommendations and comments on EBS concepts.

## B. Other Developments

In its *Third Report*, the Board expressed concern that "inadequate and unpredictable funding would endanger the continuity of a rational, long-term experimental program to develop an adequate range of design alternatives for key elements of the EBS" (NWTRB, May 1991). DOE funding levels for the waste package program, for example, had been steadily decreasing. In July 1991, the DOE increased its fiscal year 1992 funding for the waste package program from $4.7 to $9 million. However, more recent budgetary developments have again resulted in decreasing support to this program. Only with as-

sured and continuous funding can the potential of a robust, long-lived EBS be adequately studied.

As part of an effort to expand its investigation of international efforts in the area of EBS, the Board met in early November with members of the Swedish National Board for Spent Fuel and others to discuss issues related to the EBS. This meeting was scheduled in conjunction with the international Materials Research Society meeting in Strasbourg, France. Participants were asked to provide input on their respective programs on issues such as national and self-imposed criteria; present status of specific EBS programs, including a discussion of the design and materials selection processes; R&D and implementation programs for EBS development; and perceived problems. This meeting will be discussed in more detail in the Board's next report.

## C. Conclusions

1. Based on its recent activities, the Board concludes that issues of oxidizing versus reducing environments, kinetic versus thermodynamic equilibrium, and localized versus uniform corrosion are of great importance and should not be oversimplified.

2. The Board also concludes that no technical obstacle has yet been identified to the design and development of an engineered barrier system that can be shown to have a reasonable assurance of isolating radioactive wastes for thousands of years.

3. A number of concepts exist that could contribute to a robust, long-lived EBS. These concepts should be thoroughly evaluated.

4. The DOE's EBS Concepts Workshop generated tangible momentum among those interested in engineered barriers and promises significant progress. It is now necessary to extend this momentum.

5. The DOE's July decision to increase its budget allocation to the EBS program was a positive step toward assurance that the EBS's potential contribution to long-term predictions of repository behavior will be adequately assessed. The Board, however, remains concerned about the fate of this program, given the recent decision to reduce once again funding to this important program.

## D. Recommendations

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

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

# Section 4 — Environment and Public Health

The Board believes that to carry out its responsibility under the Nuclear Waste Policy Amendments Act of 1987, it must understand the regulatory context in which the DOE is required to site, design, license, operate, and seal a deep geologic, high-level nuclear waste repository. Although the Nuclear Regulatory Commission (NRC) is the nation's primary nuclear regulatory agency, the Environmental Protection Agency (EPA) has the responsibility of setting generic standards for repository performance. Since its inception, the Board has sought to gain insight into the relevant standards and regulations promulgated by these agencies. Members have attended briefings, and recommendations have been made in previous reports.

As part of this continuing effort, the Board asked the staff of the EPA and NRC to attend a Board meeting to present their current views about the regulatory requirements for high-level nuclear waste and spent fuel research, management, and disposal programs. As a result, agency representatives made presentations to the full Board at its meeting in July 1991. The EPA and the NRC reviewed the background and status of 40 CFR 191 and 10 CFR 60, respectively. In addition, the Board heard from the DOE on the history of its guidelines to the siting process, 10 CFR 960. Following is a summary of these presentations, as well as several Board conclusions and recommendations.

## A. EPA 40 CFR 191 and Proposed Amendments

These EPA standards were originally issued in 1985. As a result of a legal challenge, Subpart B and the Appendices of 40 CFR 191 were remanded to the EPA for revision. As part of this revision process, the EPA recently has made its Working Draft #3 of the proposed standards available to interested agencies for comment.

To enable a better discussion of the current status of Working Draft #3, EPA staff provided the Board with background material on the development of the original standards. According to the EPA staff, the containment standard (allowable release limits of radionuclides to the accessible environment) originally was developed through a consideration of the possible number of health effects (premature fatal cancers) that might result from releases from a set of model repositories. This set of repositories assumed four different geologic media (granite, tuff, salt, and basalt). Depending on the geologic media, calculated estimates ranged from about 4 to 200 health effects over 10,000 years due to the emplacement of 100,000 metric tons of emplaced waste. To take into account uncertainty in these calculations, the estimates were rounded up to 1,000 health effects. It was then postulated that this reasonably achievable limit of no more than 1,000 health effects over 10,000 years from the emplacement of 100,000 metric tons of waste, could serve as a level of protection that the standards hope to achieve.

To provide some perspective as to the reasonableness of this level of protection, the EPA staff then calculated possible numbers of radiation-induced health effects in the population due to the natural uranium ore (needed to produce the reactor fuel from which the 100,000 metric tons of emplaced waste are derived) assuming it had never been mined and had been left in its natural state. These calculations provided a set of projected risks ranging from 10 to 100,000 health effects in 10,000 years. The calculations bracketed the estimated health effects from the model repository calculations, thus giving the EPA confidence that standards based upon a level of protection aimed at no more than 1,000 health effects over 10,000 years from the emplacement of 100,000 metric tons of emplaced waste were not unreasonable.

The EPA then calculated the number of health effects caused by the release of one curie of each individual isotope from the repository to the accessible environment. Release limits for each isotope were then derived to ensure that there be no more than 1,000 health effects over 10,000 years from 100,000 metric tons of waste. These release limits appear in Table 1,

Appendix A in the original version of 40 CFR 191 and in Appendix B of Working Draft #3.

The choice of 10,000 years as the time interval for assessing the level of risk provided in the standards reflects an EPA judgment that using a time of 1,000 years or less would not show important differences (ground-water travel time from a generic geologic repository would be too long to allow significant releases within the first 1,000 years) but that the use of intervals of time longer than 10,000 years would be inappropriate in view of the uncertainties about future regional climatic conditions, which could overwhelm the results. (Draft #3 of 40 CFR 191 proposes that a repository licensee be required to provide a qualitative projection of level of radiation health risk up to 100,000 years in addition to meeting the limits of Table 1, Appendix B, Working Draft #3.)

In a previous report to Congress and the Secretary of Energy, the Board outlined its concerns with 40 CFR 191 and recommended that a number of issues be considered when revising the standards (NWTRB, March 1990). The DOE responded to these recommendations in the Board's *Second Report*, stating that it had "advised the EPA of its [the DOE's] concerns . . . in its comments on Working Draft 2" of 40 CFR 191 (NWTRB, November 1990). The Board, however, remains concerned about some of the same issues in Working Draft #3 of 40 CFR 191. For example, the Board believes that the procedures outlined in Appendix C to help implementing agencies determine compliance with the requirements of Subpart B are not clear. This ambiguity, if not resolved, could lead to inappropriate levels of conservatism in applying Section 191.12 and the numerical values in Table 1, Appendix B of Working Draft #3 in 40 CFR 191.

## B. NRC Regulation 10 CFR 60

According to NRC staff, initial efforts to develop NRC regulations for high-level waste repositories involved developing performance criteria as the repository was being designed. A similar approach was used successfully to develop regulations governing nuclear reactors. Subsequent to a change in NRC staff management in the late 1970s, however, this approach was changed, and the decision was made to set performance criteria *prior to* site selection and repository design.

The NRC regulations emphasize the use of redundant barriers to prevent the release of radionuclides into the accessible environment. The engineered barrier system is required to provide containment of the waste for a minimum of 300 years. The maximum annual release rate is specified to be less than one part in 100,000, and the geologic setting must be shown to have a pre-emplacement ground-water travel time of at least 1,000 years from the disturbed zone to the accessible environment.

Although many in the DOE and in the technical community underscore the importance of an overall systems approach to repository performance standards, the NRC continues to emphasize the individual subsystem performance limits, or objectives, with the option of providing the repository developer the flexibility to offer alternative subsystem performance objectives to meet repository containment standards. The basic philosophy behind the NRC's retention of subsystem performance objectives is its interest in assuring redundancy in barrier performance.

The NRC acknowledges that a problem may exist in interpreting the specific wording in 10 CFR 60 to allow the repository developer to meet overall system performance objectives while meeting NRC subsystem requirements. Although the NRC's (10 CFR 60) flexibility provision allows it to approve or to specify alternative performance objectives for the subsystems in meeting the overall repository containment standards, the process for obtaining NRC approval of alternative subsystem performance objectives has not yet been specified.

The Board believes that clarifying many of the details related to the subsystem performance objectives and the method for using the NRC's approval process for specifying alternative objectives would be a reassuring and cost-effective step.

## C. 10 CFR 960: DOE's Guidelines to the Siting Process

The Nuclear Waste Policy Act (NWPA) of 1982 directed the DOE to establish guidelines leading to the recommendation of a site for development of a repository for the disposal of high-level radioactive waste and spent fuel. The guidelines outline the procedures for progressing to the different stages in the siting process including (1) the identification of potentially acceptable sites, (2) the nomination and recommendation of those sites as candidates for characterization, and (3) the final selection of a site for recommendation to the President for development as a repository. These guidelines were issued in final form in 1984 after consultation with affected states, Indian tribes, and other federal agencies. Because the guidelines had to conform to 10 CFR 60, the NRC had to provide its concurrence. The guidelines discuss pre- and postclosure issues, as well as both overall system and individual technical issues. Preclosure guidelines address radiological safety issues, the environment, socioeconomics, and transportation, as well as issues relating to the ease and cost of siting, constructing, operating, and closing of the repository. Postclosure technical guidelines include issues such as geohydrology, climatic changes, tectonics, and natural resources. Although at the time the guidelines were prepared, the DOE envisioned that more than one site would be characterized, the DOE has decided that 10 CFR 960 requires no amendment to accommodate the Nuclear Waste Policy Amendments Act (NWPAA) of 1987, which mandates the characterization of only one site (Yucca Mountain) to determine its licensability as a repository site.

Of particular interest in 10 CFR 960 are the 24 qualifying and 17 disqualifying conditions. Under the guidelines, an evaluation is made as to whether or not these conditions are present at the site along with the determination of the level of confidence with which these conclusions are reached. This evaluation, which represents the core of the site-evaluation process, is to be conducted iteratively as new data become available.

Recently, an early site-suitability evaluation task force made up of DOE contractors completed a preliminary assessment of the suitability of the Yucca Mountain site based on judgments about the qualifying and disqualifying conditions found in the guidelines. They have submitted this assessment to external peer review. Additional data and published studies developed since the 1986 Environmental Assessment, as well as the Site Characterization Plan data, are being considered in this iteration. A final version of this preliminary contractor assessment will be issued in early 1992. The Board is encouraged by the fact that the DOE is looking at the assessment of site suitability as an iterative process, during which issues that are deemed critical can be identified and research programs can be focused to speed up the decision about the suitability of Yucca Mountain for the repository site.

## D. Concerns and Conclusions

1. The Board remains concerned that the procedures outlined in Appendix C of 40 CFR 191 to help implementing agencies determine compliance with the requirements of Subpart B are not clear. This ambiguity could lead to inappropriate levels of conservatism in applying Section 191.12 and the numerical values in Table 1, Appendix B of Working Draft #3 of 40 CFR 191.

2. The Board believes further clarification is needed for the NRC process by which trade-off alternatives among the individual barrier performances could be authorized.

3. The Board is encouraged by the fact that the DOE is actively pursuing the assessment of site suitability as an iterative process, through which those issues that are deemed critical can be identified and prioritized. The Board looks forward to the opportunity to examine in detail the 1992 release of the first iteration of the DOE contractor's early site-suitability task force study.

## E. Recommendation

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

# Section 5 — Risk and Performance Analysis

In its first three reports, the Board discussed performance assessment methodology, the use of expert judgment, the use of decision-aiding techniques in programmatic areas (task force studies) and the use of natural analogues to support performance assessment. During the past six months, the Board has examined the results of the task force studies and heard presentations on analogues. The Risk & Performance Analysis Panel (R&PA Panel) held a two-day meeting May 20-21, 1991, to review progress on the DOE's overall program in performance assessment and to hear comments from other organizations and individuals with a strong interest in performance assessment.

As a result of a May 1989 meeting with the DOE on its performance assessment program, the Board, in its *First Report* (NWTRB, March 1990), recommended that "...the DOE should not delay performance assessment until data from the planned site-characterization activities to support license application become available. Rather, the DOE should move vigorously to develop its performance assessment methodology and implement performance assessment as a guide for site-characterization management, licensing, and repository design activities. Early application of performance assessment should identify critical problem areas and facilitate timely program planning, data-gathering activities, and repository design revisions that deal with those critical problem areas." The Board felt that early application of performance assessment also could advance the date by which any potentially unsuitable feature could be identified and evaluated. As additional data become available, the performance assessment should be revised accordingly.

What follows is a discussion of the progress made by the DOE since the May 1989 meeting. The discussion centers on programmatic issues concerning the process and methods of performance assessment. The discussion does not address the critical technical areas that must be summarized in a performance assessment (e.g., the source term, ground-water flow, and radionuclide transport), the details of which will be more readily available when the DOE has completed its current overall performance assessment of the proposed Yucca Mountain repository. As described below, the DOE has indicated that it expects to complete this current performance assessment in late 1991.

## A. Overall Progress of the DOE's Performance Assessment Program

Since the last panel meeting in May 1989, the DOE has made considerable progress in the area of performance assessment. Many technical topics have been addressed in the Performance Assessment Calculational Exercises. In addition, the various task force studies, such as the Calico Hills Risk/Benefit Analysis, the ESF Alternatives Study, and the Testing Prioritization Task Study used some form of simple performance assessment. These efforts were primarily expert assessments of how different strategies could affect the release of radionuclides expressed as a fraction of the Environmental Protection Agency standards (40 CFR 191). The ongoing Early Site Suitability Evaluation also will include some performance assessment. According to the DOE, a total system performance assessment carried out by Sandia National Laboratories will be issued this year.

The DOE also has indicated that performance assessment will be the "engine of change" that Dr. John Bartlett, director of the Office of Civilian Radioactive Waste Management, would like to see drive program modifications. An integrated schedule for performance assessment activities until the year 2001 has been developed, along with the present organizational and management frameworks that will be necessary to carry out these activities.

The Board considers the fulfillment of this schedule an important indicator of the DOE's commitment to the effective use of performance assessment. In particular, the Board is looking forward to the issuance of the above-mentioned Sandia study. It will be the first comprehensive performance assessment conducted and issued by the DOE on the Yucca Mountain site since 1986. When achieved, it should be

considered a major milestone in fulfilling the Board's recommendation for iterative performance assessment. The DOE, however, acknowledges that this study is not the final evaluation before the onset of licensing activities, but rather one of many iterations.

## B. Coordination of the DOE's Performance Assessment Activities

The DOE's program in performance assessment is being carried out by different national laboratories and by private contractors. Included in this program are the field, laboratory, and analytical studies of the individual technical areas and the integrative frameworks needed to combine all the elements into useful products. There are some parallel studies being carried out that calculate total system performance. Such parallel efforts may provide assurance that conclusions regarding repository performance are robust, rather than dependent on the choice of models and methodologies used. The Board therefore believes that such parallel efforts are a worthwhile endeavor.

Managing this large, multigroup program located in different laboratories is clearly difficult, and assuming effective coordination among the participants is particularly challenging. The DOE has made great strides in improving the performance assessment program during the past two years. However, increased coordination is needed within the performance assessment teams, between the teams, and with the expert teams that provide input to performance assessment. Increased coordination would provide assurance that the DOE's multiple performance assessment efforts will give results that are current, consistent, and cost-effective, and it would ensure that these results will appropriately summarize the available scientific information.

## C. The Role of Expert Judgment in Performance Assessment

Performance assessment must necessarily rely on expert judgment. For many of the most critical aspects of performance assessment, available data and models may not provide definitive predictions, even after the site-characterization process has been completed. For example, infiltration is a critical input to analysis of ground-water flow, and the changes in infiltration at Yucca Mountain over the next 10,000 years will reflect, for example, changes in climate. While analysis of future global climate change has become a major activity as the result of concerns over greenhouse warming, predictions of local precipitation, evapotranspiration, runoff, and resulting infiltration at Yucca Mountain are highly uncertain and likely to remain so. For future precipitation and for many other inputs to performance assessment where important uncertainties cannot be resolved through the site-characterization process, it will be appropriate to assess performance as these inputs are varied over the range of possible values that they could assume. This range should be consistent with available scientific knowledge. In practice, it may be appropriate to assess judgments from expert scientists in the form of probability distributions describing the likelihood that infiltration will reach particular values within the range.

The Board recommended in its *Second Report* that the DOE continue to develop methods for assessing expert judgment in areas of significant uncertainty (NWTRB, November 1990). The Board commends the DOE for the progress achieved to date, particularly in the task force studies. However, much more refinement is needed in this important area of performance assessment methodology. The Nuclear Regulatory Commission and its Advisory Committee on Nuclear Waste have taken a strong interest in the use of expert judgment in performance assessment. It will be very important for the DOE and the NRC to achieve a common understanding on the appropriate methods for elicitation of expert judgments and on the use of such judgments in carrying out performance assessment. Major issues include how the experts should be selected; whether, and if so, how, the range in judgments of different experts should be communicated; whether, and if so, how, differing expert judgments should be aggregated together; and to what extent the basis for the expert judgments should be documented and subjected to scientific peer review.

In the *Second Report*, the Board also recommended that the DOE incorporate the views of experts from outside the DOE and its contractors, and that the basis for *each* expert judgment be carefully documented (NWTRB, November 1990). The implication of this part of the recommendation is that if aggregation is to be used, the disaggregated judgments must be accessible in the supporting information. Where significant differences between expert judgments occur, the reasoning and data underlying these differences should be fully explained.

The Board believes that philosophical/methodological differences in the assessment of expert judgment may prove critical in some future decisions, particularly in the licensing process. The Board urges the DOE and the NRC to address this issue promptly and with useful documentation rather than waiting until some time in the future when a lack of resolution of these differences has contributed to costly delay and erosion of public confidence.

## D. Communication of the Results of Performance Assessment

By its nature, assessment of repository performance is a very complex process that involves the integration of highly sophisticated technical and scientific input, the use of massive and complicated computer codes, the incorporation of expert judgment, and the comparison of calculated radionuclide releases to a regulatory standard that uses a complimentary cumulative distribution function. The public at large, and even some of the experts who have to pass judgment on the acceptability of the proposed repository site, may find this process difficult to follow with any rigor. Deeply felt fears and concerns, particularly among those in Nevada who already are apprehensive about the safety and socioeconomic impact of such a repository, may only be exacerbated by a process that is not understandable and too easily misinterpreted as obfuscation. The Board urges the DOE to engage in a program to familiarize both decision makers and the public alike with the nature of performance assessment, to increase the transparency of both the process and important results, and to provide an ongoing demonstration of how performance assessment can contribute to the safety of the public health and the environment.

## E. Conclusions

1. The DOE has made tangible progress in performance assessment over the past two years. It has proposed an ambitious schedule of activities for the next ten years. The Board considers meeting the early milestones in this schedule to be an important indicator of the DOE's commitment to the effective use of performance assessment. In particular, the Board is looking forward to the issuance of the DOE's first and preliminary total system performance assessment for the Yucca Mountain site by the end of the year. The DOE has recognized that this first assessment is not the final evaluation before the onset of licensing activities, but rather it is the first of many iterations of a total system performance assessment, and that iterations of performance assessment can make important contributions to early site evaluations.

2. The DOE has made great strides in improving its management of the performance assessment program. However, increased coordination among the performance assessment teams and with the experts that provide input to performance assessment would provide assurance that the results are current, consistent, and cost-effective, and that these results will appropriately summarize the available scientific information.

## F. Recommendation

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

# Section 6 — Quality Assurance

The Board established its Panel on Quality Assurance (QA) in March of 1990 because it recognized that QA is an important regulatory requirement and management function designed to ensure the soundness and integrity of the scientific and technical undertakings in the waste management program. The Board's initial emphasis has been on examining the process by which the DOE implements QA requirements. The Board was concerned that the initial implementation could stifle needs to be sensitive to the special requirements for rigorous and creative exploratory research necessary for repository development.

At a QA Panel meeting in November 1990, the DOE described to Board members changes the Office of Civilian Radioactive Waste Management (OCRWM) was making in QA processes in consultation with research participants and the technical project officers. In March 1991, Board members held a follow-up meeting to review the progress being made. Board staff and a consultant also visited three national laboratories in February 1991 to ascertain participant perceptions of changes in OCRWM's QA process. The Board continues its interest in the DOE QA program as a process and would like to comment on the status and progress of the program in light of recent meetings and site visits.

## A. Status of the DOE QA Program

Representatives from the DOE and the participating research organizations perceive the top management of both the OCRWM QA program and the Yucca Mountain Project Office as moving convincingly on the commitments made at the August 1990 QA workshop in Denver. Since that time, the technical representatives have worked on the issues, developed recommendations, and begun a process to implement them. They have presented their work to top project and OCRWM management and the latter's response has been positive. While the presenters at the March meeting acknowledged that some skeptics remain among the researchers, they believe that the great majority of the research providers will work effectively with OCRWM's revised QA program. This confidence is based on a lowered emphasis on the former prescriptive approach and increased emphasis on collaborative approaches to QA.

Presenters indicated that progress already is being made in a number of areas: turnaround time for publication approval; time spent on QA training; and study documentation. The sensitive issue of the process of reviewing and releasing professional publications has been addressed by holding the participant laboratories responsible for achieving the technical review of manuscripts with OCRWM examining manuscripts only for policy conformation. Training programs, which had covered all aspects of QA regardless of the applicability to specific individual researchers and which had been perceived as wasteful of technical people's time, are being modified. They will be adjusted to involve, in a timely way, only those individuals who need to be trained on specific QA requirements that pertain to them. Greater reliance on administrative oversight of training at the laboratory level and use of "read and sign," rather than a formal classroom approach, were reported as being well received by the researchers. Finally, the document hierarchy will be made simpler. There will be more flexibility permitted in documents describing prospective studies. This is especially important for research activities that are exploratory in scope.

To facilitate communication between management and the technical community and to address the more complicated QA issues, two levels of technical advisory groups have been formed: a local group for each participant laboratory, and a Yucca Mountain Project-level group. Representatives at the local level will be picked by the technical project officer. There will be membership flexibility to incorporate the needed scientific and engineering competence. At the project level, the advisory group is named the Quality Integration Group. It will have eight members, six of whom are active researchers or principal investigators, representing the technical side, and two of whom represent management, including QA management. This group will report jointly to the project manager and the QA management.

There will be an appeals process for QA decisions at both the local and the YMPO levels. Records will be kept of all technical advisory group meetings, and reports will be accessible to researchers. There will be scheduled interactions between the Technical Advisory Groups and representatives of the NRC.

The activities, recommendations, and progress of the technical advisory groups already have been presented to top project and OCRWM management. The management has responded positively to this presentation, and it backs fully the QA improvement process that is now being put in place.

Software QA problems and issues also are being addressed through a workshop process. Researchers have perceived that the initial OCRWM software QA procedures were ambiguous and that too much emphasis had been placed on documentation and paper trails, and not enough on the quality of the software required for licensing. A process is being put into place to address those issues identified as of major concern.

A standing Computer Software Advisory Group also has been established to identify important software QA issues of concern. This group will be addressing the key problems of achieving a cost-effective software QA system in a series of workshops over the 6 to 10 months following the March 1991 QA Panel meeting.

One of the more complicated areas being addressed collectively by management and technical representatives is that of "grading." In the current OCRWM QA process, all items and activities fall into only one of two categories: "Quality Affecting" or not, depending on whether these items or activities affect human safety or waste isolation. For example, items such as waste containers would be "quality affecting." The QA grading process determines which of these designations is appropriate, and, for a quality-affecting item or activity, which of the 20 QA criteria are applicable.

The proposed classification of a particular item or activity as quality affecting or not and the determination of which of the 20 criteria would apply are advanced by the project investigator and reviewed by the QA manager at the participant laboratory and by the technical project officer. However, final QA requirements must be approved by a quality review board (QRB). This board has six members and the option of adding or substituting a member to ensure the presence of appropriate subdisciplinary expertise. A total of 353 QA grading reports had been reviewed by the QRB as of the March 1991 QA Panel meeting.

Some of these specific procedures may change as the technical advisory groups and the DOE implement the recommendations to improve the QA process. One area being addressed is how exploratory or prototype research is to be treated in the grading process. Currently, such research is not always accorded the simplified QA procedures that many investigators believe are warranted.

The Board believes, however, that in a mature QA program, which encompasses more than documentation and paper trails, there may be instances where robust QA requirements for exploratory research are warranted. One such important category of activities includes those that could physically disturb the repository and its surroundings in such a way as to compromise future repository containment. Sound technical management and decision making would require assurance measures that would preclude such adverse consequences of exploratory research from occurring.

## B. Conclusions

It appears that the process to improve QA implementation, begun at the August 1990 workshop in Denver, is on track. Progress has been made. Some of the important near-term recommendations have been accepted and are being carried out by the DOE. Chief among these is the establishment of technical advisory groups at both the participant laboratory level and the project level. These measures should enhance communication between the technical community and management. The efforts to improve the QA process have been presented to top DOE management and apparently have received management's support. The technical managers by whom the panels were briefed have a positive, but cautious, outlook on the prospects. Board members are encouraged and presently see no need for a meeting on

QA in the next six months. Individual panel members and staff contacts with investigators should continue to obtain operational level perceptions of the OCRWM's revised QA processes.

One subject not discussed during the briefings was that of qualifying data that had been obtained independently of the DOE program. This is an important issue, and it will appear on the agenda at a future QA Panel meeting.

# Section 7 — Future Board Activities

The Board looks forward to continuing its technical and scientific evaluation of the DOE's civilian nuclear waste management system. Board activities have been scheduled for the coming months on a variety of topics. Future meetings will address issues including transportation, the exploratory studies facility, and backfill and sealing technologies.

The Board will take a closer look at the vulnerability of the surface and underground facilities of the proposed repository to earthquakes (fault displacement and vibratory ground motion). The Board also will examine the new total system performance assessment due to be released by the DOE. One of the issues of special interest will be the use of expert judgment in this study.

The Board continues its interest in the Early Site-Suitability Evaluation, which recently was completed by DOE contractors, and any action the DOE might take with respect to this study.

A number of important Board activities were planned for the fall of 1991. The full Board participated in a three-day conference on thermal loading and repository design (October 1991) at which experts from programs in Canada, Germany, Sweden, and the United States provided insight about thermal-loading considerations and repository design in their respective programs to manage spent fuel and high-level waste. In addition, members of the Panel on the Engineered Barrier System met (in November 1991) with international experts in the area of engineered barrier system development. This informal meeting was organized by the Board and the Swedish National Board for Spent Nuclear Fuel to coincide with the Materials Research Society meeting in Strasbourg, France. These activities will be covered in more detail in the Board's fifth report.

# Chapter 3
# Insights from the Board's Visit with Officials in Canada's Nuclear Power and Spent Fuel Disposal Programs

The Nuclear Waste Technical Review Board (the Board) believes that much can be gained by remaining apprised of the technical activities underway in other countries that are developing programs to manage spent fuel and high-level radioactive waste. Since its inception, the Board has established contact with experts in a number of countries with radioactive waste disposal programs.

As part of a continuing effort to broaden their knowledge base, members of the Board traveled to Canada in June 1991, where they were briefed on Canada's research and development (R&D) program in Pinawa, Manitoba, by staff of the Atomic Energy Canada, Ltd. (AECL), a crown corporation. Members also toured the Underground Research Laboratory (URL) near Pinawa, built and managed by the AECL. In Toronto the Board met with representatives of the technical advisory committee (TAC) for the Canadian waste management program. The committee was established in the 1970s to advise the AECL on the extent and quality of its program. Members also were briefed by representatives of Ontario Hydro, a provincial utility, on their program for transporting and storing spent fuel. Board members toured Ontario Hydro's Bruce Nuclear Power Development (BNPD). Finally, the Board traveled to Ottawa, where members met with the staff of the Federal Environmental Assessment Review Office (FEARO) to learn more about the implementation and progress of the environmental assessment and review process. Members were briefed by the president and staff of the Atomic Energy Control Board (AECB) on the process by which a repository will eventually be licensed in Canada.

During its trip, the Board was able to gather some insights on the Canadian program that may be useful to the U.S. Department of Energy (DOE) and to the Board during its ongoing review of the technical aspects of the DOE's program to manage the nation's spent fuel and high-level radioactive waste. Background information on the Canadian program, including a brief description of each of the organizations involved in managing different aspects of the program, can be found in Appendix D of this report.

## A. The Canadian and U.S. Waste Disposal Programs

As have researchers in most other nations, Canadian and U.S. researchers have concluded that geologic disposal currently is the most acceptable means for disposing of spent fuel and high-level waste. The Canadian and U.S. programs, however, differ in a number of important ways. Similarities and differences between the two programs are discussed in the following section.

*Site Characterization: Research and Development*

Canada and the United States are researching disposal in different media and geologic locations. Canada is evaluating the potential of constructing a

repository in granite, in a saturated environment, in the Canadian Shield — the exposed, tectonically stable, geologically old, basement rocks of east-central Canada. The United States is looking at the possibility of disposal in tuff (in an unsaturated environment) at Yucca Mountain, Nevada, in the Basin and Range — a zone of geologically recent tectonic activity in the western United States.

The Canadian R&D program, which is centralized under the auspices of the crown corporation AECL, is technically managed and jointly funded by the AECL and Ontario Hydro. The program is small and focused, with most research taking place at URL. The R&D covers the engineering, scientific, environmental, and social science aspects of siting, constructing, and managing an underground repository. One reason the Canadian R&D program seems focused may be that Canada first selected (in 1977) the geologic medium — granite — in which to evaluate the concept of geologic disposal (Aikin et al., 1977). Plans call for a site for repository development to be selected at a later date, following regulatory, technical and public review of the technical bases for disposal of spent fuel in a geologic repository.

The U.S. research program, which is much larger in size (in both dollars and personnel) than the Canadian program, has evolved somewhat differently. In 1987 after surveying several sites in different media, the DOE was directed by Congress to characterize *one site* (Yucca Mountain, Nevada) in tuff for potential repository development. As a result, R&D work in the United States focuses on site-specific surface characterization activities, as well as on studies to design and construct an exploratory studies facility (ESF) at Yucca Mountain, Nevada. The ESF, once constructed, will be the center of underground site-characterization work. At the moment, research is spread among more than 10 organizations around the country, including several of the national research laboratories, and the U.S. Geological Survey. The DOE has recently awarded a management and operations contract to integrate and coordinate all ongoing activities. As a result, the DOE framework for conducting research and development work on the nation's program for disposing of spent nuclear fuel is undergoing some reorganization and restructuring.

The R&D programs in both countries recognize the importance of promoting the cross-fertilization of ideas with peers from other countries. The United States, through the DOE's Office of Civilian Radioactive Waste Management (OCRWM), has or is pursuing bilateral agreements with Canada, Switzerland, Sweden, Belgium, Germany, France, the United Kingdom, Japan, and the Commission of European Communities (Isaacs 1991). Through its research program and the development of the Underground Research Laboratory, the AECL in Canada has attracted the interest of research scientists around the world. Also, those involved in developing concepts for permanent disposal and waste management keep close watch on developments in other countries to gauge the success or failure of their own efforts. In particular, those involved in spent fuel management in Canada and Sweden share information and expertise as both countries are exploring granite for repository development.

*Structural Geology & Geoengineering*
*Hydrogeology & Geochemistry*

The technical communities in both countries recognize the need for underground exploration of any potential repository site to resolve specific questions about the site's suitability and to collect data for repository design.

Both Canadian and U.S. research efforts emphasize the need for site-specific, surface-based, *and* underground exploration, regardless of the extent of prior research. No matter how suitable the surface geology of a site may appear, residual uncertainties exist that can only be addressed through underground research. Regardless of where the site eventually is located, underground exploration will be needed to observe significant structures and to address groundwater flow problems. In fact, the Canadians, through the auspices of the AECL, are conducting in-situ R&D in their URL to improve their understanding of the behavior and characteristics of the Canadian Shield. In the past, the United States has had experimental underground facilities in granite (Climax) and tuff (G-tunnel) formations on the Nevada Test Site.

The U.S. program centers on site-specific, surface-based characterization and the construction of an exploratory studies facility from which underground experiments will be performed to determine the suitability of the Yucca Mountain site for locating a repository. In light of current budget constraints, however, the DOE has delayed the construction of the ESF in favor of more surface characterization and some generic research.

Accurate mapping of fractures and the flow of ground water through the fractures will prove challenging for both countries. The Canadians are developing good techniques and instrumentation, including ground-penetrating radar and the development and/or application of sophisticated geo-mechanical instrumentation. They have concentrated their efforts on determining the performance of a variety of instruments in the saturated conditions particular to the Underground Research Laboratory in Pinawa. Much research has been carried out in other countries in saturated environments. This will undoubtedly be of use to researchers in the Canadian program.

The DOE, which is evaluating volcanic tuff in an unsaturated environment,* cannot make use of much of the Canadian research in the saturated environment. Many U.S. scientists believe the unsaturated zone offers some advantages over the saturated zone for disposal since there is less water to corrode waste canisters and to transport radionuclides away from the repository. One disadvantage, however, may be the potential difficulty of predicting the movement of any water that is present within the unsaturated zone.

However, the DOE may be able to benefit from other activities underway at Pinawa, such as the development of the sophisticated geomechanical and geohydrological instrumentation (Thompson et al., 1991; Simmons 1991). The Yucca Mountain Project may further benefit from experience gained at Pinawa regarding the prediction of water movement in shear zones within the saturated zone.

*Risk & Performance Analysis*

The Canadian technical community agrees with its U.S. counterpart that there always will be uncertainties associated with predicting the long-term performance of any permanent repository. One of the challenges facing both programs is the integration of the results of different models used to predict repository performance with the actual development of a repository. Also, both programs must find ways to communicate the results of performance assessment modeling to the public. The Canadians currently are in the middle of an exhaustive environmental assessment that may help them institutionalize a process for integrating performance assessment results in a way that is understandable to the nontechnical community. If this process meets with success, the Canadian environmental assessment process may provide other programs with useful insights.

*Engineered Barrier System*

Most countries studying geologic disposal are relying on a combination of engineered and natural barriers to achieve long-term waste isolation. Sweden and Switzerland, which are looking primarily at granite, place a heavy reliance on engineered barriers. Canada and the United States place emphasis on engineered barriers to a lesser degree. Germany, which is evaluating the advantages of disposal in salt, places heavy reliance on the natural barrier (Isaacs 1991) and even less emphasis on the engineered barriers.

Since 1977, the Canadian program generally has called for burying spent nuclear fuel between 500 and 1,000 meters underground in the Canadian Shield. The Canadians plan to build redundancy into their system by developing a container that will last for at least 500 years while relying primarily on the natural barrier that granite affords for long-term isolation. The Canadians are focusing on overall system performance rather than on the performance of individual components in the system.

* Some experiments have been carried out in an unsaturated environment at G-tunnel at the Nevada Test Site.

In the United States, an engineered barrier system must be designed to satisfy the containment and controlled release functions prescribed by Nuclear Regulatory Commission regulations. These regulations require containment for 300 to 1,000 years. Current DOE policy also calls for reliance on the natural barrier as the primary barrier for containing spent nuclear fuel beyond 1,000 years.

*Thermal Loading of Repository*

Both countries are working on potential designs for a permanent repository at depths of 300 to 1000 meters.* 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 in the United States. Consequently each ton of spent CANDU fuel has a lower thermal and radioactive output than U.S. spent fuel. As a result, maximum temperature on the exterior of the waste package could not exceed 100 degrees Celsius (i.e., low thermal loading).

The U.S. Site Characterization Plan, on the other hand, calls for emplacement of spent fuel and high-level waste with the goal of maintaining a waste-package temperature between 275 and 350 degrees Celsius. Current U.S. rationale involves keeping the temperature high enough to boil water away from the waste package, yet not so high as to adversely affect the natural barriers well below the wastes.

*Interim Storage and Management of Spent Nuclear Fuel*

Canada and the United States are facing quite different situations in managing the interim storage of spent fuel. The United States faces the more complicated challenge of managing spent nuclear fuel produced at reactors at 70 sites around the country. The DOE has concluded that it would be preferable to transport much of the fuel to a centralized monitored retrievable storage (MRS) facility. However, not only must the DOE coordinate the management, shipment, and storage of spent fuel from around the country, it also must design a transport, pickup, and storage system that can accommodate the variety of wet and dry storage options already in use at and being developed by different utilities.

In contrast, most of the nuclear energy produced in Canada is produced in one province, Ontario, which has the highest population concentration and thus the highest energy requirements. The majority of the existing spent fuel is generated, managed, and stored by one utility (Ontario Hydro) at two reactor sites (Pickering Nuclear Generating Station and Bruce Nuclear Power Development). The system in Canada for managing the spent fuel also is less complex than in the United States. In 1972, a committee assessing Canadian fuel storage concluded that on-site storage was preferable to centralized monitored interim storage because the need to transport the waste off site could be avoided and because the infrastructure for operating and monitoring the waste already was in place at the reactor stations (Ontario Hydro 1991). Storage methods are fewer in type and number than in the United States.

It appears to the Board that the technical communities in both countries believe that fuel can be stored safely on site at reactors for many decades. At-reactor wet and dry storage is being employed in both countries.

Ontario Hydro is examining the concept of a multi-purpose container for spent fuel. Made of reinforced concrete, this container could serve the multiple purpose of storage and transport.

Because of space limitations in existing spent fuel pools, utilities in the United States have begun to move the spent fuel out of pools and into dry storage. Three utilities have received licenses to date from the Nuclear Regulatory Commission (NRC) to store spent fuel on site in dry storage. All are using different kinds of concrete and metal storage container systems. For example, one company has received a license for dry storage in metal casks (1); another uses a bunker dry storage system (2); and a third has another dry storage system (3). Four addi-

* The Canadian approach to thermal loading of the repository is different from the U.S. approach.

tional licenses currently are pending before the NRC to store spent fuel on-site (4). The NRC also has certified four casks (5) for on-site storage as part of one utility's generic license. Two other casks (6) are under review for approval for referencing in site-specific licenses; and four casks (7) are awaiting a "certificate of compliance"(Sturz 1991).*

*Transportation & Systems*

Although the public is concerned about the safety of transporting spent fuel, it appears that the technical communities in both Canada and the United States have concluded that transportation of spent fuel has occurred and can continue to occur safely and that associated risks can be acceptably managed. In Canada, Ontario Hydro currently is working on a long-term plan for the transportation of spent fuel from reactor sites to a permanent repository. The bulk of Canada's experience transporting fuel has involved transportation among the various utility nuclear generating stations and AECL research facilities. A total of 500 shipments have been made to date (averaging two to three per year in recent years). The transfer of fuel takes place in specially designed, tested, and approved road casks. Since transports began, there has not been a release of radioactive materials from these shipments. Ontario Hydro also reviews the transportation policies, practices, and experiences of other countries transporting spent fuel for reprocessing purposes and notes that transportation to date in these countries has proven reliable (Ontario Hydro 1991).

In the United States, spent fuel has been shipped routinely since nuclear power generation began. Although the number of shipments is small compared to annual traffic in all hazardous materials, there is a substantial history of spent fuel shipments. From 1964 to 1989, for example, there were approximately 9,000 fuel assemblies transported in 2,600 shipments (ORNL 1990). Although truck transports account for the majority of shipments, much also has been transported by rail. Despite the higher number of overall shipments in the United States, the U.S. safety record also is excellent. There has not been a radioactive release during transport. The U.S. Department of Transportation began requiring detailed incident reports in 1976 for unintentional releases of all hazardous materials.

Another issue both programs have acknowledged, but not addressed fully to date, is the extent to which a storage and transportation system can be designed that minimizes the handling of fuel. In Canada, Ontario Hydro is evaluating its multipurpose concrete cask, which may be useful for storage and transportation. To date, research has focused on using the cask for on-site dry storage. The utility believes using such a cask for disposal may have the potential to increase system efficiency and to reduce potential risks associated with transferring fuel from storage to disposal containers. The DOE has indicated it also is evaluating the usefulness of multipurpose casks, but has raised questions about the overall impact of such casks on the cost of the waste disposal system, their potential impact on the specific design of an underground repository, and the likelihood of getting such casks licensed by the Nuclear Regulatory Commission (Bartlett 1991).

*Pressure for Progress on the Repository Program*

Of the two, the U.S. program has been most affected by a sense of urgency to site a repository and dispose of its waste. In 1987, for example, Congress revised its 1982 decision to characterize three sites as potential repositories in favor of characterizing just one site at Yucca Mountain, Nevada. Congress currently is discussing additional amendments to the original 1982 legislation that would override Nevada's authority to issue environmental permits, in

* (1) Virginia Power Company, Surry plant, Richmond, Virginia; (2) The Robinson plant, Carolina Power & Light Company, Darlington County, South Carolina, NUHOMS 7P bunker; (3) Duke Power's Oconnee station, Oconnee County, South Carolina uses the NUHOMS 24P system; (4) Carolina Power & Light, to store fuel at Brunswick in a NUHOMS 7 concrete bunker system, Baltimore Gas and Electric, to store fuel at Calvert Cliffs in a NUHOMS 24P system, Northern States Power, to store fuel at Prairie Island in TN-40 metal casks, and Public Service of Colorado to store fuel at the Fort St.Vrain in vault storage; (5) GNSI CASTOR V-21, MC-10, NAC S/T, and NAC C-28 S/T; (6) NAC STC and GNSI CASTOR-X; (7) TN-24; VSC-24; CONSTAR; and NUHOMS standardized.

hopes of speeding up site-characterization work. The DOE also is facing a statutory deadline that requires the DOE to begin accepting civilian spent fuel for disposal in 1998.

In exchange, nuclear utilities in the United States have been paying into the Nuclear Waste Fund, from which the federal government is paying for the development and implementation of the nation's commercial high-level waste management program. U.S. utilities argue that since they (through the rate-payers) have been paying for the program since 1982, they should not have to manage or store the waste after the agreed-on date. Because some utilities are running out of storage space, pressure has increased on the DOE to meet the 1998 deadline. The nuclear waste negotiator is presently trying to find a state willing to host a monitored retrievable storage facility for interim storage of spent fuel.

In Canada, the utilities have assumed responsibility for all radioactive materials resulting from the operation of nuclear reactors. Thus, spent fuel interim storage and transport, and all R&D related to these in Ontario, for example, are Ontario Hydro's responsibility. (Ontario Hydro recently released a management statement and plan for the comprehensive management of radioactive materials.)

Neither the utility, the government, nor the public appear to be in a hurry to site and develop a repository. Disposal is not envisioned to begin before 2025. In the early 1980s, the Canadians decoupled siting a repository from the process of developing a radioactive waste disposal concept for granite. The current Canadian approach to finding a way to dispose of the waste is to develop a technically and politically acceptable concept for waste disposal in granite — then to select a site somewhere in the Canadian Shield. In fact, no site selection work is permitted until the disposal concept has undergone public, technical, and regulatory reviews (by 1994 at the earliest). The geologic disposal concept currently is being reviewed by an independent panel under the auspices of the Federal Environmental Assessment Review Office (FEARO) of Environment Canada. FEARO has created an Environmental Assessment Review Panel (EARP) to review the disposal concept and is now subjecting it to close public scrutiny. In June 1991 following public scoping hearings, the EARP released its draft guidelines for preparing an environmental impact statement for such a disposal concept. (The EARP guidelines are somewhat reminiscent of the U.S. effort of 10 years ago to issue generic environmental impact statement guidelines.)

There appears to be no pressure on the Canadian government to assume responsibility for disposal of spent fuel by a certain date. In fact, Canadian utilities seem ready to provide long-term interim storage at nuclear facility sites like those in Sweden and Germany, countries that the Board has visited.

*Licensing Approaches*

Canadian regulations are less prescriptive than U.S. regulations. The Canadians have a more flexible approach to licensing a disposal facility, such as an underground repository.

Current governmental policy in Canada makes the Atomic Energy Control Board responsible for licensing a permanent repository. Any applicant (AECL) for a license to dispose of waste will have to satisfy the AECB that both natural geologic conditions and the emplacement system will reduce the risks and their consequences to an acceptable level. 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 document, R-104. The responsibility lies with the applicant (AECL) to design a facility that can minimize the possibility of radioactive release into the environment. The AECB has *ruled* that radiological risks to future generations should be no greater than those presently considered acceptable. Current AECB criteria on radiation exposure state that no facility should subject a person to a predicted radiological risk greater than a one-in-a-million chance of fatal cancer and serious genetic effects in a year (AECB 1987).

In the United States, the construction, operation, and closure of a repository also can be undertaken only if the repository is authorized and licensed by the Nuclear Regulatory Commission. The NRC has specified detailed requirements (10 CFR 60) for waste package lifetime, waste release rates, and ground-water travel time that the applicant (DOE) must meet. The NRC

also implements and enforces general radioactive exposure and containment requirements issued by the U.S. Environmental Protection Agency (40 CFR 191). In addition, to prepare for the licensing process, the DOE has issued its own set of requirements (10 CFR 960) for assessing whether a site is suitable for repository development or not.

Until a formal license application is submitted by the DOE to the NRC, these agencies will operate under a procedural agreement that provides for an ongoing exchange of technical information. Formal licensing proceedings would begin once the DOE submits its application. The application would include, among other information, the results of performance assessments required to demonstrate compliance with all applicable regulations. The NRC then would have three to four years to review the application and decide whether to authorize construction of a repository. When the repository is ready to start receiving waste, the DOE must submit an updated license application to the NRC. Once the waste has been emplaced, the DOE will submit an application to the NRC for a license amendment to decommission and permanently close the repository (U.S. DOE 1991).

*Public Acceptance of Spent Fuel Disposal Programs*

In both countries, many individuals have concerns about the safety of the underground disposal of spent fuel. The technical communities in both countries seem to acknowledge that the largest hurdle in developing a permanent geologic repository may lie in convincing the technical community and the public that it can be done safely at a specific site. The U.S. program, however, is laboring under the additional burden of having to meet statutory deadlines, regardless of public opinion. Consequently, although the DOE is expending more and more effort to keep the public informed of its activities and to bring the public into the decision-making process, this effort is being overshadowed by a sense of imminent deadlines and some public unease with the decision-making process in both the legislative and executive branches and with the federal government's past management of radioactive defense waste. Canada and its federal agencies have no similar defense waste record to overcome.

In Canada, the AECL has dedicated approximately 3 percent of its waste disposal budget to public affairs activities. The AECL contracts with Gallup and other polls to conduct surveys and report on the results to understand better the nature of the public's concerns about disposing of spent fuel in a permanent repository. The AECL also has conducted a public consultation program since 1984, wherein AECL representatives meet with a wide range of public interest groups. The AECL has found that the public has expressed reservations about scientific assessment of risk, probabilistic approaches, and predictions on the long-term safety of disposal based on computer modeling. The AECL has discovered that the public may have difficulty accepting a technology that has not yet been demonstrated. This, in turn, may result in public preference for extended interim storage before a decision is made to dispose of spent fuel permanently. This question, along with the ethical considerations surrounding waste disposal, and such a program's effects on Canada's aboriginal peoples, are emerging as issues in the AECL's sociological research (Greber 1991).

## B. Conclusions

1. The Canadian and U.S. programs are evolving somewhat differently.

The Canadians have postponed decisions about siting in favor of first reaching technical and political consensus on the concept for disposing of waste in the saturated zone in granite in the Canadian Shield. In the interim, however, R&D that will be largely applicable to any Canadian Shield site is continuing at Pinawa. In short, they are developing and rigorously demonstrating a concept and will then search for a site to fit that concept.

In addition, the Canadian utilities have retained responsibility for management, storage, and transport of all spent fuel.

The United States, in contrast, is looking at a site and developing a concept involving high thermal loading to fit the unsaturated zone at that site. Some generic research that eventually could apply to any potential site is underway at various locations across the country, and some site-specific surface-based research is being carried out in Nevada. But should Yucca Mountain be found unsuitable, the DOE may have to reevaluate its entire design concept if another site with an adequate unsaturated zone cannot be found.

Although the Canadian and U.S. programs are evolving differently, the Board has been able to identify some key aspects of the Canadian program that may prove useful to the U.S. program. The Board suggests that the DOE monitor the AECL's development of repository designs based on a low thermal-loading temperature of 100 degree Celsius. Consistent with this suggestion, the Board held (October 1991) a three-day meeting with representatives of the DOE and experts from nuclear waste management programs in Canada, Germany, and Sweden. The topic of this meeting was the effects of thermal loading on repository design concepts.

The DOE also should monitor the design and application of instrumentation and fracture mapping devices, the development of titanium and copper prototype canisters, and the AECL's efforts at incorporating the results from the geosphere and biosphere modeling into their repository design. Furthermore, the Board recommends that the DOE monitor Ontario Hydro's development and use of a concrete multipurpose container, and the FEARO's environmental assessment review process, especially its effects on public confidence in the underground isolation of spent nuclear fuel.

2. The Canadian program appears to have a number of advantages over the U.S. program.

- The system in Canada for managing spent fuel is less complex than the U.S. system. Approximately 95 percent of the spent fuel in Canada is produced in one province (Ontario) by one utility (Ontario Hydro). In contrast, the United States must consider the needs of more than 70 widely scattered utilities and the concerns of citizens in a great many states.

- Because most spent fuel is managed by one utility, storage methods in Canada are far fewer in type and number than in the United States. Consequently, spent fuel handling and transport in Canada will be simpler. In the United States, the NRC has begun to license on-site storage, and at least 10 on-site dry storage systems already have been or are in the process of being approved.

- The regulatory framework for disposal in Canada seems to be less prescriptive and more flexible. The current regulatory philosophy is to review the concept for disposal in the context of general criteria, which are not legally binding. This approach, if it succeeds, could facilitate the construction and licensing of such a first-of-a-kind facility.

- In Canada, all of the research on repository design takes place at one site — managed by one organization (AECL). In contrast, in the United States, research is underway at numerous locations across the country — managed by a complex network of contractors, at the head of which is the DOE.

- There is less urgency in the Canadian program to develop a repository (emplacement is not expected to begin before 2025). An extensive public consultation process is underway that may help assure the public that decisions pertaining to nuclear waste are not being made in a rush without adequate evaluation or public consultation. In the U.S. program, Congress has obligated the DOE to begin receipt of spent fuel for disposal as of 1998. The DOE presently plans to begin application for repository licensing in 2001 (assuming Yucca Mountain is found suitable) and repository operation in 2010. Such statutory deadlines, coupled with financial constraints, appear to be driving the U.S. program. The program also has become entangled in political controversy over site selection and clouded by public misgivings over the DOE's past management of defense wastes.