U.S. NUCLEAR WASTE TECHNICAL
REVIEW BOARD

REPORT TO THE U.S. CONGRESS AND THE SECRETARY OF ENERGY

1995 FINDINGS AND RECOMMENDATIONS

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

April 1995

The Honorable Newt Gingrich
Speaker of the House
United States House of Representatives
Washington, D.C. 20515

The Honorable Strom Thurmond
President Pro Tempore
United States Senate
Washington, D.C. 20510

The Honorable Hazel O'Leary
Secretary
U.S. Department of Energy
Washington, D.C. 20585

Dear Speaker Gingrich, Senator Thurmond, and Secretary O'Leary:

The Nuclear Waste Technical Review Board (Board) herewith submits its *Report to the U.S. Congress and the Secretary of Energy — 1995 Findings and Recommendations* in accordance with the requirements of the Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203.

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

In its report, the Board summarizes the major findings, conclusions, and recommendations that have resulted from Board activities during calendar year 1995. We believe that the information contained in this report will be useful to policy makers and Department of Energy managers and staff as they consider during the coming months the status and future of the civilian radioactive waste management program.

This was a year of great uncertainty for the DOE. The DOE's budget was cut signficantly, the Congress considered legislation to substantially revise the spent fuel management program, and a panel of the National Academy of Sciences recommended a technical basis for safety standards for a Yucca Mountain repository that would be much different from earlier standards. These budgetary, programmatic, and regulatory uncertainties

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posed a significant management challenge for the DOE. The Board believes that the challenge was met and the program improved in 1995. If progress being made at the end of 1995 can be maintained, the Board believes that a site-suitability decision can be made within five years. Since a repository *will* be needed eventually, the Board believes that the focus of the U.S. program for spent fuel management should remain on evaluating the suitability of Yucca Mountain as a potential site for a permanent repository. Adequate and stable funding will be needed if the program is to achieve this objective.

In June, 1995, three new members were appointed to the Board. The Board welcomes Mr. John W. Arendt, Dr. Jared L. Cohon, and Dr. Jeffrey J. Wong, whose experience and expertise are briefly summarized in this report. The Board would especially like to acknowledge the efforts of Dr. Dennis L. Price whose term expired in April 1994, but who continued to serve the Board as a consultant until Mr. Arendt was appointed. The Board also would like to acknowledge the continued service of Drs. Patrick A. Domenico and Ellis D. Verink, Jr., whose appointments expired in April 1994, but who continue to serve as consultants pending reappointment or the appointment of replacement members.

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

Sincerely,

John E. Cantlon, Chairman

Clarence R. Allen

John W. Arendt

Garry D. Brewer

Jared L. Cohon

Edward J. Cording

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John J. McKetta, Jr.

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* *On extended leave during 1995.*

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Executive Summary

Frustration over the federal role in managing spent nuclear fuel was widely evident in 1995. A coalition of electric utilities and public utility commissions brought a lawsuit (not yet resolved) that asserts the federal government has a legal responsibility to begin accepting spent fuel in 1998. There also were threats to escrow or end payment of fees to the federal government for managing spent fuel. Several proposals were introduced in Congress to redirect the program by developing a federal centralized facility for interim storage of spent fuel at or near Yucca Mountain. Some of those proposals could constrain repository development so severely that "interim" storage might continue indefinitely. Although none of them was enacted in 1995, the Congress did sharply reduce program funding for fiscal year 1996, leading to staff reductions, termination of some scientific studies, and increased uncertainty about the future of the spent fuel management program. As 1995 ended, proposals to restructure the program were still under active consideration within the Congress.

The Board believes that real progress was made in 1995 as the DOE began to obtain valuable information from the exploratory studies facility. But difficulties were encountered also, and opportunities for improvement of program management and operations remain. The Nuclear Waste Technical Review Board's (Board's) views are outlined in the following paragraphs of this executive summary and are discussed in more detail in the main body of this report.

A Year of Uncertainty

In December 1994, the U.S. Department of Energy (DOE) published its *Civilian Radioactive Waste Management Program Plan*. This document sought to identify and, to a limited extent, set priorities for the activities needed to evaluate the suitability of the Yucca Mountain site and to prepare a construction license application for a repository by 2001. It also set forth plans for the waste acceptance and transportation activities needed to move spent fuel from reactors to a repository. In short, the *Program Plan* was to be the "road map" for the program for 1995-2000. Program funding for fiscal year 1995 increased substantially from 1994, as did staffing levels for the DOE's management and operating contractor. Smaller funding increases were anticipated for fiscal years 1996 through 1999. As 1995 began, the DOE believed that it had a workable plan, and would receive sufficient funding, to evaluate the suitability of the Yucca Mountain site for development of a repository for disposal of high-level waste and spent nuclear fuel.

Late in fiscal year 1995, it became apparent that funding levels for fiscal year 1996 and beyond would not support the activities and milestones of the 1994 *Program Plan*. Faced with a 40 percent reduction in its budget, the DOE had to reduce the scope of its activities and set better priorities for its studies for the coming years. Surface-based programs at Yucca Mountain were cut back. Development of multipurpose canisters, which the DOE had planned to make available for at-reactor storage of spent fuel beginning in 1998, was stopped at the direction of the Congress. As a result, the DOE may need to work with private developers of canisters to ensure enough standardization of designs to allow efficient waste handling operations at a repository. Preparation for repository licensing was ended, as were efforts to develop environmental impact statements for the repository and the multipurpose canisters. The DOE is now pursuing a "viability assessment" for siting a repository at Yucca Mountain, to be completed in 1998. The purpose of this assessment seems to be to decide whether continued site studies and repository development are warranted. The relationship between a "viability assessment" and an evaluation of the technical suitability of the Yucca Mountain site is unclear.

Several bills to revise the spent fuel management program were introduced in Congress during 1995. Some of the bills would direct the DOE to begin developing a federal interim storage facility (and the needed transportation infrastructure) using funds now intended for repository development. The location of the storage facility would be at or near Yucca Mountain under most bills. The bills seem to reflect frustration with the slow pace of the disposal program and concern about the federal government's ability to accept spent fuel from the utilities beginning in 1998. The fiscal year 1996 appropriation bill also directed the DOE to plan for interim storage of utility spent fuel, although funds for developing a storage facility were withheld pending passage of further legislation.

Regulatory uncertainty continued in 1995. A panel of the National Academy of Sciences recommended a technical basis for safety standards for a Yucca Mountain repository that would be much different from earlier standards. Both the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission are now supposed to revise their regulations for Yucca Mountain to conform to the panel's recommendations. However, at the end of the year, a bill introduced into the Senate would set an individual dose limit of 100 mrem / yr — a factor of three to ten higher than the dose limits adopted by other nations. It also would limit the period of regulatory compliance to 10,000 years and it would specify an assumption that institutional controls will be effective in preventing human intrusion into, or disruption of, the repository. While it is difficult to determine whether progress in characterizing the Yucca Mountain site has been hampered by this fluctuating regulatory environment, there is an obvious risk that public credibility in the regulatory process will be undermined if it appears that the regulatory criteria are being changed to accommodate the Yucca Mountain site.

These budgetary, programmatic, and regulatory uncertainties posed a significant management challenge for the DOE. The Board believes that the challenge was met and the program focus improved in 1995. The following paragraphs summarize some of the key developments during the year and the Board's view of the program at year-end.

Key Developments in 1995

The DOE experienced both successes and failures in 1995. The most visible improvement was in the operation of the tunnel boring machine (TBM). Excavation of the exploratory studies facility (ESF) with the TBM started in late September 1994. Progress was very slow through the remaining months of 1994 and the first half of 1995. In April 1995, industry TBM experts were consulted to identify modifications that could be made to improve TBM performance. Implementation of these modifications, installation of a conveyor for removal of excavated rock, and improved quality of the rock encountered by the TBM in the ESF resulted in a significant increase in the rate of excavation — to about 27 meters (90 feet) per day.

Early in 1996, however, the rate of progress dropped to about 15 meters (50 feet) per day. Excavation slowed because of the need to use heavy steel sets for ground support as the TBM intermittently encounters regions of unstable rock. It is unclear whether the need to use the heavy steel sets results solely from geologic conditions. It also may be due to a mismatch between the geologic conditions and the available options for quality-controlled ground support. Or, the characteristics of the TBM may contribute to ground support problems. A TBM designed to allow early support of loose rock, one with a more conventional cutterhead configuration, or one of a smaller diameter could improve production rates.

The ESF is now well into the proposed repository level (about 300 meters below the surface of the mountain), allowing observations and experiments on the geologic and hydrologic conditions that are important for evaluating the suitability of the site. One of the most important factors in determining site suitability is the amount of water that could be available at the repository level to corrode waste packages, remove radionuclides, and transport them to the accessible environment. Information about the availability of water is now being collected from within the ESF.

While somewhat less visible, substantial progress also was made in developing a waste isolation strategy. This strategy specifies which barriers, engineered and geologic, the DOE will rely upon to isolate waste from the human environment. Development of the strategy provides a technically supportable basis for setting priorities for activities at Yucca Mountain and for repository design studies. The DOE also completed a more detailed total system performance assessment (TSPA) for a Yucca Mountain repository. This is a projection, based on current knowledge, of how well a repository would be able to isolate waste. Equally important, it helps identify the most important parameters affecting performance, allowing the DOE to focus its studies on those parameters.

The Board has long believed that the quality and completeness of the technical work within its purview could be adversely affected by financial or management factors. During 1995, an independent management and financial review of the Yucca Mountain project identified numerous areas where project management could be improved. The reviewers, consultants with expertise in the management of complex construction projects, concluded that the DOE was reluctant to incorporate the views of external parties into its decision making, the DOE's principal contractor lacked incentives to perform cost-effectively, and the DOE had little chance of meeting the milestones it was then pursuing. The Board believes that the recommendations of this review have enduring value for project management. Realistic schedules (with room for delays and contingency planning), effective consultation with outside experts, and use of financial incentives for efficient contractor operations will be needed if the project is to succeed.

The DOE's experience in getting a peer review of its first *Technical Basis Report* was a decided failure. This report was a compilation and analysis of scientific information about surface processes (e.g., erosion) that could affect waste isolation at Yucca Mountain. The report was the first of a series intended to lay the scientific foundation for a suitability decision about the Yucca Mountain site. The DOE asked a panel of the National Academy of Sciences / National Research Council to review the quality and completeness of the scientific data and reasoning presented in the report. The panel's criticisms of the report ranged from inadequate scientific justification to poor documentation and management control. Even though the issues addressed by the report were not very contentious from the standpoint of site suitability, there may be important lessons to be learned from this experience, not the least of which is to more directly involve the scientists who conduct the actual investigations in the preparation of the reports.

The Board's View at Year-End 1995

Progress in assessing the Yucca Mountain site appears encouraging. The program is beginning to collect geologic and hydrologic information from the repository horizon that will help determine the suitability of the site. If TBM excavation rates can be improved, and if management improvements are made and sustained in other areas, the program should be able to proceed more efficiently toward a site-suitability decision (i.e., whether there is a high probability that the site, along with the appropriate engineered barriers, can provide long-term waste isolation). It is obvious, however, that efficient progress cannot be achieved without adequate and stable program funding.

The Board believes that the best way to determine the necessary level of funding is for the DOE to update its 1994 *Program Plan*. Aside from updated schedules, the major change needed, compared to the earlier *Program Plan*, is development of a sound technical justification for the planned activities. To a large extent, this justification should flow naturally from the evolving waste isolation strategy and the results of total system performance assessments. Once in place, the updated plan would help the DOE to provide the Congress with a basis to determine adequate and stable levels of funding needed for the program. The updated plan also should provide a standard against which progress in repository development can be assessed.

Some of the problems that have caused continuing frustration with the program have yet to be resolved. Perhaps the most important of these is the perception of program inefficiency. The DOE's tardiness in articulating a technical basis for its decisions about which program activities to pursue contributes to such perceptions. The sense of inefficiency is heightened by the DOE's inadequate integration among the various activities within the program. At times, some program participants seem to have little knowledge of the activities of other participants. With a program as large as this one (about 2,000 employees), good integration is essential for efficient program management.

The program continues to be schedule-driven. Despite the sharp reduction in funding for fiscal year 1996, there seems to be an effort within the program to maintain nearly the same schedules for repository development and licensing. For example, the DOE says that projected funding will not permit a "technical site suitability" decision in 1998. The DOE's response has been to maintain a 1998 milestone, but to give the decision a new name — a "viability assessment." The technical basis for the viability assessment will be less complete than had been anticipated for the technical site suitability decision. The Board believes it would be better to establish a strong technical basis, derived from the waste isolation strategy and total system performance assessments, to determine the scope of work required. Then, more technically defensible schedules and decision points could be established.

More use of outside experts is needed. When the project consulted outside experts to improve TBM performance, the results were impressive. After months of very poor TBM performance, several modifications were made, as recommended by outside experts. These modifications allowed excavation of the ESF to greatly improve. The project also established a standing board of consultants to advise it on ESF engineering and construction. The board of consultants has suggested to the DOE a number of specific ways to improve the design and construction of the ESF. Similar use of expert consultants in other areas may identify additional ways to improve the effectiveness of the program's operations.

During 1995, the DOE made real progress in characterizing the Yucca Mountain site — especially in obtaining important underground information from the ESF. The DOE also is developing an improved technical basis for setting program priorities. If recent progress can be maintained, the Board believes that a site-suitability decision can be made within five years. Since a repository *will* be needed eventually, the Board believes that the focus of the U.S. program for spent fuel management should remain on evaluating the suitability of Yucca Mountain as a potential site for a permanent repository. As noted above, adequate and stable funding will be needed if the program is to achieve this objective.

Board Recommendations

Recommendations made in this report are repeated below. The Board makes these recommendations in the belief that they will help the DOE achieve its goal of successfully designing and implementing a program to manage the nation's civilian spent nuclear fuel and defense high-level waste in a timely fashion.

Overview

1. The DOE should continue to refine its waste isolation strategy to make it more robust, to address potential failure modes, to state the strategy's hypotheses more precisely, and to specify criteria for determining when those hypotheses have been validated or rejected.

2. The DOE should evaluate what went wrong in the preparation and NAS review of its technical basis report on surface processes at Yucca Mountain.

3. The DOE's safety demonstration for a repository should be as rigorous and thorough as practical at the time of the initial application for construction authorization. The DOE needs to continue to work with the NRC to determine an appropriate balance between the need for data and reliance on expert judgment.

Risk and Performance Analysis

1. Building on the strengths (and filling in the gaps) shown in TSPA-95, the DOE should prepare itself for the next, and critically important, role assigned to TSPA — the Yucca Mountain site "viability assessment" in 1998. Assumptions about models and input parameters will need to be highlighted and their bases clearly laid out and open for review.

2. TSPA should play an integral role in refining and testing the basic tenets of the developing waste isolation strategy. TSPA, for example, could provide an estimate of the amount of percolation flux that could, in turn, require a reexamination of the current strategy. It can also clarify what kinds of data are needed to demonstrate that the safety case has been made.

3. The DOE should make an early determination of which aspects of the next TSPA will require expert judgment and make clear to the technical community how these judgments will be obtained.

Geoengineering

1. The DOE needs to examine both the cost and the rate of progress for excavating the ESF and compare it with planned repository construction methods when assessing the viability of the Yucca Mountain site. Additional modifications to the TBM or use of a TBM of a different design may be needed to improve excavation efficiency.

2. The Board recommends that the DOE set up a procedure to provide timely monitoring of the response and actions of the M&O contractor to the recommendations of the board of consultants.

3. The Board supports initiation of a long-term, tunnel-scale thermal test as soon as possible and recommends that more thought be given to how more information can be obtained from all heater tests.

Hydrogeology and Geochemistry

1. The Board encourages the DOE to focus sufficient resources on verifying a sound conceptual model of flow in the unsaturated zone. This exploration and testing should provide the needed evidence for assigning quantitative bounds to the infiltration flux and percolation flux and should provide general support for the unsaturated zone flow model.

2. The DOE should place a stronger emphasis on predicting (or bounding) the release rates of important radionuclides from the EBS. Specifically, the DOE should evaluate alternative models for the seepage flux (water entering repository tunnels) and the concentration of neptunium in the water leaving the EBS.

Engineered Barrier System

1. The DOE should continue its efforts to identify engineering concepts that could help the EBS accomplish the three roles (complete containment, low mobilization, slow release) set out for it in the waste isolation strategy. Once identified, the DOE should set priorities for the concepts and decide which merit further investigation.

2. The DOE should consider increasing the robustness of the EBS for preventing nuclear criticality after repository closure. In particular, the use of depleted uranium in filler, backfill, or invert material is a concept the program has yet to explore adequately.

3. Attempts should be made to locate data for iron artifacts to check extrapolations of corrosion models for waste packages based on short-term data.

4. The DOE should give a high priority to the corrosion research program for candidate waste package materials and should maintain an appropriate and *consistent* level of support for the next several years.

5. The use of fillers to prevent void space collapse should be evaluated.

Environment and Public Health

1. The DOE's socioeconomic program should expand the range of standard effects being considered to include those that will arise from increased transportation of materials, and personnel, possible social problems associated with "boom-and-bust" cycles, and the effects of controversial projects on the larger social system.

2. An uncertain legal situation prevails with respect to special socioeconomic impacts. As a result, as long as the site-suitability guidelines remain in effect, the Board believes a modest research and analytic effort would be prudent. The DOE should concentrate its efforts on deriving worst-case, bounded estimates of what consequences might arise and how long those impacts might last.

Introduction

In 1982, Congress assigned the U.S. Department of Energy (DOE) the responsibility of siting, designing, and implementing a system to manage the disposal of commercial spent nuclear fuel. (Parts of this system also will be used for disposal of government-owned spent fuel and defense high-level wastes.) The plan called for the construction of a deep, geologic repository that would isolate the waste for at least 10,000 years. But, a waste management system also involves designing, developing, and implementing the physical and organizational infrastructure to package, collect, store, transport, and, finally, dispose of these radioactive materials from public utilities and defense facilities located across the country. The major challenge for the DOE is demonstrating to the satisfaction of the regulators and the scientific and lay communities that the system will perform effectively, that workers in the system — and the public at large — can be protected, and that any potential releases of the highly radioactive material to the human environment will remain below levels of regulatory concern.

In 1987, the Congress designated Yucca Mountain, Nevada as the single candidate site to be assessed for its suitability to host a repository. For more than a decade, site characterization studies have been ongoing to investigate the properties of the site that would determine its ability to isolate radioactive wastes. Initially, those studies were carried out through surface-based testing, but construction of the exploratory studies facility has now allowed access to the potential repository horizon for underground exploration and testing. As the process of site characterization matures, analyses of data through performance assessments are becoming increasingly important for a determination of site suitability. Safe performance of a repository is also determined by its design and that of the waste packages and other engineered barriers. This report uses the term “site assessment” to refer to the full range of activities needed to evaluate the suitability of the Yucca Mountain site. Much of this report evaluates the site-assessment activities during 1995. Development of transportation, storage, and other components of a complete waste management system also will be needed, but progress to date on these has been limited. Accordingly, this report places less emphasis on those activities.

In 1987, the Congress created the Nuclear Waste Technical Review Board, an independent agency within the executive branch charged with evaluating the scientific and technical aspects of the DOE’s program. The Board submits its findings, conclusions, and recommendations to the Congress and the Secretary of Energy. The DOE responds to the Board’s recommendations in writing, and these responses are published in a subsequent Board report without comment. For the most part, this report summarizes Board activities and the results of the Board’s work during 1995. Where relevant, developments that occurred early in 1996, during drafting of this report, are also discussed. While the Board conducts detailed examinations through its various panels, the conclusions and recommendations presented in this report are made by the Board as a whole.

The Board’s first report was released in March 1990. All Board reports are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 or from the Board’s Arlington, Virginia, offices.

Chapter 1
Program Overview

This chapter provides an overview, from the Board's perspective, of the United States program for management of spent nuclear fuel and high-level radioactive waste. Generally, this report describes the Board's views at the end of calendar year 1995. However, as the report was being drafted, some significant program changes were occurring. An example was the DOE's development of the concept of a "viability assessment" to replace the technical site-suitability determination previously anticipated for 1998. The DOE also was reportedly seeking ways to pursue licensing of a repository at Yucca Mountain soon after the turn of the century, despite a 40 percent budget reduction for fiscal year 1996 and the prospect of austere budgets in coming years. Where appropriate, the Board comments on developments that occurred early in 1996, in addition to providing its assessment of the program at the end of 1995.

Some Highlights of 1995

Evolution of the Program Approach

In December 1994, the DOE published its *Civilian Radioactive Waste Management Program Plan* (DOE 1994b). In it, the DOE sought to identify and, to a limited extent, to set priorities for the activities needed to evaluate the suitability of the Yucca Mountain site and to prepare a license application for a repository.

The *Program Plan* established three intermediate milestones for repository development. First, in 1998, the DOE was to state its decision on the technical suitability of the Yucca Mountain site in accordance with the DOE's siting guidelines in 10 CFR 960. Assuming a favorable suitability decision, in the year 2000, the Secretary of Energy was to recommend to the President development of a repository at the site. The basis for this recommendation would include an evaluation of the environmental, transportation, and socioeconomic issues through the development and review of an environmental impact statement (EIS) for the proposed repository. Finally, the DOE would submit, in 2001, an application to the Nuclear Regulatory Commission (NRC) for a license to construct a repository.

During 1995, the DOE made real progress in characterizing the Yucca Mountain site — especially in obtaining important underground information from the exploratory studies facility (ESF). However, it became apparent that funding levels for fiscal year 1996 and beyond would not support the planned activities and milestones. Faced with a 40 percent reduction in its fiscal year 1996 budget, the DOE had to begin reducing the scope of its site-assessment activities and set priorities for its studies for the coming years. Surface-based testing at Yucca Mountain was cut back, allowing site assessment to concentrate on underground exploration and testing, repository design, and total system performance assessment. The DOE abandoned its milestone to evaluate the technical suitability of the Yucca Mountain site using 10 CFR 960. Instead, the DOE is now pursuing a "viability assessment" for Yucca Mountain, to be announced in 1998.[1] Work products to be completed by 1998 are:[2]

1 *Statement by Secretary O'Leary before the Senate Committee on Energy and Natural Resources, (U.S. Congress. Senate 1995b).*

- More specific design work on the critical elements of the repository and the waste package.

- A total system performance assessment, based on the design and the site-characterization data available, to describe the probable performance of a repository at the site.

- A plan and cost estimate for the remaining work required to complete a construction license application.

- An estimate of the costs to construct and operate the repository.

The relationship between a "viability assessment" and an evaluation of the technical suitability of the Yucca Mountain site is unclear. The purpose of the "viability assessment" seems to be to decide whether continued site studies and repository development are warranted. As such, the 1998 decision appears to have no direct relationship to the "technical site suitability" decision anticipated in the DOE's 1994 *Program Plan*. The basis for, and the timing of, a possible recommendation to the President for development of a repository at the site also are undefined. However, according to the President's budget submission to the Congress for fiscal year 1997, the DOE now has a target date of 2002 to submit an application to the NRC for a license to construct a repository (DOE 1996).

As fiscal year 1996 began, the emphasis of activities at Yucca Mountain shifted toward an analysis and write-up of the work previously completed. This period for analysis can be quite fruitful if it is used to identify and justify the work still needed for the viability assessment, the recommendation of the site for a repository, and the construction license application. Because of the relatively long time required to document test results, analyze their significance, and incorporate the results into a license application, it is imperative for the project to formulate as soon as possible a list of required activities, their justification, and their relative priorities. This statement of "work that needs to be done" is one of the four key points of the viability assessment to be completed by 1998, but the Board agrees that preparation of the list (and its rationale) should begin now.

The large budget cutbacks have forced a reevaluation of the scientific activities at Yucca Mountain, which the Board supports. But the Board has two major concerns. First, there is a perception and perhaps a real danger that "postponed" work will be permanently curtailed, even if ongoing analyses show that it is required. Any incentive within the project to initiate further studies or analyses could be overwhelmed by concerns about budgets and schedules, as noted by the Board in its 1993 *Special Report* (NWTRB 1993a). The second concern is that the budget cuts have caused key technical expertise to leave the project with resulting negative effects on the morale of the personnel who remain.

It is obvious that efficient progress cannot be achieved in characterizing the Yucca Mountain site without adequate and stable program funding. The Board believes that the best way to determine the necessary level of funding is for the DOE to update its 1994 *Program Plan*. Aside from updated schedules, the major change needed is development of a sound technical justification for the planned activities. To a large extent, this justification should flow naturally from the evolving waste isolation strategy and the results of total system performance assessments. The revised program approach also should prioritize planned activities and should include contingency plans to accommodate budgets that are larger or smaller than expected. Once in place, the updated plan would provide the DOE with a basis for informing the Congress concerning adequate and stable funding needed for the program.

Multipurpose Canister Dropped

The fiscal year 1996 appropriations for the DOE zeroed out funding for the multipurpose canister (MPC) system. Design work, contained in an already-awarded contract, will be completed, but further developmental work on the concept has been canceled.

2 Remarks prepared by Daniel A. Dreyfus for the Board's winter meeting, (NWTRB 1996a).

Had the DOE proceeded with MPC development and deployment, its plans called for providing the canisters to all utilities in need of dry storage for their spent fuel. With the program canceled, the emerging need for dry storage at various reactor sites will be met by various vendors in the private sector, as has been the case up to now. The standardized storage technology proposed for the MPC was not very different from that now available in the marketplace, that is, a metal canister placed either vertically or horizontally in an overpack or vault made of metal or concrete. For transport, the MPC program envisioned an overpack which, together with the canister, would constitute a transport package. A few of the vendors are planning similar combinations and are currently in varying stages of the design and licensing process for the transport overpack. Thus, a dual-purpose canister system appears to be becoming available. Whether the various canisters in these potential dual-purpose systems can be uniformly incorporated into the eventual disposal package remains to be seen.

Since it was to have been widely deployed, the MPC concept had the potential to promote a degree of standardization in some of the components of the waste management system. With the cancellation of the MPC, there now will be several designs for the storage canister and the transporter, making waste handling, transportation, and logistics somewhat more complicated and potentially increasing both the cost and the operational risk for subsequent steps. The Board encourages the DOE to work with the private sector to minimize potential compatibility problems.

Environmental Standards for Yucca Mountain

The Energy Policy Act of 1992 (U.S. Congress 1992) directed the U.S. Environmental Protection Agency (EPA) to promulgate standards for protection of the public from releases from radioactive materials placed in a repository at Yucca Mountain. Before developing its standards, the EPA was to contract with the National Academy of Sciences (NAS) for a study to provide recommendations on standards for the Yucca Mountain site. The study was to address three questions:

- whether a health-based standard based upon doses to individual members of the public from releases to the accessible environment will provide a reasonable standard for protection of the health and safety of the general public,

- whether it is reasonable to assume that a system for post-closure oversight of the repository can be developed, based upon active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered or geologic barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits, and

- whether it is possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years.

On August 1, 1995, the NAS released its report (NAS/NRC 1995a). Its principal recommendations are the following:

- A limit on risks to individuals is recommended as the basis for a standard. Limits on the cumulative release of radionuclides should *not* be part of the standards.

- The risk limit should apply until the peak risk occurs, within the limits imposed by long-term stability of the geologic environment (estimated to be about a million years).

- Standards should limit the *average* risk within a "critical group" of exposed individuals. The report suggests using a probabilistic procedure to define the critical group. The report also includes a minority view which suggests a simpler, but more conservative way to define the critical group.

- Institutional controls over the site should not be relied on to prevent human intrusion or releases of radioactive waste exceeding regulatory limits.

- There is no scientifically supportable basis for predicting the probability of human intrusion. Therefore, human intrusion into the repository should *not* be included in the estimate of risk. The consequences of intrusion should be evaluated separately.

On September 11, 1995, the EPA requested comments from interested parties on the NAS report. The Board offered its views in a December 13, 1995, letter to the EPA. The Board's letter can be found in its entirety in Appendix F.

The Board believes that the recommendations of the NAS report on Yucca Mountain repository standards are generally consistent with international radiation protection guidance and with the high-level waste standards of other nations. Some of the recommendations (especially the probabilistic critical group concept) are complex, controversial, or fundamentally different from existing standards and regulatory practices at the EPA. The very long regulatory time period recommended by the NAS, if adopted, would seem to place more emphasis on the natural geologic barriers (probably including the Calico Hills formation) and on any engineered barriers that could delay or reduce releases for tens to hundreds of thousands of years (e.g., fillers and backfill). If standards are adopted that emphasize protection of individuals rather than cumulative releases of radionuclides, it will be very important to predict the transport and dilution of any waste released from a repository. Studies of the mixing and dilution potential of both the unsaturated and the saturated zones of Yucca mountain will be important, as will transport and mixing within different portions of the aquifer underlying the repository.

At the end of the year, the Congress considered imposing, by legislation, regulatory criteria somewhat different from the recommendations of the NAS panel. The proposed legislation would set an individual dose limit of 100 mrem / yr — a factor of three to ten higher than the dose limits adopted by other nations. It also would limit the period of regulatory compliance to 10,000 years and it would specify an assumption that institutional controls will be effective in preventing human intrusion into, or disruption of, the repository. While it is difficult to determine whether progress in characterizing the Yucca Mountain site has been hampered by the fluctuating regulatory environment, there is an obvious risk that public credibility in the regulatory process will be undermined if it appears that the regulatory criteria are being relaxed to accommodate the Yucca Mountain site.

An Independent Review of the Yucca Mountain Project

In 1993, in response to criticisms of program management, Secretary of Energy Hazel R. O'Leary agreed to sponsor an independent management and financial review of the Yucca Mountain project. Two firms — Peterson Consulting Limited Partnership and John Reiss, Jr. and Associates — were selected to perform the review.

Many of the review's conclusions and recommendations (Peterson 1995) address *generic* issues that are relevant regardless of what course the program and the project take in the future. The following are three such issues that the Board believes are especially important.

Project schedule

The review concluded that the Yucca Mountain project had very little chance of meeting its major milestones. It found that the schedule contained very little "float," or flexibility to recover from unexpected delays. Consequently, it was likely that the project could maintain its schedule only under the most optimistic circumstances. The review suggested that a possible by-product of an optimistic schedule is a reluctance to engage in contingency planning.

Project decision-making

The review found that project managers were reluctant to pay attention to the views of external parties, including industry experts. The review also concluded that financial and contractual considerations appeared to have been given inadequate analysis. For example, not enough attention was paid to understanding the potential advantages of leasing or contracting for services and equipment.

Project management

The reviewers were concerned that the program's management and operating (M&O) contractor did not have sufficient incentive to perform cost-effectively. The M&O contractor has a cost-plus-award-fee type of contract in which the level of the award fee is set every six months. But, according to the reviewers, only 26 percent of the weight of the award fee criteria is related to cost-effective performance. This, they believe, is inadequate. Especially in times of constrained resources, anything that might foster productivity ought to be encouraged.

The Board believes that the recommendations of this review have enduring value for project management. Realistic schedules (with room for delays and contingency planning), effective consultation with outside experts, and use of financial incentives for efficient contractor operations will be needed if the project is to succeed.

Technical Basis Reports

On November 30, 1995, a National Academy of Sciences / National Research Council panel issued its review (NAS / NRC 1995b) of the *U. S. DOE Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion* (DOE 1995). This technical basis report (TBR) was the first of a series that was supposed to lay the foundation for a site-suitability decision on Yucca Mountain using guidelines described in 10 CFR 960. Although the subject of this first TBR was not generally viewed as a serious safety concern at Yucca Mountain, the report was significant because it represented the DOE's first attempt to submit Yucca Mountain information to resolve a scientific issue. The NAS panel received the TBR in April 1995 and was asked to review the quality and completeness of the scientific data and reasoning presented. Significantly, the panel was *not* asked to judge compliance with 10 CFR 960.

According to the highly critical final NAS review, the TBR was deficient in many ways. Criticism ranged from inadequate scientific justification to poor documentation and management control. The NAS panel, for example, took issue with the report's heavy reliance on one controversial technique, varnish cation ratio dating, while neglecting or minimizing reliance on other evidence to establish past rates of erosion at Yucca Mountain. The panel also faulted the TBR for inadequate discussion of perched water and ineffective discussion of water supply issues. The NAS panel found that the report was not comprehensible to a broad audience, there was no clear statement of questions to be answered, and referencing and synthesis were inadequate. Of particular importance was the fact that those scientists who conducted the site investigations were not involved in preparing the report and there was no peer review. Although an earlier *Topical Report* (DOE 1993) submitted to the NRC on the topic of erosion had also been similarly criticized for its scientific reasoning, it was not mentioned in the TBR, nor were any of the NRC's criticisms heeded.

Finally, it appears to the Board that the DOE attempted to set up a *context-free* review of the issue. The DOE requested a purely scientific review that could *not* take into account the significance of the science with respect to the issue at hand — the safety of the proposed repository. While this may be pleasing from an academic point of view, it is not very helpful to a mission-oriented agency (with a limited amount of funding) trying to focus on those issues that count.

Even though there are no plans for additional TBRs, the DOE needs to try to understand what went wrong. If the DOE has trouble resolving what most scientists consider to be a non-issue,[3] how can it hope to resolve the more difficult and important ones and defend its position to a wider audience?

3 *On February 29, 1996, the staff of the Nuclear Regulatory Commission informed the DOE that it considered the issue of erosion to be resolved. Resolution was not based solely on the Topical Report or the Technical Basis Report discussed here but also on ongoing investigations subsequently initiated by the DOE and on studies carried out by other parties.*

Current Status of the Program

Underground Exploration and Testing

Progress in underground exploration and testing is, in large part, synonymous with progress in ESF excavation. As excavation of the ESF proceeds, details of the various geologic features and formations are revealed and physical samples can be obtained for analysis. At selected points along the tunnel, especially fault zones and major contacts between different geologic strata, alcoves are excavated in which hydrogeologic and other testing can be conducted using horizontal or vertical drill holes.

Excavation of the ESF with a tunnel boring machine (TBM) started in late September 1994. Initial progress was very slow, averaging only about 120 meters (400 feet) per month through July 1995. After installing a conveyor system for more efficient removal of excavated rock, modifying the TBM, and entering less fractured rock, production improved dramatically. During the months of September, October, and November, 1995, the TBM averaged about 550 meters (1,800 feet) of tunnel excavation per month, more than four times the earlier rate of progress. (In addition, during this period, the construction contractor excavated three test alcoves without interrupting TBM activities.) However, by the end of February 1996, geologic conditions had worsened. TBM progress slowed to about 15 meters (50 feet) per day and remained low through March and early April. On April 16, 1996, the TBM had completed the north ramp and nearly three-fourths of the main tunnel, totalling approximately 4,900 meters (16,000 feet) of tunnel.

Underground exploration has indicated *so far* that the quality of the rock inside Yucca Mountain is better than anticipated from surface mapping. Some differences are being found between the predicted orientation of several faults and what was actually observed, although these differences are not likely to affect the site's suitability. One *favorable* difference may be in the nature of the Drill Hole Wash Structure. The apparent insignificance of this suspected structure may permit expansion of the repository block to the northwest, allowing more room for waste emplacement. Finally, access to the repository horizon has allowed collection of numerous rock and fracture coating samples, which may help to better define the hydrologic conditions within Yucca Mountain.

Information of these types clearly illustrates the importance of subsurface exploration and testing as an integral part of the site-characterization effort at Yucca Mountain.

Program Priorities

At the beginning of 1996, the DOE's reduced budget led to many changes in the program. For example, emphasis in characterizing the site shifted to underground exploration and testing while surface-based testing was cut back significantly. What was not clear was *the technical basis* for the DOE's decisions. While the Board would like to believe that the DOE's decisions seek to maximize the quantity and quality of the scientific information available for evaluating the safety of a Yucca Mountain repository, the Board is well aware that funding and schedule are important constraints.

An especially evident problem is the planning for 1996 ESF activities. At the beginning of fiscal year 1996, approximately $60 million was earmarked for ESF activities, a 40 percent reduction from fiscal year 1995. There is strong pressure being exerted by the top managers of the DOE to use these limited funds to pursue completion of the entire north portal-to-south portal loop. Current plans call for the loop completion by late January, 1997.

The decision to complete the portal-to-portal loop is not a technical decision, as little additional information will be obtained to support the repository design. Considering the difficult geologic conditions that may be encountered while excavating the south ramp, a large part of the fiscal year 1996 and 1997 budgets may be required to complete the portal-to-portal loop. This would preclude any possibility of initiating other more important exploration such as an east-west crossing of the geologic block.

The Evolving Waste Isolation Strategy

The Board has previously recommended (NWTRB 1995b) that the DOE articulate a clear and coherent waste isolation strategy, which would provide an understandable technical rationale for identifying the most important issues about the suitability of the site, for setting priorities for the studies to be completed for the Yucca Mountain site, and for designing the engineered barriers of a repository. During 1995, the DOE made considerable progress in developing such a strategy. The following paragraphs summarize and provide the Board's views on the key features of the evolving strategy.[4] More detailed discussions of some parts of the strategy are presented in the next chapter. It is important to emphasize that the waste isolation strategy must be updated periodically as additional information is acquired about the Yucca Mountain site, the expected performance of engineered barriers, and licensing standards.

The Board is pleased with the obvious progress that is being made in the formulation of the waste isolation strategy and in the use of that strategy to set priorities for the activities of the Yucca Mountain project. The comments offered below, and the recommendations at the end of this chapter, should be taken as constructive suggestions for improving future iterations of the strategy and not as criticism of efforts to date.

Key features of the strategy

The DOE has formulated two general safety objectives for the performance of a repository at the site.

- Contain the wastes within waste packages for thousands of years.
- Limit the radiation dose rate to any member of the general public at any time.

The strategy then presents five hypotheses about how natural and engineered barriers might contribute to achieving these goals.

(1) There will be little seepage of water into the emplacement tunnels of the repository.

(2) Waste packages will provide complete containment for thousands of years.

(3) The rate of waste mobilization will be low after waste packages are breached by water.

(4) Engineered barriers will limit the rate of release of radionuclides to the host rock.

(5) The site's natural barriers (groundwater flow and mixing) will provide substantial dilution of any releases that might reach the water table.[5]

The strategy also hypothesizes that several crosscutting issues can be dealt with successfully as the repository is designed (thermal effects) or will not significantly degrade repository performance (climate change, human interference, tectonics, seismicity, and volcanism). The strategy outlines tests and analyses to be pursued in the near future to try to substantiate the five basic hypotheses and to address the cross-cutting issues.

Board's views on the strategy

Following are some general observations about the DOE's evolving waste isolation strategy. More specific comments are presented in the next chapter.

- The strategy lacks robustness (defense-in-depth) because of its heavy reliance on the presumed continued dryness of the Yucca Mountain site. Most, if not all, of the five hypotheses would be called into question by the discovery of any intermittent, but significant, flowing water at the pro-

4 *Drafts of the strategy, dated October 1995 (TRW 1995b) and January 15, 1996 (TRW 1996c) were provided to the Board. The analysis in this section is based on the January 15 draft as well as presentations to the Board throughout 1995 and in January 1996.*

5 *The Board notes that dilution may be a more complex process than indicated here (and in the draft strategy). A combination of low and intermittent percolation, low radionuclide mobilization rates, and slow transport through the natural barriers will provide only occasional pulses of radioactive material reaching flowing ground water in the saturated zone beneath the repository. Subsequent mixing and sorption may provide high levels of dilution of radionuclides as they are transported beyond the repository.*

posed repository location. A more robust strategy should be considered that would identify hypotheses that could be used to compensate for an unexpectedly high percolation flux between the repository horizon and the water table.

- All of the five basic hypotheses address favorable conditions. The discussion of possible failure modes is limited to evaluations of some external events in the appendices of the draft strategy. The strategy would be strengthened if the body of the document placed more emphasis on identification of potential failure modes and on formulation of testable hypotheses about their importance. A more thorough evaluation of the significance of external events is needed, as is identification and evaluation of "internal" failure modes (e.g., unanticipated hydrologic conditions or poor engineered barrier performance).

- Safety objectives and hypotheses are stated qualitatively. While this is appropriate for the early stages of strategy development, more precision will be needed as the strategy evolves toward license application. This is especially true for the safety objectives, which are now subject to a very wide range of interpretation due to their qualitative formulation. At a minimum, the Board believes, the strategy needs to designate a numeric limit for radiation doses to individuals and to specify the conditions under which exposures to released radioactive materials will be assumed to occur.

- The strategy contains no criteria for validating or rejecting the five hypotheses. A clearer understanding is needed of the degree of proof that is being sought for each hypothesis. Because the strategy is so dependent on the apparent dryness of the site, it would be especially useful to try to determine the amount and distribution of percolation flux that would require additions to, or revisions of components of, the waste isolation strategy.

- While the strategy is still evolving, it is *not* too early to begin using it to identify the most important issues about the suitability of the Yucca Mountain site. Presentations to the Board indicate that the DOE is beginning to use the strategy to this end.

Transportation of Spent Fuel

Congressional budget decisions for fiscal year 1996 have eliminated practically all of the waste acceptance, storage, and transportation activities within the DOE's Office of Civilian Radioactive Waste Management.[6] The DOE interprets the congressional action as direction to leave equipment development efforts to private businesses which have substantial experience in developing various types of casks.

If the Congress directs the DOE to establish an interim storage facility within the next five years, it will be necessary to develop the capability to transport 2,000 to 3,000 metric tons of spent fuel per year. This will be politically, environmentally, and technically challenging if the site is to be at or near Yucca Mountain, since no rail access currently exists there. Heavy-haul transport (i.e., 12-axle trailers, slow travel speeds, escorts required) over existing roads may be an option as a stopgap measure for relatively small quantities of spent fuel. However, a sustainable, large-capacity transportation system may require construction of a rail spur (or upgraded and/or dedicated roadway) to the site. Obtaining needed approvals for the routing as well as the actual construction of a rail spur may be difficult and would likely require several years to complete.

Availability of enough transportation casks is another challenge, although not an insurmountable one. Licensed, legal-weight truck casks exist today, and additional casks of the same (or similar) design could presumably be fabricated and put into service quickly. Existing rail casks have been "grandfathered" for use, but cannot be replicated because

6 *The Phase I design contract with Westinghouse for the multipurpose canister will be completed, but later phases will be terminated. The advanced truck cask development program with General Atomics will be suspended. Half-scale testing for the GA-4 cask has just been completed, but further certification activities will not be pursued. Other activities will be minimal. While the Congress earmarked $85 million for interim storage planning, those funds are not available to the DOE until additional legislation is passed.*

they would not satisfy current licensing requirements. A dual-purpose (storage and transportation) rail cask has been certified for transportation and other casks are being developed. These too can be fabricated in quantity if it appears that there is an assured market for them.

Other issues need to be resolved before significant amounts of spent fuel could be transported to a storage facility. Some of these pertain to physical facilities (e.g., adequacy of rail spurs to reactor sites), some to logistics and operations (e.g., assembling appropriate management expertise), and some to institutional issues (e.g., providing technical assistance for safety officials along the routes). Some of these issues may involve multiple parties, and some may involve substantial costs. However, these are not insurmountable difficulties. Although the magnitude of the amount of spent fuel to be transported is very large compared to historic volumes, the nation has more than three decades of experience transporting both civilian and DOE-owned spent fuel using commercial carriers. In the 1980s, 100 to 200 such shipments typically were transported each year. Both highway and rail modes were used. For example, in the mid-1980s more than 200 highway shipments of fuel originated from West Valley, New York, to return fuel to the plants where it was generated originally. About 30 rail shipments each originated from the Monticello plant in Minnesota and the Cooper Station plant in Nebraska destined for the GE Morris facility in Illinois. The safety performance of these shipments, as with all of spent fuel transportation, has been excellent. The Board notes, however, that the public's *perception* of transportation risks is sometimes much different from the risks projected from analyses of the statistical record. Public opposition may be encountered, in some locations, to large-scale shipments of spent nuclear fuel. This may make projecting the schedule for developing and operating a transportation system for moving large amounts of spent fuel to a centralized storage facility more difficult.

In the Congress

Renewed Focus on Waste Acceptance

Calendar year 1995 began with bipartisan recognition in the Congress that the DOE's high-level radioactive waste management program would not lead to federal acceptance of commercial spent fuel by the end of January 1998. Legislation was introduced in both the Senate (S. 167) and House of Representatives (H.R. 1020) to create an interim storage facility on the Nevada Test Site quickly. Provisions were included in both bills for major streamlining of the regulatory development process.

The Senate Committee on Energy and Natural Resources convened an initial legislative hearing[7] on March 2, 1995. There was general recognition by government and industry witnesses alike that, despite progress achieved in 1994 by the DOE, the waste acceptance date set forth in the Nuclear Waste Policy Act was not achievable. The DOE's stated objective was not initiation of waste acceptance but, rather, to reach closure on the scientific activities at Yucca Mountain and determine if the site is technically suitable by 1998. The DOE's approach to this objective was set forth in the December 1994 *Program Plan* (DOE 1994b) and supported by the DOE's fiscal year 1996 budget request.

Hearings on the interim storage of spent nuclear fuel were also held in the House of Representatives.[8] There was general agreement among subcommittee members that an interim storage component should be integrated into the DOE's nuclear waste management program. The DOE's preliminary estimate for the construction cost of such a facility was $600 to $800 million and, once the facility was constructed, about $250 million would be required annually to support the movement of approximately 3,000 metric tons of spent fuel from reactors to the interim storage facility. As reported, H.R. 1020 directed the DOE to develop an interim storage facility within Area 25 of the Nevada Test Site in two phases. The first phase, with a capacity of 10,000 metric tons,

7 *Hearing before the Senate Committee on Energy and Natural Resources (Senate 1995a).*

8 *Hearings before the Subcommittee on Energy and Power (House 1995a).*

would occur as early as 1998 and would be modeled after the existing independent spent fuel storage installations already licensed by the NRC. The second phase, with a capacity of 40,000 metric tons, would be licensed for 100 years.

The Senate Committee on Energy and Natural Resources ended 1995 with a December 14 hearing to obtain the Administration's position on pending nuclear waste legislation.[9] Secretary of Energy Hazel R. O'Leary stated that the Administration opposed the pending legislation. While the objectives of this legislation were consistent with the long-established federal obligation to provide for the long-term custody of the nation's spent fuel and high-level waste, the Secretary expressed concern over the likelihood that the priorities in the pending legislation would so constrain funding that an efficient schedule for the geologic disposal program could not be maintained.

The Secretary also expressed concern about the emphasis on establishing an interim storage facility and the unreasonable deadlines that would result from the legislation. While the Secretary expressed support for generic work toward early waste acceptance, she observed that under existing law Nevada should be excluded from consideration as an interim storage site. She also noted the President's opposition to the preemptory designation of Nevada as a site for an interim storage facility. In fact, the President threatened to veto the fiscal year 1996 Energy and Water Development Appropriations bill if it authorized the construction of an interim storage facility in Nevada (EOP 1995).

Implications for the Program

As 1998 approaches, pressure for the federal government to "do something" about acceptance of spent fuel is likely to increase. The principal legislative initiatives during 1995 concentrated on developing a federal centralized storage facility to allow federal acceptance in 1998 or soon thereafter. The Board's recently published report on spent fuel storage (NWTRB 1996b) analyzed the implications of developing such a storage facility. The Board believes that a federal storage facility will be needed eventually, but the nation also needs a geologic repository for permanent disposal of commercial spent fuel and government-owned wastes. The Board is particularly concerned that developing a storage facility now could cause competition for funding and other resources that, in turn, could slow repository development so much that storage at an "interim" facility would need to continue indefinitely.

The Board believes that the timing of any decision to develop a federal storage facility at or near Yucca Mountain will be important. The Board believes that the suitability of the Yucca Mountain site for repository development should be determined by the DOE *before* a storage facility is developed there. A premature storage siting decision is likely to cause a real or perceived prejudicing of the repository site-suitability evaluation.

The Board is concerned that the existing Nuclear Waste Fund may not be able to support both storage and disposal. The existing fee assessed on generation of nuclear power was intended to finance disposal — not long-term storage. Projections indicate that the current fee is inadequate to pay for *both* storage and disposal. In fact, the fund may be deficient by $3 to $5 billion for disposal only, based on the current fee of 1 mill per kilowatt-hour (Peterson 1995). If the Nuclear Waste Fund is used to provide federal interim storage of spent fuel, without a fee increase, a taxpayer bail-out of the fund is likely to be needed to pay for the latter phases of repository operation and closure. The Congress should consider an increase in the existing fee, or imposition of a new storage fee, to pay for any new federal storage facility that might be authorized.

Shifting Program Milestones

The Board recently stated its belief that the suitability[10] of the Yucca Mountain site can be determined within five years, given sufficient and consistent

9 *Hearing on S. 1271 on December 14, 1995 (U.S. Congress. Senate 1995b).*

program funding (NWTRB 1996b). However, the DOE is now using the term “viability assessment” to describe the next major milestone for its evaluation of the Yucca Mountain site. This assessment is to be completed in 1998. The DOE also has suggested that a license application for authorization to construct a repository could be completed in 2002 (DOE 1996). Since the DOE maintains that the viability assessment is not a suitability decision, it is unclear at what time and in what manner the suitability of the site for repository development will be determined.

Site Suitability

In its December 6, 1994, letter to the DOE (NWTRB 1994d), the Board spelled out the key activities that it believes are needed for a technically defensible site-suitability decision. These activities can be summarized as follows.

- Continue development of a coherent waste isolation strategy.
- Continue underground exploration north-south and east-west across the proposed repository area to access major geologic structures and rock types and to investigate hydrogeologic characteristics of the site.
- Predict or bound the amount of water that could reach the repository, corrode the waste packages, and transport radionuclides to the environment.
- Collect initial results from underground tunnel-scale heater experiments to predict better the movement of water in the rock surrounding the hot waste packages.

The Board continues to believe that a suitability decision, based on the information acquired from these activities, is a necessary next step toward repository development. Furthermore, the Board believes that if the DOE can maintain the recent pace of its program, sufficient information will be available to make this decision within five years. Any decision that might be attempted with less information would be difficult to support technically and might need to be reexamined as more complete information is acquired later.

Licensing Information Needs

The Board notes that additional work beyond the DOE’s site-suitability decision must be completed to provide the technical basis for applying to the NRC for a license. In the Board’s view, a license application should include a demonstration of repository safety that is based on and supported by field and laboratory measurements whenever practical. It should *not* rely on expert judgments in lieu of reasonably obtainable data. To the extent that conservative or bounding assumptions are used, the validity of those assumptions must be demonstrated. In general, the safety demonstration should be as rigorous and thorough as practical at the time of the initial application for construction authorization.

The following are examples of the types of information the Board believes can reasonably be developed to support a license application.

- Several years of in-situ thermal test data will be needed to improve model predictions of geologic and hydrologic responses to repository heat loads.
- Additional design work will be needed to integrate the repository’s engineered components with the site conditions found during site characterization.
- More material-specific corrosion data must be collected for waste package materials and their use.
- Alternatives to the major components of the repository system must be evaluated including, but not limited to, the waste package(s), waste package fillers, backfill, and waste handling systems.

10 *By suitable, the Board means that there is a high probability that the site, along with the appropriate engineered barriers, can provide long-term waste isolation.*

- The geologic and hydrologic conditions of the Calico Hills formation may have to be determined by excavating into the formation.[11]

- The probabilities and consequences of volcanism, seismicity, and other potentially disruptive processes and events should be determined through data collection, natural analogs, and elicitation of expert judgments.

In the past, construction of a repository would be authorized only after a thorough safety demonstration for the proposed facility. Now, funding restrictions and pressures to speed up spent fuel acceptance are causing the DOE to delete some planned tests and to defer others until after its initial construction license application is submitted. In effect, some testing will be carried out simultaneously with repository construction and operation, rather than during the initial phase of site assessment. The Board has two concerns about such a shift. First, as the project builds up momentum during construction and operation, it will become more and more difficult to persuade opponents and skeptics that any test results that might question the facility's safety have been objectively evaluated. And, if funding continues to be constrained, there may be a tendency to defer planned tests indefinitely, resulting in an inadequate scientific basis to support safety decisions about the facility. The Board believes that it will be important to establish a sound technical basis to support a license application. As the first step in developing this technical basis, the program should maintain its focus on evaluating the suitability of Yucca Mountain as a site for a permanent repository.

Conclusions and Recommendations

Conclusions

1. The Board commends the DOE for its efforts toward developing a waste isolation strategy. As the strategy evolves, the Board believes that it will provide a technically supportable basis to help the DOE set priorities for its exploration and testing.

2. The program approach announced by the DOE in its December 1994 *Program Plan* needs to be revised to reflect the realities of fiscal year 1996 and future appropriations. The DOE needs to improve the technical basis for its decisions on program priorities, especially by linking those decisions more tightly to the waste isolation strategy and to the results of total system performance assessments. The revised program approach should include contingency plans to accommodate budgets that are larger or smaller than expected.

Recommendations

1. The DOE should continue to refine its waste isolation strategy to make it more robust, to address potential failure modes, to state the strategy's hypotheses more precisely, and to specify criteria for determining when those hypotheses have been validated or rejected.

2. The DOE should evaluate what went wrong in the preparation and NAS review of its technical basis report on surface processes at Yucca Mountain.

3. The DOE's safety demonstration for a repository should be as rigorous and thorough as practical at the time of the initial application for construction authorization. The DOE needs to continue to work with the NRC to determine an appropriate balance between the need for data and reliance on expert judgment.

11 Recommended by the Board to support the site-suitability decision (NWTRB 1994d). The DOE apparently has no plans for excavation into the Calico Hills formation during any phase of repository development.

Chapter 2

Panel Activities, Conclusions, and Recommendations

This chapter presents the Board's more detailed analyses of several aspects of the program (especially the Yucca Mountain Project). It begins with a review of the total system performance assessment completed in 1995 (TRW 1995c) for a potential Yucca Mountain repository.

Risk and Performance Analysis

Total system performance assessment (TSPA) is the principal method for evaluating the ability of the proposed repository (both engineered and natural components) to contain and isolate waste. It serves several functions. It will be an important part of the DOE's assessment of the suitability of Yucca Mountain as a site for a high-level waste repository. If the site is judged to be suitable, TSPA will be the primary analytic tool by which the NRC will evaluate whether the repository can be built and operated so as to keep the future risk of radioactive exposure below levels of regulatory concern. Before these decisions are made, TSPA can (and should) help guide site assessment activities, assess priorities, and evaluate different engineering designs. Performance assessment can also play an important role in testing and refining the DOE's waste isolation strategy, the underlying set of concepts by which the DOE believes Yucca Mountain can safely contain and isolate waste.

In the following paragraphs, the Board outlines the basic structure and results of the latest version of TSPA for Yucca Mountain (TSPA-95), evaluates the insights developed, and makes several recommendations as to how future TSPAs can be used and improved. Additional detail on specific aspects of TSPA-95 can be found in the Hydrogeology and Geochemistry and the Engineered Barrier System sections of this chapter.

Background

The DOE sponsored two earlier iterations of TSPA for Yucca Mountain. In 1991 a study by Sandia National Laboratories (SNL 1992) and another by Pacific Northwest Laboratory (PNL 1992) were issued. They currently are referred to as *TSPA-91*. In 1993, the next iteration of TSPA also appeared as two separate studies, one by Sandia National Laboratories (SNL 1994) and the other by the M&O contractor (Intera 1994). They were discussed by the Board in 1994 (NWTRB 1994c) and currently are referred to as *TSPA-93*.

There have been many other performance assessments of Yucca Mountain that are not discussed here. These include those carried out by the Electric Power Research Institute, the Nuclear Regulatory Commission, and several less comprehensive DOE-sponsored studies conducted throughout the years.[1]

1 *A more complete discussion of past and present TSPAs at Yucca Mountain appeared in a DOE presentation by A. Van Luik, titled "Total System Performance Assessments: A Context for TSPA-95" at the Board's October 1995 meeting (NWTRB 1995f).*

TSPA-95 was presented to the Board at its October 1995 meeting. It consists of only one study, carried out by the M&O contractor. Subsequent to the October, 1995 Board meeting, which reviewed a draft version of the TSPA, the Board received a final version of the report documenting TSPA-95. This discussion highlights the many assumptions made in TSPA-95 and is based on material presented at the October meeting and in the final report (TRW 1995c).

A Synopsis of TSPA-95

The repository and its setting

Yucca Mountain is a fault-bounded uplifted block made up of layers of consolidated volcanic ash, called *tuff*, laid down more than ten million years ago in a series of eruptions from a very large volcanic center some 30 kilometers to the north. The area is presently arid, with an average precipitation of about 170 mm per year and a potential *evapotranspiration* of about 1,000 mm per year. The planned location of the repository is in one of the volcanic tuff layers called the Topopah Springs *welded* tuff. Welded tuff is ash hardened by intense heat and pressure into rock consisting of a relatively impermeable *matrix* and highly permeable fractures.

The repository horizon is in the unsaturated zone, several hundred meters below the crest of the mountain and several hundred meters above the water table, the upper limit of fully saturated rock. It is assumed that 63,000 metric tons (MTU) of spent fuel from civilian reactors and 7,000 MTU of defense high-level waste will be placed in about 10,000 metal containers, each consisting of an outer layer of *corrosion-allowance* material (carbon steel) over an inner layer of *corrosion-resistant* material (nickel-based alloy). These containers will be emplaced on the floors of a series of drifts (tunnels).

The spent fuel and high-level waste generate heat due to the decay of radioactive materials. An important design consideration is the thermal loading of wastes in the repository. Under the TSPA-95 assumption of *high thermal loading*, the containers are emplaced densely (83 MTU per acre) so that the temperatures in the vicinity of these containers will remain high (above the boiling point of water) for thousands of years. Under the alternate TSPA-95 assumption of *low thermal loading*, the containers are emplaced less densely (25 MTU per acre) resulting in a much shorter period of high temperature. Different assumptions also are made about the presence of backfill, that is, a gravel fill placed in the tunnels around the containers.

Movement of moisture into the repository

Moisture is assumed to enter the mountain as infiltrating precipitation moving through the mountain as *percolation flux*,[2] distributed (depending on the rock properties) between *matrix flow* and *fracture flow*. As the percolation flux increases, the amount and proportion of water flowing in the fractures increases. Two scenarios based on interpretations of data collected at Yucca Mountain are used. The low percolation scenario assumes that moisture only flows downward through the rock directly above the repository and results in a percolation flux of approximately 0.02 mm/yr. The high percolation scenario assumes that water can also move laterally into the rock layers above the repository, from areas of higher infiltration, increasing the downward flow, resulting in a percolation flux of approximately 1.2 mm/yr.[3]

As modeled in TSPA-95, the percolation flux at the repository horizon is divided into about 10,000 local *catchment areas*, each one corresponding to a single waste package. *Any water in a fracture is assumed to drip directly into a tunnel containing a waste package*, while water in the rock matrix is assumed to remain in the rock surrounding the tunnel. Whether, and how much, fracture flow (and dripping) occurs in a particular catchment area is a function of the rock properties and the percolation flux. Rock properties are extrapolated from existing data, while the percolation flux is assigned an assumed mathematical sta-

2 *TSPA-95 uses a term called infiltration flux which is assumed to be equivalent to the percolation flux at the repository horizon.*

3 *The low and high percolation scenarios are modeling assumptions that may or may not represent actual site conditions.*

tistical distribution centered about the "low" or "high" percolation scenarios discussed above. It is important to note that almost no packages become wet at a flux of 0.01 mm / yr, while nearly 50 percent of the waste packages are affected at a flux of 1.0 mm / yr.

Corrosion of the waste package and release of radionuclides

Heat generated by the radioactive waste affects the temperature and relative humidity in the tunnel. This is important because it influences the onset of corrosion. Two environments, with and without gravel backfill, are assumed along with two thermo-hydrologic models for predicting the temperature and relative humidity. The original thermohydrologic model used in TSPA-95 shows significantly higher relative humidities than that proposed by Buscheck and others (1996). As discussed later, this can be a critical difference.

It is assumed that contact with either liquid water or humid air can initiate corrosion of the metal waste container. The container's carbon steel outer layer is oxidized (corroded) more easily than the alloy making up the inner layer. When these two metals touch each other in the presence of an electrolyte (water with dissolved salts) the outer container corrodes first, inhibiting corrosion of the inner container. This is called *cathodic protection*. It is assumed that cathodic protection operates until the outer container's thickness is reduced by a factor of 75 percent. It is further assumed that a waste package fails (radioactive waste becomes exposed) once the first corrosion *pit* penetrates the inner container. (The zircaloy *cladding* surrounding the fuel pellets is not assumed to provide any protection.)

When water reaches the radioactive waste, the radionuclides must be mobilized to be available for transport. This is dependent on two factors, the *dissolution rate* (*how fast* the radioactive nuclides can dissolve) and the *solubility limit* (*how much* of a given radionuclide can be dissolved.) Dissolution rates vary for spent nuclear fuel and vitrified high-level radioactive waste.

Once dissolved, the release of radionuclides into the surrounding rock can occur via two mechanisms. *Advective release* describes radionuclides that are transported by moving water, while *diffusive release* describes radionuclides that move (at a much slower rate) from regions of high solute concentration to lower solute concentration. In the *drips on waste* mode (the first pit through the inner barrier allows dripping water to come in direct contact with the waste), advective transport occurs through the waste package and the other engineered barrier system (EBS) components. In the *drips on waste container* mode, corrosion products are assumed to block advective transport through the waste container, but not through the other EBS components. Transport through the penetrated waste package must occur by diffusion through the corrosion products. In the *Richards' (capillary) barrier* mode, the backfill is designed to divert advective flow away from the waste package and the underlying invert such that only diffusive transport is allowed from both the waste package and the other EBS components. The Richards' barrier concept assumes that differences in capillary pressure across unconsolidated material of different grain size in the backfill can achieve this goal.

TSPA-95 also allows some radionuclides (^{14}C, ^{129}I, and ^{36}Cl) to be released from the waste in gaseous form. These radionuclides are not assumed to reach the earth's surface as gases. Rather, they dissolve in, and are transported by, water in the rock surrounding the tunnel in which the waste package is emplaced.

The transport of radionuclides

Once the radionuclides reach the rock wall of the tunnel, their transport through the unsaturated zone and, eventually, the saturated zone becomes the main focus of TSPA-95. Physical and chemical rock properties determine the rate at which the radionuclides move. In the unsaturated zone below the repository, the relationship between matrix and fracture flow is extremely important. Continuous, interconnected, and permeable fractures could lead to *fast paths* in which flow through fractures is relatively very rapid. Fracture flow itself is controlled by the amount of percolation flux assumed and how this flux is divided between fractures and the matrix.

Two assumptions about the initiation of fracture flow are made: one, that liquid flow in the fractures begins only after the matrix is fully saturated; and two, that fracture flow can begin at a lower level (95 percent) of saturation. Other matrix-fracture interactions are simulated by changing the length of fracture through which water is assumed to travel before it reenters the matrix. The longer the uninterrupted fracture flow, the more rapid the radionuclide transport.

Another important factor is that of *retardation* or the slowing down of radionuclide transport as a result of physical or chemical processes. A primary example of a retardation mechanism would be the *sorption* of dissolved radionuclides by *zeolitic minerals* in the less fractured Calico Hills *non-welded* tuff formation beneath the repository horizon. TSPA-95 bases retardation on extrapolation of laboratory data. One potentially important mode of transport not included in TSPA-95 is *colloidal transport*.[4]

In the saturated zone, a composite flux model, based on an average of matrix and fracture permeability, is used. Retardation is derived from that assumed in the unsaturated zone. It is also assumed that the radionuclides traveling through the saturated zone are dispersed in the direction of flow and that all the radionuclides reaching the water table are mixed in the top 50 meters of the saturated zone. This leads to *dilution* of the radionuclides, an important consideration in estimating the dose any individual might receive. Peak individual dose is calculated assuming that a *maximally exposed individual,* located five kilometers from the repository, ingests two liters per day of water drawn from the top 50 meters of the saturated zone in the region of highest radionuclide concentration.

External changes

The possibility of future long-range climate change due to repeated cycles of global *glaciation* and *deglaciation* is taken into account by assuming that such cycles last 100,000 years. Precipitation and evapotranspiration (and, therefore, infiltration and percolation) vary during that time. At its peak, the percolation flux is assumed to be as high as five times that under present conditions. The increased percolation is also assumed to result in a range of water table rises (0 to 80 meters) above the present elevation. The effects of earthquakes, volcanism, and human intrusion (examined in some previous TSPAs) are not evaluated in TSPA-95, which is primarily concerned with the undisturbed performance of the repository.

Results

Repository performance is measured in several ways: (1) release of radionuclides from the EBS to the surrounding rock (primarily over the first 10,000 years), (2) cumulative release of radionuclides to the *accessible environment* (defined in TSPA-95 as rock more than five kilometers from the repository) over the first 10,000 years, (3) peak individual dose during the first 10,000 years, and (4) peak individual dose out to the first 1,000,000 years. The criteria that ultimately will be used to judge the safety of the proposed repository currently are being revised. It is important, however, to note that the first performance measure listed above presently exists in the NRC's regulations (10 CFR 60), the second is derived from the original EPA standard for disposal of high level radioactive waste (40 CFR 191), which no longer applies to Yucca Mountain, the third is related to that being proposed in several bills in Congress, and the fourth performance measure is related to that recommended by the panel appointed by the National Academy of Sciences (NAS / NRC 1995a).

EBS release is most sensitive to cathodic protection and the mode of release. According to TSPA-95, cathodic protection could postpone any releases until after 10,000 years. After that time, the peak release rates would be only one-tenth of the peak release rates had there not been any cathodic protection. Similarly, limiting releases to the diffusive mode, particularly by means of a capillary barrier in the backfill, cuts down on all radionuclides except those

4 *Colloids are minute particles, ranging in size from about 10^{-8} meters (a few tens of atoms) to about 10^{-5} meters, that may be suspended in water and, because they experience little or no retardation, may be highly mobile.*

in the gaseous phase. Percolation flux also is important, as is a lower thermal load which results in lower releases to the EBS. The Buscheck and others (1996) thermohydrologic model predicts that low relative humidity causes significantly less corrosion, and, therefore, lower EBS releases than the model originally used in TSPA-95.

Releases to the accessible environment and peak individual doses are displayed using *complementary cumulative distribution functions (CCDFs)*, that is, plots showing the probabilities of exceeding different levels of radioactive release or peak individual doses, in the time frame of reference. The probabilities are calculated from derived or assumed uncertainties. The uncertainty associated with conceptual models (for example, the presence of cathodic protection) is not taken into account as in some previous TSPAs. Usually, it is treated in sensitivity studies showing the impact of each assumed model on the calculated results.

None of the CCDF calculations exceeds the 10,000-year cumulative release limits prescribed in the original EPA standard (40 CFR 191).[5] Indeed, if one assumes that percolation flux is limited to the low range, *or* that cathodic protection is operative, *or* that high thermal loading is used and the Buscheck and others (1996) low humidity thermohydrologic model is correct, *or* that flow in the unsaturated zone is restricted to the rock matrix (no fracture flow), there are *no* releases to the accessible environment in 10,000 years.[6]

When calculating the 10,000-year peak dose for those assumptions that result in releases, the most important radionuclides are ^{99}Tc and ^{129}I. The size of the dose is most influenced by the amount of percolation flux assumed and the extent to which fracture flow exists in the Calico Hills non-welded tuff beneath the repository horizon. The mode of release from the EBS also affects peak individual dose. The presence of a capillary barrier alone reduces the dose somewhat, but the presence of this barrier and the assumption that there is no gaseous release of iodine or chlorine from the waste package greatly reduces the dose.

Considering the maximum individual dose within one million years leads to somewhat different conclusions. Many of the assumptions that can delay the release and transport of radionuclides for up to hundreds of thousands of years have little or no effect on the million-year peak dose. These include retardation, the relationship between matrix and fracture flow, cathodic protection, thermal loading, and the thermohydrologic model. A factor that remains important is the mode of release. For example, assuming the *dripping on waste container* mode instead of the *dripping on waste* mode reduces the peak dose by a factor of 25, while assuming the presence of a capillary barrier (and no gaseous release of ^{129}I or ^{36}Cl) reduces the dose by an additional factor of 200. This is based on the assumption of high percolation flux where the dominant radionuclide is ^{237}Np. Under the most pessimistic assumptions the peak dose from neptunium could be significantly greater than that usually allowed by dose regulations around the world. If one assumes low percolation flux, however, the peak dose is much less because the amount of neptunium released is exceedingly small. Then, the dominant radionuclide released is ^{129}I. This again points to the importance of percolation flux in calculating dose, even over very long periods of time. The rate at which ground water flows in the saturated zone is another important factor in determining dilution, and, therefore, peak dose.

5 *TSPA-91 and TSPA-93 showed that the release of gaseous ^{14}C from the repository to the atmosphere may exceed the original EPA standard. In TSPA-95 this release is not taken into account because the risk (individual dose) associated with the release is considered to be negligible. While this may be true, it is not appropriate to exclude atmospheric release of gaseous ^{14}C (if it occurs) when comparing calculated results to a strictly release-based standard. However, if it could be shown that ^{14}C remains dissolved in water in the unsaturated zone, it would be a more acceptable assumption.*

6 *This suggests that it may be possible to develop a very robust repository system at Yucca Mountain. It should be easier to demonstrate the safety of such a repository during licensing than would be the case for a less robust system. However, demonstrating the validity of any of these assumptions is likely to be very difficult.*

Comments

Board comments on many of the more detailed technical issues raised in TSPA-95 can be found in the Hydrology and Geochemistry and the Engineered Barrier System sections of this chapter. The following comments are more general and refer to some overall aspects of the study.

1. *TSPA-95 represents an improvement over previous iterations.* The increased level of detail in modeling the thermohydrological environment near the waste package, waste package degradation, release of radionuclides within the EBS, and EBS performance provide important insights into repository performance. New data sets, such as those for infiltration and humid air corrosion, have been incorporated into the calculations. A significant increase in the number of sensitivity studies, as recommended by the Board (NWTRB 1992) has been accomplished. Indeed, the most important function of TSPA-95 is not so much whether it shows the proposed repository complying with an assumed standard,[7] but rather the demonstration of the sensitivity of performance measures to different assumptions and models.

2. *The importance of several critical and uncertain assumptions remains to be explored.* The impact of a number of assumptions about models and input parameters whose bases have not been established sufficiently and have a large effect on the computed results remains unknown. One example would be the effect of assuming a different criterion for the onset of fracture flow. The TSPA-95 model assumes that, aside from full matrix saturation, fracture flow could begin when the rock matrix in tuff is at 95 percent of full saturation. Because fracture flow is so important, what would happen if it was assumed that fracture flow could be initiated at less than 95 percent of full saturation? Another example is the thickness of the degraded outer container at which cathodic protection of the inner container is assumed to cease. Similarly, a good deal of information exists about infiltration (and percolation) flux. However, given its importance and the difficulty in accurately determining what it may be like in the future, it would be very useful to know the level of flux at which the performance or longevity of engineered barriers would be compromised severely. Such an evaluation could help determine the extent to which different hypotheses need to be pursued.

3. *TSPA-95 provides a clearer definition of program priorities than past TSPAs.* The Board has criticized past TSPAs for not clearly designating programmatic priorities (NWTRB 1992). TSPA-95 represents an improvement over these studies. It lays out priorities among those *process-level models*[8] needed for future TSPAs, data that could be used to evaluate these models, and measures that could be used to evaluate the significance of these models. Models of the unsaturated zone hydrology on both site and tunnel scales are considered to be of highest priority. The question still remains whether the DOE will make, as the Board recommends, "... a management and organizational commitment to develop more systematic ways of using total system performance assessment to guide site characterization and set priorities at Yucca Mountain" (NWTRB 1995b). There are signs that this is beginning to take place.

4. *The next iteration of TSPA will require greater attention to compliance-related issues.* The next iteration of TSPA currently is planned for 1997-1998. It is envisioned as being the centerpiece for an assessment of the "viability" of the site. It must compare the performance of the proposed repository to standards and regulations that are to be enacted by that time. There are likely to remain a number of issues for which definitive evidence for the choice among alternative conceptual models (or input parameters) will be lacking. If sensitivity tests indicate that some

7 *The authors of TSPA-95 estimated possible conservatism and non-conservatism in their analysis. They concluded that reasonably likely conservative factors could have resulted in an overestimate of long-term dose by up to eight orders of magnitude, while reasonably likely non-conservative assumptions could have resulted in an underestimate in long-term dose by up to three orders of magnitude (TRW 1995c).*

8 *In the vernacular of Yucca Mountain TSPA, the simplified, or abstracted models used in TSPA need to rest on a firm basis of conceptual and detailed understanding of the processes involved. At present, very few process-level models exist from which the abstracted models can be drawn confidently.*

of these models could result in the exceedance of existing standards or regulations, the DOE will have to substantiate its choice of any single model or find some way of evaluating, weighing, and combining multiple models such that an overall estimate of performance can be made. This was not done in TSPA-95. Combining conceptual model uncertainty has been viewed to be a major problem in showing compliance at the proposed repository for transuranic waste in New Mexico.[9] In general, all assumptions about models and input parameters will need to be highlighted and their bases clearly laid out and open for review.

5. *TSPA efforts should be integrated closely with the development of a waste isolation strategy*. The Board believes that performance assessment can be used to test and refine a waste isolation strategy (NWTRB 1995b). Although there was some interaction, the current waste isolation strategy was developed, in large part, independently of TSPA-95. They are generally, but not completely, similar in identifying those elements that are considered most important to waste isolation. In the waste isolation strategy, for example, little discussion is devoted to the capillary barrier concept which greatly reduced radionuclide release and individual dose in TSPA-95. The analytical tools provided by TSPA, along with engineering considerations and the ongoing results of exploration and testing, provide a powerful means for developing and substantiating the basic tenets of an effective waste isolation strategy. Of particular interest would be determination of the amount and distribution of percolation flux that would require revisions to the waste isolation strategy.

Conclusions

1. TSPA has come a long way since the initial efforts. The inclusion of new data and more detailed modeling has helped sharpen its focus and provided needed insights.

2. TSPA-95 points out the importance of some factors, such as percolation flux, on all measures of performance over distant time periods. It also shows the relative difference in importance assigned to other factors, such as engineered barriers, delaying processes in the natural barriers, and dilution, depending on which measure of performance or which time period is being considered. DOE management has to meet the challenge of making effective use of these insights.

3. To meet the needs of the next phase of TSPA, additional data have to be collected, models have to be developed and substantiated, expert judgments must be obtained, and ways of treating uncertainty have to be addressed.

Recommendations

1. Building on the strengths (and filling in the gaps) shown in TSPA-95, the DOE should prepare itself for the next, and critically important, role assigned to TSPA — the Yucca Mountain site "viability assessment" in 1998. Assumptions about models and input parameters will need to be highlighted and their bases clearly laid out and open for review.

2. TSPA should play an integral role in refining and testing the basic tenets of the developing waste isolation strategy. TSPA, for example, could provide an estimate of the amount of percolation flux that could, in turn, require a reexamination of the current strategy. It can also clarify what kinds of data are needed to demonstrate that the safety case has been made.

3. The DOE should make an early determination of which aspects of the next TSPA will require expert judgment and make clear to the technical community how these judgments will be obtained.

9 Presentation by D. R. Anderson (Sandia National Laboratories) titled "An Overview of the WIPP Performance Assessment" (NWTRB 1994a).

Geoengineering

At each of the four Board meetings in 1995, sessions were allocated to geoengineering concerns, including ESF progress and construction sequence update; Calico Hills access; east-west crossing of the Yucca Mountain block; thermal management, thermal testing, and an evolving thermal-loading strategy; and the repository operational strategy and advanced conceptual design. On two occasions (August 15, 1995, and November 28-29, 1995), members of the Board and staff attended informal discussions with the DOE to seek clarification of specific issues included in the Calico Hills System Study (TRW 1995a) and the waste isolation strategy. There were no formal meetings of the Panel on Structural Geology and Geoengineering during 1995.

Underground Excavation and Testing

The TBM started operating in late September 1994, but only about 90 meters (300 feet) of the north ramp had been excavated by early January 1995. This poor performance continued through May and was due to a number of reasons including poor geologic conditions in the area of the north portal and the upper reaches of the north ramp. As a result of this early experience, the DOE developed a very conservative ESF construction plan for the balance of fiscal year 1995.

Presentations to the Board in January 1995, indicated that the goal for TBM performance for the year would be approximately 12 meters (40 feet) per day, assuming TBM operations would be three shifts per day, five days per week. This goal was approximately one-third of the performance that would be expected in commercial applications. By these performance goals, an image of “being ahead of schedule” was maintained during the early months of 1995. It was hoped that about 1,200 meters (4,000 feet) of tunnel would be completed by October 1995, with the north ramp to be completed by March 1996.

In response to Board recommendations, industry TBM experts were consulted in April 1995 about modifications to improve TBM performance. A number of these modifications were made and a conveyor system, used to remove the excavated rock from the tunnel, was started in late July. In August, TBM performance began to improve noticeably, and during the subsequent months averaged about 27 meters (90 feet) per day. The TBM reached the end of the north ramp early in November and, by the end of the year, was about one-quarter of the way across the geologic block at the repository level, completing more than 3,500 meters (i.e., 11,600 feet) of tunnel, along with three test alcoves.

Predictions indicated that the favorable tunneling conditions would continue. However, by the end of February 1996, geologic conditions had worsened. TBM progress slowed to about 15 meters (50 feet) per day and remained low through March and early April. Excavation slowed because of the need to use heavy steel sets for ground support as the TBM intermittently encountered regions of unstable rock. It is unclear whether the need to use the heavy steel sets results solely from geologic conditions. It also may be due to a mismatch between the geologic conditions and the available options for quality-controlled ground support. Only two types of quality-controlled ground support are available to the tunneling contractor — rockbolts and the heavy steel sets. Whenever rockbolts are inadequate, the constructor must install the heavy steel sets — a slow process. If intermediate types of quality-assured ground support were available, which could be installed more quickly, excavation could progress more rapidly. The characteristics of the TBM also may contribute to ground support problems. A TBM designed to allow early support of loose rock, one with a more conventional cutterhead configuration, or one of a smaller diameter could improve production rates.

The exploration at Yucca Mountain provided a number of geologic revelations not anticipated from surface-based activities (i.e., geophysical mapping and drilling). Although stratigraphic data from within the tunnel agreed quite well with data from surface-based activities, the rock mass quality and the nature of the structural features (faults, major fractures) proved to be quite different. The rock mass quality, which provides an indication of the probable difficulty of tunneling, proved to be better, at least in some portions of the tunnel, than predicted. A difference between the predicted nature of the faults and what was observed also occurred. The faults underground were not as nearly vertical as anticipated, and their orientation was north-to-northwest not north-to-northeast.

The northwest end of the Yucca Mountain geologic block is defined by a fault zone referred to as the Drill Hole Wash Structure (i.e., thought to be a complex of interconnected faults). Surface features suggested that difficult tunneling conditions would be encountered over an extensive length of the north ramp while excavating through this feature. This difficult zone was not encountered. Tunneling conditions did not change in the region where this feature was expected. Since this structure now appears to be much less significant than expected earlier, it may be possible to expand the repository block to the northwest, allowing more room for waste emplacement.

In addition, the main tunnel, which traverses the repository horizon from north to south, is providing valuable fracture coating samples[10] as it is being excavated. Data from these samples are providing spatial sampling, which is proving to be valuable in the development of the waste isolation strategy discussed in the first chapter of this report. This information clearly illustrates the importance of subsurface exploration and testing as an integral part of the site-characterization effort at Yucca Mountain. Perhaps most importantly, no significant percolation flux has been encountered at the repository horizon during the fall and winter when it would be most likely.

Years of underground construction worldwide show that no amount of surface-based testing can eliminate the potential for geologic surprises. It is the Board's position that a technically defensible evaluation of the site cannot be made without exploration that would eliminate or greatly decrease the potential for a major geologic surprise subsequent to the decision. The Board continues to believe that an east-west crossing of the geologic block west of the Ghost Dance Fault (i.e., the upper waste emplacement block) is necessary prior to any technically defensible decision on site suitability. The current design for the repository has all, or almost all, waste emplacement in the upper waste emplacement block. This block, which is 4 kilometers (2 1/2 miles) long and 1.2 kilometers (3/4 mile) wide, has not been explored by drilling or by subsurface exploration. Without the needed east-west exploration, the geologic and hydrologic characteristics of the unexplored portion of the repository block must be extrapolated from those found in the portal-to-portal loop. Extrapolation over such a long distance would be difficult to justify technically.

Board of Consultants

In late October 1995, the M&O contractor convened the first meeting of a board of consultants.[11] Its purpose is to provide periodic reviews of the Yucca Mountain project's geoengineering activities and to report observations, concerns, and recommendations about cost-effective tunneling, safety, and design adequacy.

The Board is pleased to see that the consultants are documenting, in some detail, opportunities to improve the efficiency of the ESF construction operations. In its most recent report (Bartholomew 1996), the consultants seek a better identification of costs and performance of various components of the ESF construction program and compares them to what typically would be expected with a commercial tunneling project. For example, it was found that the cost of buildings and surface facilities at the north portal is abnormally high because they were designed to support four TBM and two drill-and-blast operations *simultaneously*. However, this scenario was abandoned by the DOE in 1992.

10 *Minerals coating ESF fracture surfaces precipitated from low-temperature, aqueous solutions percolating through the unsaturated zone. The decay of natural radioactive isotopes, such as uranium-238 and carbon-14, that are incorporated into the minerals at the time of deposition provides the basis for calculating when the solid phase was formed. Although these deposits do not contain direct information about the age or travel time of the source of ground water, they represent one of the few means of assessing past water movement through Yucca Mountain.*

11 *Establishment of a geoengineering board was recommended by this Board (NWTRB 1993b, 1995b).*

In addition, the consultants questioned spending nearly $14 million in fiscal year 1995 on quality control of the *temporary* ground support installed in the tunnel. The consultants recommended that every possible means should be explored to remove the present quality assurance (Q-list) classification of temporary ground support elements (i.e., steel sets and rock bolts) in the tunnel.

The consultants reported (Bartholomew 1996) that the Yucca Mountain tunneling operation managed by the M&O contractor has a salaried staff of 176. They estimated that staffing levels for a comparable tunnel in typical commercial practice would require a staff of 27 (based on comparison with four recent, ongoing projects). They also estimated that a staff of 39 might be appropriate at Yucca Mountain, given the non-typical nature of some of the activities there. The consultants report that at least part of the difference between the M&O staffing level and commercial practice is the addition of 21 engineering managers and staff, 36 business managers and staff, and 47 quality assurance / quality control managers and staff, at a total cost of about $10 million per year.

The positive experience with the consultants strongly suggests that the DOE would benefit by greater use of knowledgeable experts in other areas of its program.

Repository Thermal Loading and Thermal-Testing Strategy

The present DOE thermal-loading strategy is baselined for 83 MTU / acre, with the acceptable range being 80 to 100 MTU / acre. At this areal mass loading it will be possible to accommodate the projected 70,000 MTU into the Yucca Mountain geologic block. An areal mass loading of this magnitude will increase temperatures in the vicinity of the waste packages above the boiling point of water[12] and evaporation of pore water will take place. Theoretical computations predict that the process of evaporation and movement of vapor away from the repository will establish a dryout region, implying a low relative humidity environment in the emplacement tunnels.

If the relative humidity is sufficiently low next to waste package surfaces, aqueous corrosion will not take place, and the integrity of the waste containers will be assured during the long (up to 10,000 years) thermal pulse. It is also expected that rewetting will take place slowly after the thermal pulse decays, thus the total time for “complete containment” can be at least several thousand years. This is the theoretical scenario of an “extended dry repository.”

Validation of thermal predictions

There is considerable uncertainty associated with thermohydrologic processes at Yucca Mountain: uncertainty in the relevant processes, uncertainty resulting from geologic heterogeneity, and parameter uncertainty. The relatively limited experience of the scientific community in modeling complex thermohydrologic problems in highly heterogeneous media like the Yucca Mountain unsaturated zone will make it especially difficult for the DOE to establish the validity of its predictions through short-term thermal testing.

It is clear that performance cannot be predicted adequately through more detailed or refined computations without appropriate laboratory and field experiments. There remains a strong possibility for changes until model predictions are substantiated by complementary computations and more representative and precise observational data. Because of the high temperatures and the evaporation, gradient flow of vapor, and precipitation of water, various chemical / physical processes will occur that have the potential for altering the physical state of the rock (i.e., porosity, permeability, and saturation) in a way that these changes might affect the repository performance. In-situ thermal testing is the best way to provide some data on the importance of the interactions between thermal, hydrological, and chemical processes.

12 The boiling point of pure water varies with atmospheric pressure. At the elevation of the Yucca Mountain site, the boiling point would be 97°C. Solutes dissolved in water raise the boiling point.

Thermal-testing objectives

In mid-January a mechanical miner started excavating a thermal test alcove at the repository horizon. This excavation may be completed by mid-year, and will have provision for conducting two separate thermal tests. The DOE has not clearly defined the objectives of, and the justification for, the thermal tests. There is unanimity that some heater tests have to be carried out and the mountain response observed, but there is no clear enunciation of what type(s) of data are to be collected, how they will be obtained, or the ultimate use to which the data will be put. Obviously, little will be available for use in the DOE's 1998 viability assessment for the site.

Plans for two tests have been made — a small-scale, short-time test that will cost about $1 million and is considered a "shakedown" test, and a larger-scale, longer-time test that is projected to cost around $10 million. If the goals of the two tests are not more clearly defined and more closely linked to repository performance or design issues, there is a possibility that the results won't warrant the expense.

Two thermal-testing goals that could provide this linkage are (1) to determine if backfill is essential in waste emplacement tunnels to enhance long-term repository performance, what characteristics it must have, and its feasibility and cost; and (2) to use a simple tunnel-scale heater test to show that no adverse (e.g., geophysical or geochemical) changes occur at the representative thermal load.

More detailed testing could be conducted during the construction and operation period (and even during the 100-year retrievability period). During this prolonged testing, the in-tunnel environment should be monitored and the data analyzed to see if predictions are accurate. After a lengthier period of observation and analysis, the technical basis for a decision on repository performance after closure should have a firmer basis.

Repository Operational Concept and the Advanced Conceptual Design

At the January 1996 Board meeting, the director of the DOE's Office of Civilian Radioactive Waste Management (OCRWM) announced a program refocusing which concentrates on a new set of milestones in the form of specific work products that will contribute to a viability assessment in 1998. The specific work products defined to support the assessment were: (1) more specific conceptual designs for the critical elements of the repository and for the waste package, considering only those aspects that are critical to *repository performance, cost, and technical feasibility;* (2) a total system performance assessment based on the designs and existing site-characterization data; (3) a plan and cost estimate for the work remaining to complete a license application; and (4) an estimate of the costs to construct, operate, maintain, and close the repository (i.e., the repository portion of the total system life-cycle cost) (NWTRB 1996a).

A key element of these work products is a technically credible repository conceptual design, referred to as the advanced conceptual design (ACD). The ACD developed by the DOE originally was scheduled for completion by March 1997. Restructuring the program accelerated the delivery date to March 4, 1996 (TRW 1996b). This deliverable includes a design concept for the repository surface and subsurface facilities, concepts of operation, a design concept for the waste package, and a life-cycle cost estimate and associated schedules for the repository.

According to the repository ACD, construction of a repository at Yucca Mountain may require excavation of 160 kilometers (100 miles) of tunnels. At 15 meters (50 feet) per day, over 40 years would be required for the excavation, unless multiple TBMs were operated simultaneously. The DOE needs to examine both the cost and the rate of progress for excavating the ESF and compare it with planned repository construction methods when assessing the viability of the Yucca Mountain site. Additional modifications to the TBM or use of a TBM of a different design may be needed to improve excavation efficiency.

The Board will review and evaluate the ACD during 1996 and 1997, and is not commenting further on it in this report.

Conclusions

1. During 1995, the DOE made significant progress, both in the rate of tunneling and in the total tunnel length excavated. This progress has opened the way for observations and scientific investigations to take place over a much larger volume of the subsurface. But important work, including accessing more of the underground for exploration and testing and developing confidence in model predictions, still remains. Drawing on the evolving waste isolation strategy and the results of TSPA-95, the DOE should develop a technically defensible basis for evaluating the need for, and the timing of, additional underground excavations.

2. The Board is pleased to see that a board of consultants is providing the Yucca Mountain Project with numerous recommendations for improving ESF construction. Reduced overhead and improved productivity can be expected if the project enthusiastically implements these recommendations. The DOE, as well as the M&O contractor, needs to institutionalize a mechanism to ensure such implementation.

3. Predictions of the longevity of waste package containment depend greatly on the prediction of the in-tunnel environment, both during and after the heating episode, as well as the types of waste package materials used. Predicting and verifying the long-term in-tunnel environment remains a challenge. There is sufficient variation in the in-tunnel temperature and relative humidity predictions so that presently unambiguous conclusions cannot be drawn. A long-term experiment, over a significant portion of the preclosure period, would develop confidence in the DOE's predictive capabilities.

4. The main issues concerning the thermohydrologic response of the mountain and the long-term in-tunnel environment cannot be resolved by short-term, small-scale heater experiments. It is not possible to simply scale up the results of a smaller scale test and expect them to represent a tunnel-scale or mountain-scale response. Thus, the Board supports the prospect of long-term, tunnel-scale tests being started as soon as possible. However, plans for the short- and long-term thermal tests should be linked more closely to repository performance and/or design issues.

Recommendations

1. The DOE needs to examine both the cost and the rate of progress for excavating the ESF and compare it with planned repository construction methods when assessing the viability of the Yucca Mountain site. Additional modifications to the TBM or use of a TBM of a different design may be needed to improve excavation efficiency.

2. The Board recommends that the DOE set up a procedure to provide timely monitoring of the response and actions of the M&O contractor to the recommendations of the board of consultants.

3. The Board supports initiation of a long-term, tunnel-scale thermal test as soon as possible and recommends that more thought be given to how more information can be obtained from all heater tests.

Hydrogeology and Geochemistry

The Board continues to believe that resolving key issues of the Yucca Mountain unsaturated zone hydrology is fundamental to a site-suitability determination. The volume of water that might reach the proposed repository to corrode waste containers and transport radionuclides to the accessible environment remains a critical issue. As discussed in Chapter 1, the waste isolation strategy is highly dependent on the presumed dryness of the unsaturated zone beneath Yucca Mountain. TSPA-95 clearly shows that if the percolation flux through the repository horizon is small (e.g., less than the saturated matrix conductivity of 0.1 mm/yr for the Topopah Springs welded tuff), the hypotheses of the waste isolation strategy probably can be validated. If the percolation flux is substantially higher, it may be more difficult to develop an acceptable repository at the site.

During 1995, the Board reviewed the progress made on the unsaturated zone hydrology, the evolving waste isolation strategy, and the results, process models, and assumptions of TSPA-95. What follows is a more detailed discussion of the status of the hydrologic knowledge at Yucca Mountain and what the waste isolation strategy implies about the future data needs leading to suitability and licensing.

Unsaturated Zone Hydrology

Yucca Mountain is composed of tilted layers of variably welded, variably fractured ash-flows and ash-falls. Due to the varying textures, these units exhibit highly variable hydrological and material properties. Because Yucca Mountain is an arid environment, the water table is relatively deep and the infiltration / percolation flux through the mountain is anticipated to be small.

In descending order from the land surface, the major stratigraphic layers of importance are the Tiva Canyon welded (TCw); the Paintbrush nonwelded (PTn); the Topopah Spring welded (TSw), the proposed repository horizon; the Calico Hills nonwelded (CHn); and the Crater Flat (CFu), in which much of the present water table is located beneath the proposed repository. The Paintbrush nonwelded unit is primarily unfractured and separates the two highly fractured, permeable units TCw and TSw. The PTn primarily consists of nonwelded ash-fall tuff and bedded tuff. It has a porosity of nearly 0.40, like a typical well-sorted sand, and a relatively high matrix conductivity of approximately 1 m / yr. The matrix conductivities of the Tiva Canyon and TSw units, in comparison, are much smaller (~10^{-4} m / yr). The primary conductivity in these two units is a consequence of intense fracturing. The Calico Hills unit is composed of vitric and extensively zeolitized units, most likely relatively free of fractures, and has been viewed as an important barrier to rapid radionuclide transport to the saturated zone.

Pneumatic pathways

The PTn plays an important role in the air circulation, and thus the gaseous releases of radionuclides, at Yucca Mountain. The PTn is a pneumatic barrier between the highly fractured TCw and TSw units, both of which have total air permeabilities much higher than that of the PTn. This was verified in December 1995 when the TBM penetrated the PTn and there was a noticeable equalization of atmospheric pressure response between the TCw and TSw units. Atmospheric pressure variations were being measured underground via the ESF tunneling and could be used as a pressure probe of the mountain. By instrumenting wells ahead of the ESF, the U.S. Geological Survey (USGS) was able to measure the pressure response in these wells as the tunneling progressed. These measurements were then compared to the predicted response of the Lawrence Berkeley Laboratory / USGS site-scale model providing a clearer picture of the pneumatic response of the mountain.

Infiltration of water

Detailed measurements by USGS scientists have provided an estimate of the fraction of the average precipitation that infiltrates and subsequently percolates deeper into the mountain. Measurements over the last ten years have shown that the average precipitation at Yucca Mountain has been approximately 170 mm / yr. Most of this water is lost to runoff and / or stored in the alluvium and later lost to evapotranspiration. However, episodic high-precipitation events can overwhelm a thin alluvium cover locally and then water can percolate deeper into the mountain through preferential paths, such as fractures. From their saturation versus time data, the USGS scientists have estimated that on the average approximately 10 to 20 mm / yr infiltrates deeper (below the root zone) into the mountain. This range of values represents the spatially averaged infiltration. In reality, infiltration is spatially very heterogeneous with a few regions of very high infiltration and most other areas with little or none at all. Because of the difficulties in translating saturation measurements into a percolation flux, this estimate has a large degree of uncertainty.

Lateral water movement at the PTn

A basic hypothesis of flow in the site's unsaturated zone is that a large fraction of the infiltration is diverted laterally at the PTn unit, which thus acts as an "umbrella" over the proposed repository horizon (TSw) limiting the downward percolation flux. As noted above, there is evidence that the spatially averaged infiltration flux could be in the range of 10 to 20 mm/yr.[13] This range of values is approximately two orders of magnitude larger than the saturated matrix conductivity of the underlying TSw unit. As long as this flux can be accommodated laterally, the hypothesis is that capillary forces prevent fracture flow initiation in the underlying TSw, thereby limiting the percolation flux. The magnitude of the percolation flux at the repository horizon is one of the most important variable(s) affecting the site's ability to isolate waste for long periods of time. If it can be shown definitively that the percolation flux at the repository horizon is primarily matrix flow, less than 0.1 mm/yr, then it probably would be difficult not to deem the site "suitable" on hydrologic grounds.

It is important to get a better quantitative bound on the infiltration flux and how much of this flux contributes to the downward percolation flux through fractures in the TSw. Lateral flow diversion at the PTn is a plausible hypothesis but, presently, sufficient data for an unambiguous conclusion do not exist. If a high lateral flow exists in the PTn, there should be some observations of its consequences, e.g., regions of highly localized downward flow, perhaps at faults.

Age dating in the ESF

Other observations presently being pursued in the ESF are age dating of encountered waters and of minerals in fracture fillings.[14] Minerals coating fracture surfaces in the Exploratory Studies Facility (ESF) precipitated from low-temperature, aqueous solutions percolating through the unsaturated zone. The decay of natural radioactive isotopes such as uranium-238 and carbon-14 that are incorporated into the minerals at the time of deposition provides the basis for calculating ages of when the solid phase was formed. Although these deposits do not contain direct information about the age or travel time of the source of groundwater, they represent one of the few means of assessing past water movement through Yucca Mountain.

Calculating ages of mineral deposition in fractures is not the final goal of the unsaturated-zone paleohydrologic studies. Ultimately, estimates of past water fluxes are more critical for waste isolation strategies. Therefore, measurements of the volumes of material represented by a given age span are equally as important as their numeric ages. Only after a large enough data set has been accumulated and synthesized will relations between the hydrologic processes responsible for deposition, or lack of it, and relations with potential climate variations become apparent. These data could provide information on time and perhaps magnitude of recent and past movement of waters through fractures.

Fracture Flow

On June 26-27, 1995, the Panel on Hydrogeology and Geochemistry held a meeting on waste isolation in unsaturated, fractured rocks (NWTRB 1995e). The purpose was to hear recent evidence on the potential for fast pathways, i.e., fracture transport at Yucca Mountain and in other arid regions around the globe, and to discuss its relevance to the Yucca Mountain site characterization. Historically, it has been assumed that unsaturated rocks in arid climates, even though they may be fractured, were potentially good sites for isolating waste. This assumption was based on the belief that significant fast transport through the fractures[15] was unlikely because of the low precipitation and strong matrix-fracture interaction. Presentations during this meeting, by scientists from the United States and Israel, showed that wherever fractures are abundant, unsaturated, low-permeability sediments, such as shale, tuff, or chalk, cannot automatically be considered hydrological barriers, even under desert condi-

13 *The Center for Nuclear Waste Regulatory Analyses has analyzed the same data and arrived at a comparatively similar value for the average infiltration. These estimates require various approximations and the use of computer simulations, and thus should be used with caution.*

14 *These data contain integrated information on past water movements at Yucca Mountain.*

15 *Fractures can provide rapid pathways for solute and contaminant transport from land surface to significant depths in the unsaturated zone, bypassing most of the nearly stagnant matrix water, even under very arid conditions.*

tions. The primary feature common to all cases was that fast/preferential paths can be activated during intense precipitation events at spatial locations conducive to initiating fracture flow. The significance of transport through these pathways is not an easy question to resolve and must be evaluated on a case-by-case basis.

Because the infiltration and downward percolation of water is not uniform, but highly localized in a few fractures, it is difficult to measure these flows in space and time. Much of the evidence and conclusions are based on measured isotopic and chemical tracers such as carbon-14, tritium, chlorine-36, and various ions (e.g., chloride and bromide) found in waters at depth. These tracers, although often difficult to interpret, provide information on the long-term, integrated water flux through the rocks (e.g., water volumes and residence times). Tritium measurements at depth at the Yucca Mountain site indicate that some water has traveled rapidly to the top of the Calico Hills unit. The measurements are very sparse, and it would be useful to substantiate them. But they are consistent with the locations where these waters can be expected to be found, at the units where lateral diversion of waters is anticipated. Perhaps of even greater significance will be the isotopic age data from minerals being collected in the ESF. These data might give a better indication of the extent and magnitude of fracture flow in the TSw. Direct observation in the ESF, perhaps in sealed alcoves to eliminate drying effects of ventilation, over a longer period of time also could provide some quantitative indication of the probability of a dripping fracture.

Radionuclide Mobilization and Transport

Releases of radionuclides from the engineered barrier system depend strongly on the rate of water seeping into the emplacement tunnels and contacting the waste packages. The most important parameters needed to quantify this process are (1) the volume of water contacting the waste per unit time, and (2) the concentration of the radionuclides in the water when it leaves the EBS. If one assumes the long regulatory time period proposed by the National Academy of Sciences panel (NAS/NRC 1995a), it is the long-lived, soluble radionuclides that will be the most important. Thus, it is especially important to be able to estimate or bound the concentration of neptunium that would be leached from the waste. Although these predictions are highly model dependent, they can be useful in bounding the radionuclide release rates. To make a site-suitability decision, it will be necessary to show that the range of possible values of the seepage flux is "sufficiently" small and that it will remain so during anticipated climate changes.

Backfill or other engineered barriers can be designed to limit the amount of water that will contact the failed canisters. Various methods are being evaluated now in a system study. If water is prevented from directly contacting the failed canisters, then the only mechanism of transporting the non-gaseous radionuclides from the EBS will be diffusion. Because diffusion in a partially saturated medium such as a granular tuff is extremely slow, the release rates would be exceedingly low, and the repository performance very good. The only question that would remain is the stability of the engineered barrier over the 1 million year period.

Seepage into the tunnels

The percolation flux at the repository horizon is composed of a slow component moving through the rock matrix and a faster episodic component moving through the fractures. Due to capillary forces it is anticipated that seepage into emplacement tunnels will occur only when a flowing fracture intercepts a tunnel, i.e., the "dripping" fracture scenario. The local matrix component will flow around the tunnels. Thus, in this model a higher local percolation flux implies a higher probability of local fracture flow, and thus a higher probability of a "dripping" fracture intersecting a tunnel. The local percolation flux is an upper bound to the local seepage flux, and through this conceptual model the specific relation between the two can be computed.

The primary uncertainties concerning this model are (1) the adequacy with which the strongly heterogeneous nature of fracture flow has been modeled, and (2) the uncertainty in the critical parameters in the formulation.[16] The model appears to be somewhat conservative in that it predicts a relatively high probability of dripping fractures encountering waste canisters when the percolation flux increases. It is possible that a bounding computation for the seepage flux will prove to be overly conservative. Thus, it might be useful to attempt alternative conceptual/mathematical formulations of this critical relation.

Three time intervals for waste isolation

It is useful to view long-term waste isolation as being composed of three major periods. First, there is an initial period of several thousand years or more of essentially complete containment. This is followed by a very long period, perhaps several hundred thousand years, during which the thermal pulse decays and the canisters begin to corrode and progressively fail, exposing the waste to mobilization and transport out of the EBS. During this period, the release rate from the repository is, in all probability, monotonically increasing. The third phase occurs when the canisters are largely degraded, the mountain has returned to the ambient hydrology, and the long-lived radionuclides are released at a time-averaged "constant" rate. This "constant" rate is approximately proportional to the volume of water contacting the waste and the concentration of the dissolved radionuclides. During the third phase, it is anticipated that the dominant radionuclide will be neptunium. *Bounding the concentration of neptunium that is in the water leaving the EBS is a crucial activity.* The magnitude of the release rate from the EBS determines to a large degree the peak dose at the accessible environment.

Dilution in the saturated zone

Natural barriers will retard, disperse, and dilute the concentration of radionuclides as they migrate toward the accessible environment. Quantitatively, the most important dilution process in TSPA-95 occurs when radionuclides in the unsaturated zone are carried to and mix with the greater fluxes of water in the saturated zone. The assumption here is that the radionuclides mix instantaneously with the waters of the saturated zone to a depth of 50 meters (e.g., screened interval of a well penetrating the saturated-zone aquifer). The dilution factor is then proportional to the ratio of the two fluxes of water. Additional dilution in the saturated zone occurs due to dispersion of the contaminant plume as it moves to the accessible environment. For an average percolation flux of 1.25 mm/yr and a saturated zone flux of 2.0 m/yr, the radionuclide concentrations are diluted by a factor of $\sim 10^{-4}$.

Adsorption on mineral surfaces, as it is modeled, retards (delays) the transport of radionuclides but does not dilute the concentrations. Thus, over a sufficiently long period of time, if the release rates are continuous, adsorption is predicted not to have a major effect on the magnitude of the peak dose of long half-life radionuclides such as neptunium reaching the environment, although it will delay the arrival of this peak. On the other hand, adsorption would be an effective process in decreasing the peak dose of short-lived radionuclides.

Dilution by mixing in the saturated zone is conceptually easy to visualize and depends on reasonably well-understood processes and measured parameters. Dilution/dispersion in the unsaturated zone, due to the travel time heterogeneity, is model dependent, difficult to verify experimentally for the scale of interest, and thus much more difficult to substantiate.

Exploration and Testing Suggested by the Waste Isolation Strategy

The DOE's waste isolation strategy is based on the assumption that significant releases can occur only when there is seepage of water into the tunnels and

16 TSPA-95 handled heterogeneity by assuming that there is a log-normal probability distribution in the local percolation flux, as well as a log-normal distribution in the saturated matrix conductivity — the average values and widths of these distributions being fixed by "measured" or assumed values. Unfortunately, the only measured quantities used were saturated hydraulic conductivities on core size samples, which might not be representative of the values at the tunnel scale. The parameters fixing the percolation flux distribution were educated guesses. By then randomly sampling from these two distributions, a "dripping" fracture is encountered only if the sampled percolation flux q_{perc} is larger than the sampled matrix conductivity q_{mat}. The difference (q_{perc} - q_{mat}) is then the flux of water dripping into the tunnel. By continuing this sampling, a probability distribution of dripping fractures is developed.

the water contacts the waste to leach the radionuclides. Thus, *it is imperative to bound the percolation flux and/or seepage rate into the tunnels and the concentration of critical radionuclides, i.e., neptunium, in the water as it leaves the EBS.* Further exploration and testing underground is essential to determine the potential for fracture flow or evidence of frequency of past flows. During the Board's October meeting, the DOE presented an update on the ESF testing program designed to provide some data on the flow in the repository horizon. Included in the program were underground access to and testing of the Ghost Dance and Solitario Canyon faults; collection of isotopic age data on encountered water; and isotopic age data of minerals deposited in fracture fillings indicating past flows. Contemplated are observations of dripping fractures where the ventilation of the tunnels can be halted (NWTRB 1995f).

Because fracture flow is intermittent and spatially variable, exploration and testing should be carried out over a large areal extent. Although much data has been collected in the ESF, no data will be available across the main repository block. The decision on the suitability of the site would be significantly strengthened if the exploration and testing program included an east-west crossing of the main repository block.

If through the above investigations the percolation flux can be shown to be sufficiently "low," then the seepage rate will be low causing releases and peak dose to be low also. If the peak dose is low it is *of secondary importance when it occurs.* In this case, the transport properties of the Calico Hills (adsorption / retardation of Np and potential for fracture flow) are of secondary importance, and exploration of the Calico Hills would not be as high a priority as the other hydrologic / geochemical investigations.[17]

If the peak dose is estimated to be "large," by whatever measure is being used, then determining when the peak dose will arrive at the accessible environment becomes important. In this case the transport properties of the Calico Hills, specifically how much fracture flow or fast transport through the unit is possible, may become an important issue.

Long-term, essentially complete containment depends strongly on the in-tunnel environment, both during and after the heating episode, and the types of materials best suited for that environment. *Predicting and verifying the long-term, in-tunnel environment remains a challenge.* There is sufficient variation in predictions of the in-tunnel temperature and relative humidity so that presently, unambiguous conclusions cannot be drawn. A short-term thermal test will not provide the information required to influence an early site-suitability decision. The most useful testing will be the in-situ long-term heating experiment, probably during a significant part of the preclosure period, to develop confidence in the long-term predictive capabilities.

Conclusions

1. A decision on whether Yucca Mountain is suitable for development of a repository requires that underground observations, age dating and analysis of waters and fracture fillings, and other hydrological tests will support the present conceptual model of the unsaturated zone.

2. The critical hydrologic and geochemical parameters / models have been identified clearly. The most important are (1) the upper bound on the percolation flux at the repository horizon, (2) the conceptual model that predicts the seepage rate into the tunnels, and (3) placing a tighter bound on the concentration of neptunium and any other relevant radionuclide in the waters contacted by the waste. Dilution can do only so much, so a convincing analysis showing that the radionuclide release rate is low will be required for a successful license application.

3. Although far from perfect, the isotopic data on pore waters and minerals filling fractures provide primary evidence of ground-water "residence

17 If there is an early package failure (less than 300 years or so), then the peak dose could be much larger because other radionuclides are more abundant at these early times. After 10,000 years or longer, neptunium increasingly becomes dominant.

times" and/or ages of major past water movements at Yucca Mountain. The isotopic age data being collected in the ESF will give a spatially more comprehensive data set of ground-water flow paths at Yucca Mountain. Interpreting the data has been difficult due to the small data set and the inherent "noise," in the data. But, with the extensive sampling at the repository horizon in conjunction with other direct hydrological and exploratory observations, the preponderance of data should provide a clearer picture of past ground-water flow paths at Yucca Mountain.

Recommendations

1. The Board encourages the DOE to focus sufficient resources on verifying a sound conceptual model of flow in the unsaturated zone. This exploration and testing should provide the needed evidence for assigning quantitative bounds to the infiltration flux and percolation flux and should provide general support for the unsaturated zone flow model.

2. The DOE should place a stronger emphasis on predicting (or bounding) the release rates of important radionuclides from the EBS. Specifically, the DOE should evaluate alternative models for the seepage flux (water entering repository tunnels) and the concentration of neptunium in the water leaving the EBS.

The Engineered Barrier System

The engineered barrier system (EBS) comprises the constructed, or engineered, components of a disposal system designed to retard or prevent the release of radionuclides from the underground facility or into the geohydrologic setting. It includes the waste forms, fillers, waste containers, shielding, material placed in, over, or around such containers, backfill, and any other engineered components of the repository that contribute to safety performance. This section addresses four aspects of the EBS: (1) the role of the EBS in the waste isolation strategy, (2) criticality control in a repository, (3) corrosion and waste-package failure modeling in TSPA-95, and (4) EBS design.

The Role of the EBS in the Waste Isolation Strategy

The DOE made very significant strides in further defining a waste isolation strategy for Yucca Mountain throughout 1995. In the latest version of the strategy (TRW 1996c), the EBS continues to have a number of roles: (1) providing complete containment of the waste by waste packages for thousands of years; (2) ensuring low mobilization rates for waste after the waste packages are no longer intact; and (3) ensuring slow release rates for the waste from the breached containers to the host rock.

The Board considers each of these three roles to be both important for safety and feasible to implement. The first role is important because complete containment by the waste packages during the initial period of a repository allows the large quantities of comparatively short-lived (half-lives of about 30 years or less) radionuclides present in the waste to decay below levels of importance. All of the TSPA-95 calculations showed substantially complete containment for at least a thousand years.

The second role for the EBS — ensuring low mobilization rates — is important because it limits the concentration of radionuclides in any water percolating through the container. Low mobilization ultimately leads to reduced doses to humans in the accessible environment. The feasibility of the second role is due principally to the low solubilities of many radionuclides, low dissolution rates of the spent fuel and high-level waste, and the anticipated low percolation flux.

The third EBS role — ensuring slow transport rates to the host rock — is very important because it delays release of radionuclides from the EBS and spreads the release over a longer time period. This, in turn, leads to reduced concentrations of radionuclides in the ground water reaching the accessible environment and, therefore, reduced risks for humans. The third role is feasible because corrosion products are less dense than the metals from which they derive and, therefore, will tend to seal off passages by which advective transport could occur. Consequently, transport must be by diffusion, which is very slow, rather than by advection. The use of fillers in the spent fuel waste packages and the use of packing or backfill outside the waste packages could also enhance this role for the EBS.

How well the EBS performs these three roles depends strongly on the amount and timing of water contact with the EBS, the design of the EBS, and the temperatures near, on, and within the containers. A substantial degree of control of container temperatures is possible by engineering design, e.g., by varying the spacing among containers, by using conducting or insulating materials outside the containers to affect heat transfer, by forced or natural cooling (ventilation or natural convection), or by ageing the wastes. While the amount of precipitation falling on Yucca Mountain and the potential evapotranspiration there are not controllable, there are engineering means to reduce the amount of water reaching the waste packages or to delay its arrival. As discussed in the Geoengineering section, such means include the use of decay heat from the spent fuel to keep the waste package, backfill (if present), and tunnel rock temperatures high enough to evaporate incoming water away from the waste packages. Also, more conventional civil engineering structures could be used, such as ditches and drains to divert water away from the repository or shields in the emplacement tunnels over the waste packages. (Such structures are based on well-established technologies and are inexpensive.)

Many of these concepts are under active consideration by the DOE. Some are not, however. The DOE should make a concerted effort to identify *all* engineering concepts that could help the EBS accomplish its three roles in the waste isolation strategy and should screen these concepts to determine which merit further investigation.

Assuming one can predict, or at least bound, the amount and chemical characteristics of water reaching the EBS as a function of time, one should be able to predict, or at least bound, EBS performance over very long periods with a high degree of confidence. This is because the physical and chemical characteristics of the EBS will be known accurately and in detail at the time of emplacement. If bounds on the environment (temperature, water composition, humidity, etc.) within which the EBS will perform can be estimated, then appropriate models can be developed to project EBS performance. These models would be based on existing data and theory, together with data that will be collected in OCRWM-sponsored laboratory research programs over the next five to ten years. They would also be confirmed by performance confirmation programs before repository closure.

The EBS is of highest importance during the first ten thousand years of a repository. As a repository ages further however, the contribution of engineered barriers to safety will become progressively less important. The contribution of the EBS to safety may never vanish completely, however. For example, while the waste package will eventually succumb to corrosion, the corrosion products themselves can serve as an important barrier. They will provide a chemical "barrier" to reduce solubilities (by saturating whatever water flows through with low radioactivity isotopes), a physical barrier to retard flow, and an adsorption barrier for certain radionuclides. Furthermore, the geometry, physical characteristics, and chemical characteristics of the EBS will be known accurately at the time of emplacement, and the changes in chemical characteristics as corrosion proceeds are already well known. Thus, neglecting external events, the ability to predict, or at least bound, EBS behavior function of its environment should remain high for tens, if not hundreds, of thousands of years.

Criticality Control in a Repository

At its April 1995 meeting (NWTRB 1995c), the Board heard two presentations regarding the prevention of sustained nuclear chain reactions in a repository containing commercial spent fuel and defense high-level waste from reprocessing. The always important topic of criticality control became more visible in the spring of 1995, due to articles and stories in the national media regarding the possibility of sudden energy releases due to criticality events. So far the Board has seen or heard no credible evidence that a nuclear explosion (a sudden, high-power release of significant energy due to supercritical nuclear reactions) in a well-designed repository at Yucca Mountain containing commercial spent fuel and defense high-level waste would be even remotely probable.

Brief, low-power criticality events may not be impossible, however. It is incumbent on the DOE to identify and analyze what is required to initiate such events and to determine their likelihood and consequences. The design of the EBS (chiefly the waste package, but invert and backfill materials also can perform significant roles) must ensure that the probability of such events is so small as to be clearly unimportant or the consequences insignificant. While these analyses need to be done for the cases where individual waste packages are still in their original, as-emplaced geometric configuration, they should be done as well for cases where corrosion has breached the waste package; physical events, such as rockfalls or earthquakes, have disturbed the overall geometry of the waste package and scrambled the contents within it; and water has begun moving through the package, perhaps further rearranging its contents and leaching away some of the neutron absorbers.

Estimating the probability of criticality within an intact or damaged waste package will be less difficult than estimating "external criticality," i.e, criticality that may occur due to selective dissolution and transport of neutron absorbers and fissile materials, and their recombination outside the waste package. Although external criticality may be highly unlikely, it can not be dismissed without thorough analysis. The Board understands that the DOE intends to use a probabilistic risk analysis methodology to address external criticality. While such an approach is appealing, it may turn out to be costly and time-consuming to the point of impracticality in a repository context because of the very large number of events and geometric configurations possible in a repository. The Board suggests that the DOE consider increasing the criticality control robustness of the EBS. Examples of increased criticality control robustness could include a longer waste-package lifetime, more criticality control material inside the waste package, the use of fillers, and the use of criticality control material in packing, inverts, and backfill. In particular, the use of depleted uranium in filler, invert, or backfill material, or in all three, is a concept the program has not yet explored adequately. Conceivably, increasing the criticality control robustness of the EBS could turn a potentially intractable analysis of external criticality into a comparatively easy one.

Corrosion Modeling in TSPA-95

The following corrosion models were used in TSPA-95:

- Humid-air corrosion of corrosion-allowance[18] materials.
- Aqueous corrosion of corrosion-allowance materials.
- Localized corrosion of corrosion-resistant[19] materials.

In addition, a highly simplified cathodic protection model was used for certain TSPA-95 sensitivity studies.

Intera, Inc., a component of the DOE's M&O contractor, developed these models with input from other M&O components. Descriptions of and Board comments on each of the models follow.

Humid-air corrosion of corrosion-allowance materials

As currently conceived, waste packages would be closed, double-shelled, metal cylinders. The outer shell would be a thick, corrosion-allowance material (e.g., 100 mm-thick carbon steel), and the inner shell would be a less thick corrosion-resistant material (e.g., 20 mm-thick Alloy 825, an alloy of approximately 40 percent nickel, 30 percent iron, 20 percent chromium, and small amounts of other metals). The largest waste packages contemplated would hold 21 pressurized water reactor (PWR) or 44 boiling water reactor (BWR) assemblies.

18 Corrosion-allowance materials fail primarily by generalized corrosion.

19 Corrosion-resistant materials fail primarily by localized corrosion and fail more slowly than corrosion-allowance materials.

It has long been known that the rates of corrosion of many metals in air depend, among other things, on the temperature of the air, how long the metal has been exposed to it, and its relative humidity. It is also known that corrosion rates are much higher above a certain relative humidity than below it. The relative humidity value dividing the much higher corrosion rates from the lower ones varies with the metal studied, but usually lies between 60 and 75 percent.

The relative humidity to which the surface of an emplaced waste package is exposed will vary over its repository lifetime. When ventilation is in use at Yucca Mountain, e.g., during container emplacement, repository relative humidity will almost always be very low because of the normally very dry, desert air that will be used for ventilation, coupled with decay heat. After ventilation ceases, the decay heat from the waste packages will raise the temperatures in the vicinity of the waste package, driving water away and resulting in a low-humidity environment during the times when temperatures are well above boiling. Eventually, however, the rate of decay heat generation will diminish to a point where temperatures are no longer above boiling, allowing water to return to the vicinity of the waste packages. A high-humidity environment is then likely to be established.

To develop the humid-air corrosion model for corrosion-allowance materials, Intera began by using 166 data points for atmospheric exposure of commercial cast irons and carbon steels taken from the general corrosion literature. The data included corrosion depths, exposure periods, and average exposure temperatures and humidities. The longest term data spanned 16 years. Most of the data were for exposure periods of less than two years, however. The data were used to develop a general humid-air corrosion model of corrosion depth as a function of time, temperature, and relative humidity. A pitting factor multiplier was added to the general humid-air corrosion model by assuming that the pitting factor is represented by a normal distribution with a mean of 4 and a standard deviation of 1.[20] The resultant humid-air corrosion model with pitting factor was used in TSPA-95 to represent corrosion of corrosion-allowance material in a humid-air environment.

Board comments

Under all post-closure repository scenarios, there will be long periods when the air's relative humidity will be above 70 percent, but there will be no free water present on many or all waste packages. Therefore, modeling of humid-air corrosion is needed. Humid-air corrosion models have not been used in TSPA exercises prior to TSPA-95. As a first version, the new model is a good start. The Board has many concerns with the model, however. These concerns should be taken into account as the model evolves in subsequent TSPA iterations.

The first concern is that the model is based on comparatively short-term data, yet is being extrapolated for very long periods — thousands of years. A serious attempt should be made to locate data for iron artifacts for the purpose of a gross check on the model.[21] Another concern is that the quality of the data utilized to build the model is variable and probably impossible to verify. It is crucial to conduct long-term laboratory work to produce quality-assured data confirming the model.

The humid-air model was developed for higher relative humidities — values above about 60 percent to 70 percent. For lower relative humidities, particularly for relative humidities approaching zero, it is known that the corrosion rate is very low. Apparently, many, possibly all, of the TSPA-95 runs were made assuming *no* corrosion for low-humidity conditions. Regardless of the degree to which low-humidity corrosion may affect results, omission of low-humidity corrosion detracts from the credibility

20 Pitting factors below 1 were set to 1.

21 The artifacts should range in age from 100 years to the beginning of the Iron Age (approximately 3,500 years ago). Such data are likely to exist only in an archaeological context. It is recognized that the quality of such data would probably be insufficient to allow accurate corrosion models to be constructed. However, the data could be very useful for checking or bounding any model. Artifacts from ancient mines and tombs in desert environments would probably be the best contextual and regional analogs.

of TSPA-95. A low-humidity corrosion model should be incorporated in future total system performance assessments.

Aqueous corrosion of corrosion-allowance materials

Aqueous corrosion refers to corrosion that occurs when liquid water covers a material completely. Intera also developed the aqueous corrosion model for corrosion-allowance materials. Intera used 44 data points of immersion of corrosion-allowance materials in river water and lake water. The data were taken from the general corrosion literature. The data included corrosion depths, immersion periods, and temperatures. The longest term data spanned 16 years. Most of the data were for immersion periods of less than four years, however. Because the immersion data covered only a narrow temperature range, seven short-term laboratory data points for the corrosion of mild steel in oxygenated distilled water over a temperature range from 5°C to 90°C were used to develop the model's temperature-related components. The same pitting factor multiplier was added to the general aqueous corrosion model that was used in the general humid-air corrosion model. The resultant aqueous corrosion model with pitting factor was used in TSPA-95 to represent aqueous corrosion of corrosion-allowance materials.

Board comments

Liquid water may contact one or more emplaced waste packages intermittently or, more rarely, continuously at some time after repository temperatures fall below the boiling point of water. Therefore, modeling of aqueous corrosion is needed. Aqueous corrosion was first modeled in TSPA-93, and the Board viewed this first use of a rudimentary, mechanistic model as a welcome step in the right direction. The aqueous corrosion model used in TSPA-95 is an improvement because it is based on more data and because it better fits the behavior of aqueous corrosion as a function of temperature. Nevertheless, the Board has concerns with the model, many of which are the same as the Board's concerns with the humid-air corrosion model. These concerns should be taken into account as the model evolves.

The first concern is that the model is based on comparatively short-term data, yet is being extrapolated for very long periods — hundreds to thousands of years. A serious attempt should be made to locate data for iron artifacts for the purpose of a gross check on the model. Also, the number of data points used to build the model is limited and the quality of the data is variable and probably impossible to verify. It is crucial to support long-term laboratory work to produce quality-assured data confirming the model. Another concern, albeit minor, is that the model used does not allow the possibility of layers of corrosion products beginning to slough off once they reach a critical thickness. This would be especially likely in response to seismic events, rock falls, and other disturbances.

Although there may be mechanistic differences between humid-air corrosion and aqueous corrosion in oxygen accessibility to metal surfaces as the relative humidity approaches 100 percent, one would expect the models to behave very similarly. This does not seem to be the case as a function of temperature. The humid-air corrosion model predicts that the corrosion rate increases with temperature, while the aqueous corrosion model predicts that the corrosion rate increases with temperature until about 60°C, then *decreases* with temperature. This anomaly must be resolved.

Localized corrosion of corrosion-resistant materials

Intera assumed that the only type of corrosion that the corrosion-resistant material would undergo would be aqueous pitting corrosion. In the absence of data, pit growth rates as a function of temperature were elicited from Lawrence Livermore National Laboratory personnel to develop a simple model. This model was used in TSPA-95 for corrosion behavior of corrosion-resistant materials.

Board comments

The inner shell of the waste package should be an important barrier. However, neglecting whatever cathodic protection the outer shell may give to the inner shell, the approach used to model inner shell corrosion in TSPA-95 indicates — incorrectly in the Board's opinion — only limited usefulness of the inner shell after liquid water or high humidity returns to the waste package environment and the outer shell has been penetrated.[22] Data should be obtained for corrosion of corrosion-resistant materials, and a model for inner shell corrosion should be developed from the data for use in future TSPAs.[23]

Cathodic-protection "model"

When two metals are in contact in the presence of an electrolyte, the more active metal serves as an anode and goes into solution (corrodes), while the less active (the cathode) is protected from corrosion. This phenomenon is known as cathodic protection. Intimate contact is necessary for effective cathodic protection, but the contact does not have to be continuous. Carbon steel is considered to be more active than, and thus protective of, Alloy 825. Thus, assuming adequate contact, the outer shell of the waste package should continue to provide cathodic protection for the inner shell long after the outer shell is penetrated.

Intera performed several sensitivity studies assuming the outer shell would cathodically protect the inner shell as long as the outer shell retained the equivalent of 25 percent or more of its original thickness. In all cases, cathodic protection improved waste package performance very significantly.

Board comments

Cathodic protection has the clear potential to be a major contributor to repository safety. Laboratory activities to verify that cathodic protection can work under repository conditions (including a range of temperatures, pHs, and dissolved salt compositions) are already under way. Additional work will be needed to determine how continuous the contact between the inner and outer shells must be to ensure cathodic protection.[24] All work must be undertaken in close cooperation with the waste package designers.

Corrosion models not *used in TSPA-95*

One of the sensitivity studies performed by Intera for TSPA-95 examined the effect of spent fuel cladding failure on the rate of release of radionuclides from the EBS. Intera simply assumed three cladding failure cases — 1 percent failed, 10 percent failed, and 100 percent failed. ("Failure" was considered the complete absence of cladding.) Not surprisingly, the sensitivity studies showed that greater cladding failure led to larger and earlier releases.

Almost all commercial spent fuel cladding is a zirconium alloy. Because it consists of a different material than the waste package outer or inner shells, the cladding could serve as a valuable additional barrier. Based on presentations and reports by M&O personnel,[25] the Board believes that models already exist that could conservatively bound the degradation behavior of zircaloy cladding under repository conditions. These models should be adapted to and incorporated in future versions of TSPA.

EBS Design

It is convenient to discuss the design of the EBS in two parts: (1) design of the waste package and its internal structure and (2) design of EBS components outside the waste package. The DOE continued to make progress in waste package design in 1995, culminating in the issuance of a multivolume draft design document at year's end (TRW 1996b).

22 *The model used by Intera assumed that pit growth rate was independent of period of exposure to aqueous conditions. Generally speaking, however, pit growth rate slows with time. To test the importance of a decreasing pit growth rate, Intera performed a set of sensitivity studies assuming that pit growth rate decreased with the square root of exposure time. (This is a conservative assumption, since many pit growth studies show pits grow with the cube root of time.) The studies showed that only about 5 percent of the waste packages had been penetrated 100,000 years after emplacement. This is a strong argument for obtaining site-relevant experimental data on pit growth rate to confirm or refute its variation with time.*

23 *The Board understands that recently obtained data on corrosion of Alloy 825 (the inner shell material in current waste package designs), under conditions that may apply to Yucca Mountain, may indicate that the performance of Alloy 825 is marginal and that it should be replaced by a more corrosion-resistant alloy (i.e., one with a higher nickel content).*

24 *This work should include measurements of the areal density of pits and the distance between pits.*

25 *Presentation by Kevin McCoy on zircaloy cladding as a disposal barrier (NWTRB 1994b).*

Waste package design

There currently are designs for two types of spent fuel waste packages:

- Canistered spent fuel waste package (for spent fuel that arrives at a repository already prepackaged in a thin metal canister containing multiple assemblies)
- Uncanistered spent fuel waste package (for spent fuel placed into the waste package, one assembly at a time, at the repository)

All spent fuel waste packages have double shells. The material of the inner shell is 20-mm thick Alloy 825. The material of the outer shell is either 100-mm thick carbon steel or 50- to 65-mm thick 70/30 cupronickel.[26] Both the canistered and the uncanistered spent fuel designs have several variations: large and small, pressurized water reactor (PWR) and boiling water reactor (BWR) spent fuel, carbon-steel and 70/30 cupronickel outer shell.

Canistered spent fuel waste package design. Since some spent fuel will arrive at a repository's waste packaging facility prepackaged in a thin metal canister containing multiple assemblies, packaging activities carried out at the facility would consist of little more than inserting the spent fuel canister in the waste package and welding the waste package shut. This is how a true multipurpose canister would function.[27]

The largest canistered spent fuel waste package designed by the DOE would be capable of accommodating a canister holding 21 PWR (or 40 BWR) assemblies. It would be approximately 1.8 m in diameter and 5.7 m long, and it would weigh approximately 66,000 kg fully loaded with 21 PWR assemblies (but assuming no fillers).

Uncanistered spent fuel waste package design. The largest uncanistered spent fuel waste package designed by the DOE would be capable of holding 21 PWR (or 44 BWR) assemblies. It would be approximately 1.6 m in diameter and 5.3 m long, and it would weigh approximately 48,000 kg fully loaded with 21 PWR assemblies (but assuming no fillers).

Board comments on spent fuel waste package designs. The waste packages in the current designs are certainly "robust" when compared to the earlier thin-wall, low-capacity conceptual design. Still, the Board is concerned that the current designs may not be sufficiently robust. The objective for the waste package in the evolving waste isolation strategy, the criteria for the waste package in certain key design assumptions (TRW 1996a), and the continuing uncertainties about the temperatures, relative humidities, and amounts of water the waste packages will experience over time in a repository at Yucca Mountain all combine to press for an adequately robust waste package. In general, the Board believes that a more conservative design philosophy than that represented by the current design is appropriate until a better understanding of Yucca Mountain is obtained.

The thickness of the waste package's outer shell is an example that illustrates the Board's concern. The thickness is 100 mm in all designs using carbon steel. According to the M&O, this thickness gives adequate strength (e.g., for protection against rockfalls after emplacement) and resists radiolysis-enhanced corrosion of the outside of the waste package. Despite the outer shell's ruggedness, however, it is unclear whether it and the inner shell together meet the evolving waste isolation strategy's objective of containing the waste in the waste package for "...thousands of years" or the design criterion of providing a mean waste package lifetime "...well in excess of 1000 years," given the uncertainties in the temperature and relative humidity of the waste package environment as well as times and amounts of liquid water that may contact a waste package.

26 *70/30 cupronickel is an alloy with approximately 70 percent copper and 30 percent nickel. The DOE has performed comparatively little analysis of the spent fuel waste package with a 70/30 cupronickel outer shell.*

27 *A true multipurpose canister (MPC) is a canister that, with appropriately different overpacks, would be suitable for at-reactor storage, transportation from a reactor to a repository, and disposal in a repository. The idea is that spent fuel would be loaded into the canister at the reactor, then permanently welded shut. As discussed in Chapter 1, the DOE canceled all future development work on the MPC.*

Clearly, increasing the outer shell thickness would affect waste package performance positively: a thicker shell would last longer until penetrated by corrosion, would retain mechanical strength longer, would provide cathodic protection to the inner shell longer, etc. It could also provide increased assurance until the waste isolation strategy's hypothesis of low seepage into the emplacement tunnels can be established. Simply stated, a thicker shell would give better performance. Although carbon steel is relatively inexpensive, a thicker outer shell would cost more.[28] Thus, there is a trade-off between cost and performance. Given the uncertainties about Yucca Mountain, it would seem that a more conservative design, i.e., a thicker wall, should be chosen, particularly if it is not a high-cost item. It would be easier to reduce wall thickness later, if justification is developed, than to increase it.

A similar situation exists with regard to the amount of neutron absorber material used in the 21-PWR uncanistered fuel waste package. Neutron absorber material is incorporated into the current package design by surrounding each assembly with a 5-mm tube of stainless steel containing approximately 2 percent boron (a neutron absorber). Eventually some of the waste packages may corrode and their internal configurations may change by the action of corrosion and rockfalls. The stainless steel tubes eventually will corrode too, conceivably allowing the boron to migrate to where it would be ineffective. Possibly, probabilistic evaluations may show such a sequence of events to be so unlikely as to be essentially impossible. Until then, however, a more conservative design for the use of neutron absorber material, for example one that supplements the boron by "control rods" or one that uses neutron absorber material in fillers[29] (or both) would seem prudent. The Board is aware that both of these options are under consideration and encourages continued evaluation.

DHLW waste package design. In contrast to the many design variations for spent fuel waste packages, there is only one design for defense high-level waste from reprocessing (DHLW). The DHLW waste package has a 20-mm thick Alloy 825 inner shell and a 50-mm thick 70/30 cupronickel outer shell. It is sized to accommodate four standard Savannah River pour canisters (each approximately 0.6 m in diameter by 3 m long) of DHLW glass. The DHLW package is approximately 1.7 m in diameter and 3.7 m long and weighs approximately 22,000 kg when fully loaded with four glass-filled canisters, but assuming no fillers to occupy the voids in between.

Board comments on the DHLW waste package design. The package's outer shell is 70/30 cupronickel. It, rather than carbon steel, has been designated because some data indicate that iron corrosion products could accelerate the dissolution of DHLW (DOE 1994a). It is a much more expensive material than carbon steel, however. Even if the use of 70/30 cupronickel does result in a decreased dissolution rate for glass, it is not at all clear this would have a significant effect on overall repository performance (or that a thicker, but cheaper, carbon steel outer shell would not give performance equal to the thinner, 70/30 cupronickel shell). The reasons for this are that: (1) at time of emplacement, the radioactivity of a metric ton of DHLW is only about one-fifth as much as a metric ton of commercial spent fuel; and, (2) DHLW has a much lower content of long-lived radionuclides (particularly actinides) than commercial spent fuel. The final decision about which outer shell material to use should be based on repository performance considerations relative to spent fuel. DHLW should meet the *same* repository safety standards as spent fuel.

EBS design outside the waste package. A repository could include EBS components outside the waste package having the exclusive purpose of improving repository safety performance, e.g., by increasing waste package life or by retarding radionuclide

28 *It would also weigh more and be larger. These need not be obstacles per se for waste package design or repository operations.*

29 *The Board continues to have a high degree of interest in the roles that waste package fillers could play in ensuring the safety performance of a repository. For example, corrosion and physical disturbances may cause a waste package to slump, creating a depression in which water could collect. By reducing void spaces in waste packages, fillers could reduce the size of such depressions or even eliminate them.*

transport to the host rock. Examples of such components include backfills and drip shields. TSPA-95 results indicated that backfills, particularly capillary barriers, could significantly benefit repository performance. The Board understands that a major systems study of engineered barrier components outside the waste package is under way and is to be completed soon. If the systems study indicates such components would be effective and feasible additions to the EBS, as the Board thinks some are likely to be, they should be included in the design rapidly so their efficient emplacement requirements can be incorporated into repository design.

Many repository operational and structural materials (such as steel rock bolts, mesh, and rails; concrete tunnel liners; and even invert materials) can benefit repository performance. Examples of potential benefits would be the locally reducing environments that steel structural materials could help create or maintain, leading to reduced solubilities, and thus reduced transport, of many radionuclides. Concrete tunnel liners could provide and prolong a moderately high pH environment, good not only for lower solubilities for some radionuclides but also for a lower steel corrosion rate. They also could reduce the severity of rockfalls on a waste package. Cost will also enter into these decisions.

Any organic compounds associated with repository operational and structural materials could influence repository performance negatively. It is inevitable that microbes will return to the vicinity of the waste packages after the temperature drops below boiling in the tunnels. The organic compounds will provide nutrients for the microbes, possibly exacerbating their tendency to increase corrosion rates or accelerate radionuclide transport. The DOE must continue its efforts to understand the role of microbes in corrosion at Yucca Mountain. Repository design should take into account the effects of operational and structural materials on post-closure performance.

Conclusions

1. The Board considers each of the three roles for the EBS in the evolving waste isolation strategy (complete containment for thousands of years; low mobilization rates; slow release to the host rock) to be important and feasible.

2. The Board has not yet seen any credible evidence that a nuclear explosion (a sudden, high-power release of significant energy due to supercritical nuclear reactions) in a well-designed repository containing commercial spent fuel and defense high-level waste would be even remotely probable at Yucca Mountain.

3. Cathodic protection has the clear potential to be a major contributor to repository safety.

4. The DOE should adopt a conservative design philosophy for the engineered barrier system until the level of understanding of future EBS performance justifies a less conservative approach.

5. Void spaces within the waste package may, upon collapse, contribute to water collection points over the spent fuel.

6. If a soon-to-be completed systems study shows that EBS components outside the waste package, e.g., backfills or drip shields, are worthwhile, the DOE should move rapidly to incorporate them into the repository design.

Recommendations

1. The DOE should continue its efforts to identify engineering concepts that could help the EBS accomplish the three roles (complete containment, low mobilization, slow release) set out for it in the waste isolation strategy. Once identified, the DOE should set priorities for the concepts and decide which merit further investigation.

2. The DOE should consider increasing the robustness of the EBS for preventing nuclear criticality after repository closure. In particular, the use of

depleted uranium in filler, backfill, or invert material is a concept the program has yet to explore adequately.

3. Attempts should be made to locate data for iron artifacts to check extrapolations of corrosion models for waste packages based on short-term data.

4. The DOE should give a high priority to the corrosion research program for candidate waste package materials and should maintain an appropriate and *consistent* level of support for the next several years.

5. The use of fillers to prevent void space collapse should be evaluated.

Environment and Public Health

This section discusses three subjects within the purview of the Panel on the Environment and Public Health: (1) terrestrial ecosystem activities at Yucca Mountain, (2) environmental impact statements, and (3) socioeconomic impacts. Reduced funding levels for fiscal year 1996 have caused a virtual halt in the environmental activities of the program. Preparation of environmental impact statements has been deferred.

Terrestrial Ecosystem Activities

In 1990, the Board noted (NWTRB 1990) that there are potentially significant, but highly localized, ecological risks related to site-characterization activities and to any future construction and operation of a repository. However, site-characterization activities at Yucca Mountain are not different in kind or intensity from ongoing mining, construction, and pumped irrigation activities in southern Nevada. The Board recommended efforts to characterize and understand the desert ecosystem at Yucca Mountain. Such understanding would provide a basis for predicting the potential effects of repository construction and operation, as well as the effects of site-characterization activities.

During 1995, substantial changes occurred in the terrestrial ecosystems component of the DOE's environmental activities at Yucca Mountain. Experience with the desert tortoise program allowed a reduction in the number of tortoises that will be monitored with radio transmitters, reduced surveillance of ravens (predators of young tortoises), and permitted less frequent sampling for a respiratory disease thought to be spread among tortoises by human contact. The monitoring program for site-characterization effects was revised extensively by reducing the number of monitoring plots from 48 to 18 and by using both "near-field" and "far-field" control plots as baselines against which to evaluate the possible environmental effects of site characterization. While the nominal purpose of this program is to support site characterization, it also provides descriptive information about site biological composition and the environmental conditions. This information will contribute to the baseline description needed if the site is judged suitable and an environmental impact statement is prepared for a repository at the site. (The Board notes, however, that the early years of the effort included little attention to ecosystem processes at the site.)

During 1995, the DOE initiated a thermal-loading ecosystem study at Yucca Mountain. The study was intended to develop or adapt existing models of ecosystem functions to try to predict how the Yucca Mountain ecosystem would respond to the heat of a repository. Field measurements of soil moisture and temperature, and of precipitation, were to be used as input to the models (and to validate their predictions), but no soil heating experiments were planned. This work was largely curtailed at the end of 1995 because of reduced funding for fiscal year 1996.

Environmental Impact Statements

During 1995, the DOE began preparing two environmental impact statements (EISs) — one for procurement of multipurpose canisters and the other for development of a repository at Yucca Mountain. The first step in preparing an EIS, called scoping, seeks public input on the scope of the analysis, the types of environmental effects to be evaluated, and the specific alternatives to the proposed action that will be considered. The scoping process was largely completed for both EISs during 1995.

The Board provided comments to the DOE on the scope of a repository EIS. The Board recommended that a broader range of alternatives be considered including different repository designs, types and inventories of waste,[30] and environmental issues. The Board's letter of comments can be found in its entirety in Appendix E.

The Board did not comment on the DOE's suggested scope for the MPC EIS.

At the end of 1995, reduced funding for fiscal year 1996 caused the DOE to cease development of both environmental impact statements. Responsibility for the MPC EIS was transferred to the U.S. Navy which may develop an MPC for spent naval reactor fuel.

Socioeconomic Impacts

The DOE must consider the socioeconomic impacts of disposing of spent fuel and high-level waste at Yucca Mountain. It must evaluate those effects in the repository EIS. Moreover, the DOE's own site suitability guidelines, 10 CFR 960,[31] currently require, as a qualifying condition, a finding that locating a repository at Yucca Mountain will not cause significant social and economic impacts that cannot be offset by reasonable compensation and mitigation to surrounding communities and regions.[32]

Large and rapid population changes cause many socioeconomic impacts. These are often termed *standard effects*. Under guidelines promulgated by the Council of Environmental Quality (40 CFR 1500-1508), the DOE is clearly obligated to examine a broad range of standard effects in its repository EIS (see 40 CFR 1508.8). As long as the DOE's siting guidelines remain in force, an analysis of whether those impacts are significant and can be offset by compensation or mitigation must also be undertaken.

At its January 1995 meeting, the Board heard how the standard effects were being assessed. The DOE reported that it has been monitoring population fluctuations associated with the Yucca Mountain project for several years (NWTRB 1995a). This monitoring consisted principally of recording the population changes directly attributable to the project in Las Vegas and in other jurisdictions where project participants reside. The DOE also has conducted some "procurement monitoring" to record where and how the project's funds are spent. Representatives of Clark and Nye Counties and from the eight affected rural counties also presented their analyses of the standard effects arising from the Yucca Mountain Project (YMP). These local governments suggested that the repository development effort could generate a number of impacts that the DOE has not assessed, including an increase in political divisiveness, strained intergovernmental relations, and effects on the transportation infrastructure.

The standard socioeconomic impacts that the DOE has monitored appear to be quite small. The recent explosive economic growth of southern Nevada has lured hundreds of thousands of new residents to the area. Consequently the total number of people associated with the YMP is a very small fraction of the total population. The number of new arrivals brought to southern Nevada to work on the YMP is also a very small fraction of the total new residents. Although both fractions grow if one looks at population changes in rural areas such as Nye County, they are still less than one percent.

Perceptions of risk attached to a repository may cause other socioeconomic impacts. These impacts are often termed *special effects*. A Supreme Court de-

30 *A bill (S. 1271) was recently voted out of the Senate Committee on Energy and Natural Resources. It would require the DOE to maximize the capacity of a repository at Yucca Mountain (NWTRB 1995b).*

31 *According to a statement submitted by Daniel A. Dreyfus for an appropriations hearing on March 26, 1996, the DOE intends to propose revisions to 10 CFR 960 before October 1, 1996 (DOE 1996).*

32 *Section 175 of the Nuclear Waste Policy Act also requires the DOE to determine whether measures should be adopted to mitigate the effects of constructing and operating a repository at Yucca Mountain. In December, 1988, the Secretary of Energy made a preliminary finding that, for the 14 specific areas enumerated in the Act, the impacts were either minimal or readily mitigatible. (DOE 1988).*

cision involving the restart of the undamaged unit at Three Mile Island appears to have removed any DOE obligation to analyze special effects in the context of an EIS (NRC 1983). It is, however, an *open question* whether the DOE must examine special effects in the context of its site-suitability regulation.

Because the DOE does not acknowledge any such obligation, it has conducted only very limited studies of the perceived risks of a Yucca Mountain repository and the possible socioeconomic effects arising from those perceived risks. Nevertheless, the Panels on Risk and Performance Analysis and the Environment and Public Health met jointly in April 1995 to consider how a technically sound analysis of perceived risks and their socioeconomic consequences might be conducted if the DOE decided to do so on its own or if it became legally necessary.[33] The panels invited ten distinguished social scientists to address four questions, which are listed below along with the overall conclusions reached by the social scientists.

- What are the origins of risk perceptions?

There is a strong understanding of what factors (attitudinal, demographic, cultural, knowledge) influence risk perceptions. Very little consensus has emerged about the relative importance of those factors.

- What is the link between attitudes and behaviors?

There appears to be only a modest link between attitudes, such as risk perceptions, and consequent behaviors. The relationship is contingent on the saliency and intensity of the attitudes, how they are elicited, and what behaviors are predicted. Much of the information in this area comes from evaluations of advertising campaigns, which may not be fully relevant to nuclear waste management.

- How do individual behaviors translate into socioeconomic impacts?

The relationship between individual behaviors and socioeconomic impacts has almost exclusively been inferred from anecdotal or case study evidence. Should another anecdote or case suggest a contradictory conclusion, no basis currently exists for distinguishing among different interpretations. For example, a radionuclide contamination incident in Brazil supports the existence of an economically devastating stigma effect while the long record of testing of nuclear weapons in Nevada does not. Moreover, other environmental, economic, and social conditions or trends could influence the socioeconomic well-being of southern Nevada, making isolating the impacts associated with a future repository very difficult.

- How are impacts evaluated? How can they be compensated for or mitigated?

At the core of the compensation and mitigation issue are three questions: How do you know if some response is needed — especially for a project that will be implemented over the next century? How can any harm experienced be quantified in monetary terms? Are there certain types of harm that intrinsically cannot be compensated for or mitigated against either because of their nature or their magnitude? The social sciences have not yet provided very determinative answers to those questions.

These four questions specify a set of logical connections that the DOE would have to analyze to satisfy its site-suitability guideline for socioeconomic impacts arising from risk perceptions. The relevant social sciences are sufficiently mature so that findings on the first pair of questions can be made with some confidence. Answers to the second pair of questions, however, are likely to be much less precise, especially for predictions that stretch beyond several years. For those questions, plausible answers can probably be obtained for some “worst-case” scenarios.

33 *Courts have not required that agencies engage in crystal ball gazing, only that they show that their conclusions have some analytic support. See, for example, Vermont Yankee 1978.*

Conclusions

1. Revisions to the terrestrial ecosystem activities in 1995, including reductions in the scope of some of the monitoring activities, appear to be appropriate. An adequate baseline of descriptive data about site conditions has been compiled to support preparation of an environmental impact statement for the site. The reduced scope of monitoring should be adequate to detect any longer term effects associated with site characterization. However, information about the baseline ecosystem processes at Yucca Mountain is inadequate for predicting the long-term ecosystem impacts of repository heating and their significance to the repository and the regional biota.

2. Standard socioeconomic impacts have been analyzed in a variety of contexts using relatively standard methodologies. It may be possible to make projections with confidence for time periods of as much as 10-20 years. Special socioeconomic effects, caused by perceptions of risk, are much more difficult to predict. Substantial theoretical, methodological, and conceptual obstacles need to be overcome before much confidence can be given to predictions of more than a few years.

Recommendations

1. The DOE's socioeconomic program should expand the range of standard effects being considered to include those that will arise from increased transportation of materials, and personnel, possible social problems associated with "boom-and-bust" cycles, and the effects of controversial projects on the larger social system.

2. An uncertain legal situation prevails with respect to special socioeconomic impacts. As a result, as long as the site-suitability guidelines remain in effect, the Board believes a modest research and analytic effort would be prudent. The DOE should concentrate its efforts on deriving worst-case, bounded estimates of what consequences might arise and how long those impacts might last.

Chapter 3
Summary of 1995 Board Activities

The Nuclear Waste Technical Review Board conducted numerous activities between January 1 and December 31, 1995. This chapter summarizes those activities and issues not discussed in Chapters 1 and 2.

New Board Members

Selecting from a list of nominees provided by the National Academy of Sciences, President Bill Clinton appointed three new members to the Board on June 29, 1995.

Mr. John W. Arendt is the founder and senior consultant of John W. Arendt Associates, Inc., and has five decades of experience in uranium processing, handling, packaging, and transportation. He also has extensive experience in the management of engineering projects, including uranium processing facilities, their quality assurance, quality control, and inspection. Mr. Arendt is a member of the Nuclear Standards Board, vice chair of the Nuclear Standards Board Planning Committee, and chair of the ANSI Committee N-14 on packaging and transportation of radioactive materials and non-nuclear hazardous wastes. He also is a registered professional engineer and certified nuclear materials manager. Mr. Arendt was a research engineer for the Manhattan Project for the University of Chicago from 1943-1945.

Dr. Jared L. Cohon is dean of the School of Forestry and Environmental Studies at Yale University and a national authority in the area of environmental systems analysis and hydrology. Prior to his duties at Yale University, Dr. Cohon served as full professor at Johns Hopkins University as well as assistant and associate dean of engineering and vice provost for research. He is a member of the American Geophysical Union, the Operations Research Society of America, the Institute for Management Sciences, the American Water Resources Association, the American Society of Civil Engineers, and the Maryland Society of Professional Engineers. Dr. Cohon has held editorial positions for *Water Resources Research*, *Civil Engineering Systems*, and *Hazardous Waste and Hazardous Materials*.

Dr. Jeffrey J. Wong, science advisor to the director of the Department of Toxic Substances Control, California Environmental Protection Agency, brings to the Board extensive experience in risk assessment and scientific team management. Dr. Wong has more than 14 years' experience in the area of toxicology, including assessment of risks associated with exposure at hazardous waste sites; hazardous waste treatment, storage, and disposal facilities; and hazardous material spills and accidents. Dr. Wong has published various book chapters and many articles relating to both toxicology and risk assessment and management and has been a member of the editorial board of the *Journal of Contaminated Soils*, as well as the National Academy of Sciences / National Research Council Committee on Remedial Action Priorities for Hazardous Waste Sites. He also has been an international scientific consultant and expert witness on the design, conduct, and evaluation of health and ecological risk assessments for hazardous waste sites, permitted facilities, and landfills.

Board Meetings

From January 1, 1995, through December 31, 1995, the Board and its panels sponsored eight meetings. A chronological list of the Board's activities (beginning January 1995 and including those scheduled for the future) can be found in Appendix C. (A list of the people who participated in Board- and panel-sponsored meetings is available on request from the Board's staff.) In addition to these meetings, several Board members and staff visited experts in the spent fuel and radioactive waste management program in Canada, and the Board sent representatives to international conferences on high-level nuclear waste in England, Germany and France.

At a meeting on June 14, 1995, in Arlington, Virginia, the Board's Panel on Transportation and Systems was briefed on various aspects of the DOE transportation program and on DOE progress in implementing a systems safety and human factors engineering program within the site characterization program at Yucca Mountain. The Board was presented with updates on a variety of projects in the DOE transportation program, including status reports on operational activities and implementation of the so-called "Section 180 (c)" requirements for providing technical and financial assistance to the states along potential transportation routes. The technical assistance to impacted communities is required by the Nuclear Waste Policy Amendments Act to enhance capabilities in accident prevention and emergency response (NWTRB 1995d).

DOE presenters also described for the Board the system safety procedures and human factors engineering plans that were being implemented for the site-characterization effort. A variety of safety assessments and hazard analyses have been undertaken. Significantly, a substantial portion of them involve the actual application of system safety to TBM operations in the ESF. The Board is encouraged that the DOE has moved from planning to actual implementation and application of system safety concepts to specific operations.

The conclusions of other Board and panel meetings were presented in Chapters 1 and 2.

Board Interactions with Congress

In 1995, the Congress was particularly active in nuclear waste areas. It considered amendments to the Nuclear Waste Policy Act and initiated major budgetary reforms that constrained fiscal year 1996 appropriations for the DOE's Office of Civilian Radioactive Waste Management — and for the Board. The Board participated in and followed these congressional deliberations with considerable interest because of their potential impact on the DOE's site-characterization activities at Yucca Mountain.

Initial Senate Hearings

At the initial legislative hearing[1] on March 2, 1995, by the Senate Energy and Natural Resources Committee, the Board submitted a statement for the record (Senate 1995a) which reviewed Board activities related to oversight of the DOE's new program approach. The Board expressed concern about the DOE's schedules and funding, as well as the question of when the DOE would be able to begin accepting spent fuel from nuclear utilities. The Board stressed the importance of the DOE setting priorities within the waste management system based on a coherent waste isolation strategy.

House Appropriations Hearings

On March 16, 1995, the Board testified before the House Appropriations Subcommittee on Energy and Water Development Appropriations on the fiscal year 1996 budget request. The testimony reviewed the Board's recent accomplishments and conclusions from its ongoing technical and scientific review of the DOE's high-level radioactive waste management program. Board membership and the status of pending nominations also were reviewed (House 1995a). As a result of this testimony, the subcommittee included a provision in the fiscal year 1996 Energy and Water Development Appropriations bill that enables

1 *At the time, the principal bill was S. 167 (Mr. Johnston (D.-La.)), the Nuclear Waste Policy Act of 1995. Other bills included S. 429 (Mr. Bryan (R.-Nev.) and Mr. Reid (D.-Nev.)), Independent Spent Nuclear Fuel Storage Act of 1995; S. 443 (Mr. Grams (R.-Minn.)), Electric Consumers and Environmental Protection Act; S. 473 (Mr. Wellstone (D.-Minn.)), Nuclear Energy Policy Act of 1995; and draft legislation that was later introduced as S. 1271 (Mr. Craig (R.-Idaho)), the Nuclear Waste Policy Act of 1995.*

Board members to continue to serve beyond their stated appointments until replacements are appointed by the President.

The Board testimony noted the DOE's significant progress in addressing a number of program management problems and in refocusing program resources based on the *Program Plan*. At the time, it was the Board's preliminary view that the *Program Plan* offered both opportunities and risks. Among the opportunities was the chance to streamline the program and to establish clear, near-term goals against which real progress could be measured. Among the risks were the increased technical and scientific uncertainties that could result due to less data being collected and, therefore, available for analysis.

House Oversight and Legislative Hearings

On June 30, 1995, the House Commerce Subcommittee on Energy and Power held oversight hearings[2] on the interim storage of spent nuclear fuel and the DOE's nuclear waste repository program. Dr. John Cantlon, on behalf of the Board and accompanied by Dr. Garry D. Brewer, presented testimony (House 1995b) on the DOE's nuclear waste management program. At the hearings, Chairman Cantlon cautioned that the storage of spent fuel was not a substitute for disposal. The Board was concerned that, as a result of efforts to address the concerns of the nuclear utilities regarding spent fuel storage, the repository development program might be curtailed as funds were diverted for storage activities not originally envisioned. The Board pointed out that, if the program were streamlined and priorities were set effectively, even with reduced funding, the program could continue and real progress could be made in determining the suitability of the Yucca Mountain site. However, the Board noted that a program constrained by funding very likely could result in major delays in repository start-up. Delay in repository start-up could in turn increase pressures to develop a large centralized storage facility. As storage activities increasingly compete with disposal activities for limited resources, a valued national goal — geologic disposal — would recede farther and farther into the future. The Board believes that maintaining the major focus on site characterization at Yucca Mountain and on the continued development of a credible repository program may be the best way of reaching the national goal of safe disposal while helping ensure the success of any storage option.

In subsequent answers to questions for the record, the Board stated that before a site-suitability decision could be made with confidence, the basic activities set forth in its December 6, 1994, letter to the OCRWM would need to be completed (NWTRB 1994d). The Board was most concerned about maintaining progress on those activities related to exploratory tunneling, verifying geologic structures at depth, and initiating the necessary hydrogeologic and thermal tests.

The Board also believes that, although the DOE could begin accepting legal title to spent fuel in 1998, it is impossible to develop a centralized storage facility by 1998 under current regulatory and statutory requirements. Under the best of circumstances, significant amounts of spent fuel realistically could not be moved from reactor sites to a storage facility until sometime around 2002. Directing the DOE to develop a storage facility by 1998 — without a commensurate increase in funding for storage activities — will almost surely delay the repository program (U.S. Congress. House 1995). Therefore, before changing current policy, the Congress needs to give serious consideration to the potential consequences that lowering the priority on disposal would have for the credibility of the country's entire waste management program. The success of the program appears to be quite dependent on sustaining public

2 *The principal radioactive waste management legislation being considered was H.R. 1020 (Rep. Fred Upton (R.-Mich.) and Rep. Edolphus Towns (D.-N.Y.),et. al) on behalf of the Nuclear Energy Institute. (H.R. 1020 also was referred to the House Committee on the Budget and the House Committee on Resources, Transportation and Infrastructure.) Other bills introduced in the House were: H.R. 496 (Mrs. Vucanovich (R.-Nev.)), Nuclear Waste Policy Reassessment of 1995; H.R. 1174 (Mr. Upton, at the request of the DOE), Nuclear Waste Disposal Funding Act; H.R. 1032 (Mr. Gutknecht (R.-Minn.)), Electric Consumers and Environmental Protection Act of 1995; and H.R. 1924 (Mrs. Vucanovich and Mr. Ensign (R.-Nev.)), the Interim Waste Act.*

trust and confidence. Balancing the objective of meeting the desires of utilities to remove spent fuel from reactor sites with the need to assure the public that safety will be maintained is a delicate process.

Concluding Senate Hearing

The year concluded with a hearing on December 14, 1995, by the Senate Committee on Energy and Natural Resources to obtain the Clinton administration's position on pending nuclear waste legislation (Senate 1995b). The Board sent a letter (NWTRB 1995g) to the Congress and the Secretary of Energy which contained the following observations regarding the DOE's high-level radioactive waste program:

> *the OCRWM's program has received significant criticism — some warranted, some not — since its inception. Indeed, our Board has made many suggestions for its improvement. Recently, substantial funds were cut from the program's budget while the agenda was expanded conditionally to include the storage of commercial spent fuel.*
>
> *Specifically, …the Board was very pleased to hear about progress in excavating underground at Yucca Mountain; the tunnel boring machine is now advancing at very close to commercial rates. It has reached the level of the proposed repository, and the program is acquiring important data about the suitability of the site. Several of our members and staff returned recently from examining the tunnel. So far, the rock at the repository level looks very good, and no significant water has been found at the repository level. The Board also was very pleased to see recent progress in the development of the waste isolation strategy, which is becoming increasingly well defined and coherent. In combination with recent advances in performance assessment, this strategy should enable the OCRWM to undertake an aggressive delineation of program priorities and allocate available funds more efficiently among the various activities of the groups of scientists and engineers working at Yucca Mountain.*
>
> *The Board is very encouraged about these developments and believes that real progress has been and continues to be made by the OCRWM both in the conduct and in the management of its investigations of the Yucca Mountain site. In the Board's judgment, the timely completion of these activities is critical to the future success of the DOE's entire high-level radioactive waste management program.*

Congressional Staff Participation at Board Meetings

At the Board's October 1995 meeting (NWTRB 1995e), an overview of congressional budgetary and legislative deliberations regarding the DOE's radioactive waste management program was presented by a panel of senior professional staff members from the House of Representatives[3] and the Senate.[4] The panelists commended the Board for its work but observed that there is a big gap between the Congress trying to solve political problems and technical people trying to solve technical problems.

Based on the panelists' presentations, the Board reached several conclusions. First, the Congress is impatient with the DOE's radioactive waste management program and, despite recent progress, a great sense of austerity is setting in. The time lag between the originally proposed dates for completion of activities at Yucca Mountain and what is actually happening is unacceptable; namely, it is not solving the political problem by closing the end of the nuclear fuel cycle.

3 *Mr. Troy Timmons, the Republican professional staff member with the House Commerce Subcommittee on Energy and Power, is responsible for nuclear issues and Ms. Sue D. Sheridan, the Democratic counsel for the House Commerce Committee, is responsible for nuclear energy and electricity policy.*

4 *Mr. Alex Flint, a legislative assistant to Senator Pete V. Domenici (R.-N.M.), is responsible for energy, science, and commerce issues and Mr. Sam Fowler, the Democratic chief counsel for the Senate Committee on Energy and Natural Resources, is responsible for civilian nuclear power issues, including nuclear waste and uranium enrichment.*

Second, there is a political consensus that geologic disposal is a solution that works. There also is a general belief that the Yucca Mountain site will be found suitable. However, there is concern that a regulatory regime has been created that dooms to failure the licensing of any site anywhere because the negatives can never all be disproved.

Third, there is the perception in the Congress that, if an interim storage facility were to be constructed at Yucca Mountain, it would fit in with the general activities that are already going on at the site. The issue, therefore, is how best for the DOE to minimize the amount of time and resources spent on constructing and operating an interim storage facility.

Fourth, the Congress considers the federal government's obligation to begin accepting commercial spent fuel important. The Congress is aware of the tension that exists between the decision on site suitability and proposals for interim storage. The Congress believes that something needs to be done to relieve this tension and the consensus is that a federal interim storage program is necessary.

Fifth, the Congress recognizes the need to find a solution for the disposal of defense wastes.

Finally, there is a budgetary problem. The Congress has raised questions about the DOE's program, and the appropriations committees are dubious about giving the DOE more money until those questions are answered satisfactorily.

The panelists observed that there is the risk that Congress, in its frustration, will let the repository program wither. In the view of one panelist, this danger is something on which it would be useful for the Board to advise the Congress.

Other Board Presentations

In addition to the Board's regular activities and its presentations before Congress, individual Board members were invited to make presentations at a transportation conference hosted by the state of Nevada, a decision makers' conference sponsored by the Radioactive Exchange, and a conference on geologic disposal in England.

In January, Dr. Dennis Price provided the Board's views on the requirements for a transportation system for high-level nuclear waste at the Nevada transportation conference. His talk centered around system safety and human factors, with emphasis on minimizing spent fuel handling. Dr. Price also spoke at the media-sponsored decision makers' conference in Virginia in February, presenting the Board's views of the DOE's new *Program Plan* (DOE 1994b), with its attendant advantages and risks, and on the minimum requirements for determining the suitability of the Yucca Mountain site as a deep geologic repository for civilian spent nuclear fuel and defense high-level waste. In March, Dr. Donald Langmuir spoke on the Board's behalf at the Geologic Disposal of Radioactive Waste conference in London, England. Dr. Langmuir provided the conference with the Board's background, charter, and views and concerns about the current U.S. nuclear waste program.

Board Interactions with Foreign Programs

The Board members' international work to date has focused on keeping abreast of scientific, technical, organizational, and managerial developments in the nuclear waste disposal programs of selected other countries. The purpose has been to determine if there are any opportunities for the U.S. program to learn from the experiences of those involved or from their specific technical or scientific findings. Over time, the Board's purpose has expanded to some extent to include keeping the Board's international contacts apprised of key developments in the U.S. commercial spent fuel disposal program.

Canada

During 1995, a small delegation of the Board visited Atomic Energy of Canada Limited (AECL) facilities near Pinawa, Manitoba. The primary purpose of the visit was to allow Board members and staff who had been unable to participate in the Board's visit to the facilities in June 1991 the opportunity to meet key people and learn about the activities there.

Essentially all research for the Canadian program is carried out at the AECL facilities at Pinawa or is directed by personnel employed there. All Canadian research and development on high-level waste to date has been non-site specific. AECL published a comprehensive environmental impact statement on the Canadian waste disposal concept in October 1994 (AECL 1994). The document is undergoing a lengthy government and public review process, including extensive public hearings, at which the AECL has the opportunity to respond to questions raised by the government and the public. In brief, the AECL proposes to dispose of up to 10 million bundles[5] of used CANDU fuel containing up to 190,000 metric tons of uranium by placing the waste in a disposal vault 500 to 1000 meters below the surface of the earth in plutonic rock of the Canadian Shield. A system of multiple barriers would protect humans and the natural environment from both radioactive and chemically toxic contaminants in the waste. These barriers would be the waste form; the container; the buffer, backfill, and other vault seals; and the geosphere. Institutional controls would not be required to maintain safety in the long term.

The waste would be sealed in a container to facilitate handling of the waste and to isolate it. The container would be designed to last at least 500 years to ensure that the waste would be completely isolated during operation of the disposal facility and until there is substantial decrease in the radioactivity and heat output of the waste. The containers would be placed either in rooms underground or in boreholes drilled off of the rooms. Each container would be surrounded by a buffer, which would most likely contain clay. Each room would be sealed with backfill and other vault seals. All tunnels, shafts, and exploration boreholes ultimately would be sealed in such a way that the disposal facility would be passively safe. Generic research and development work has been ongoing by AECL since the governments of Canada and Ontario established the Nuclear Fuel Waste Management Program in 1978 to investigate many issues associated with the disposal concept outlined above. This has included, but is not limited to, research on the disposal container, waste form, vault seals, geosphere, biosphere, total system performance, and assessment of environmental effects.

The Atomic Energy Control Board of Canada (AECB) requires that quantitative estimates be made of the radiological risk associated with a disposal vault up to 10,000 years following closure. Radiological risk is defined as the probability that an individual of a “critical group” will incur a fatal cancer or serious genetic effect due to radiation exposure. The AECL constructed extensive mathematical models of the disposal system based on research and knowledge gained in Canada and other countries. The models were constructed to estimate probabilistically the performance of the disposal system considering both the expected performance and the effects of potentially disruptive processes and events. The AECL’s work to date concludes that for periods of time up to 10,000 years the estimated mean dose rate to an individual in the “critical group” is virtually nil. For periods of time over 10,000 years, the releases from the disposal system would result in effects similar to those of a uranium ore body containing the same amount of uranium (AECL 1994).

Despite the differences in geology between the Canadian and U.S. sites likely to be explored for the eventual disposal of spent nuclear or CANDU fuel, the Board finds many similarities in the scientific and technical issues that must be resolved to determine if a site could be suitable. The Board continues to be impressed with the thoroughness of the methodology used by the AECL and the extent of research that has been conducted on a modest budget by U.S. program standards (approximately $40 million Canadian per year). The Board also notes that the AECL’s waste isolation strategy is well developed, even though a specific site is unlikely to exist for some time to come. The Board may be looking at the

5 *The amount of used fuel to be generated will depend on the future of nuclear power in Canada. At the end of 1993, the inventory of used fuel was about 1.1 million bundles containing about 17,100 metric tons of uranium. If existing nuclear power plants operate for 40-year lifetimes, but are not replaced, the inventory would be about 4.3 million bundles containing about 81,700 metric tons of uranium. A higher inventory of 10 million bundles containing about 190,000 metric tons of uranium is foreseen only if existing nuclear power plants are replaced after 40 years of operation or if new nuclear generating capacity is added.*

AECL's waste isolation concept as well as those of other countries in the months ahead to see if their methodologies and priorities in developing a strategy have any information of potential benefit to the U.S. program.

Other Programs

During 1995 individual Board members of the Board and/or staff attended three international conferences:

- *Geologic Disposal of Radioactive Waste,* London, England, March 1995.
- *International Conference on Nuclear Waste Management and Environmental Remediation*, Berlin, Germany, September 1995.
- Global '95, *International Conference on the Evaluation of Emerging Nuclear Fuel Cycle Systems*, Versailles, France, September 1995.

International Visitors and Participation in Board Meetings

In addition to the previously mentioned activities, the Board has invited international experts to make presentations at Board meetings. Where possible and appropriate, people have been invited to make presentations on different aspects of other countries' programs. Issues addressed range from an overview of a specific country's approach to waste disposal to engineered barrier system research to various approaches used in conducting underground research. A number of delegations from other nations also have visited with Board and staff at the Board offices in Arlington, Virginia.

Issues from International Programs of Interest to the Board

Certain issues have emerged as a result of examining the programs of other countries because the Board believes they hold information of potential benefit to the site-characterization work at Yucca Mountain. Other issues have emerged because of the Board's interest in examining approaches used by the various countries visited to address scientific uncertainty. Still other areas emerged because of interest in finding the best way to build and maintain a successful disposal program. Areas of ongoing interest to the Board, not in order of priority, include: engineered barrier system; volcanic/seismic work; performance assessment work; regulatory framework and long-term safety issues; public understanding/acceptance of scientific and technical work; natural or anthropogenic analogues; findings in saturated and unsaturated zones; site investigation strategies; and the nature, extent, and cost of conducting underground research and testing programs. On this last issue, the Board has been interested in not only the findings, but in the research methods used to study thermal effects, fracture and matrix flow, and waste package performance.

Board Observations

The Board's observations following visits to nine selected countries are detailed in several of the Board's earlier reports. The Board's December 1992 report (NWTRB 1992) contains a more in-depth analysis because the Board concluded that the majority of the programs visited up to that time used some approaches in their waste program that, in the Board's view, could be of potential use to the U.S. program.

The Board continues to be impressed by the cost-effectiveness of the underground research programs of other countries, especially Canada. Significant scientific information is being developed at very modest cost. While some costs in the U.S. can be attributed to quality assurance and other activities needed for licensing, the Board believes that there is continued excessive overhead in the U.S. program. It is likely that useful lessons could be learned by examining the management techniques and contracting relationships of other countries. Several other countries also have developed "safety cases" which serve as clear and concise explanations of how they intend to develop a repository to isolate waste from the environment. These safety cases may prove useful guidance to the DOE as it develops its waste isolation strategy.

Board Publications

The board prepared two reports in 1995. The *Report to The U.S. Congress and The Secretary of Energy - January to December 1994 - Findings and Recommendations* (NWTRB 1995b) summarized the Board's activities during 1994 and was published in March 1995. It covered aspects of the DOE's *Program Plan*, the emerging waste isolation strategy, and the transportation program. It also explored the Board's views on minimum exploratory requirements and thermal-loading issues. One chapter of the report focused on site-assessment lessons that have been learned from projects around the world. Another chapter dealt with volcanism and resolution of difficult issues. The Board also detailed its observations on the nuclear waste disposal program visited in Japan. Report findings and recommendations centered around structural geology and geoengineering, hydrogeology and geochemistry, the engineered barrier system, and risk and performance analysis. The Board's second report of 1995 was a December 13 letter (NWTRB 1995f) which provided the Congress and the U.S. Secretary with an update of the Board's views on progress in excavating the exploratory studies facility at Yucca Mountain (see Appendix I).

Also in 1995, the Board completed its analysis of the many considerations affecting interim storage of commercial spent fuel and, specifically, arguments concerning the development of a federal centralized storage facility. This analysis, along with conclusions and recommendations, was published as *Disposal and Storage of Spent Nuclear Fuel — Finding the Right Balance* (NWTRB 1996b) and delivered to the Congress and the Secretary of Energy in March 1996.

The subject is a complex and controversial one. Many of the issues reflect the concerns of strongly held and sometimes conflicting perspectives. Some are technical in nature; most are policy related. Because of the diversity of views, reaching a decision about how best to store commercial spent fuel until a repository is built involves making value judgments.

As a technical review panel, the Board found the connection between storage and disposal to be of crucial relevance in this discussion. If the decision is to develop a federal facility, the timing of when to proceed has significant implications for repository development.

What follows is a brief summary of the major findings and conclusions of the report, along with the Board's recommendations.

Major Findings and Conclusions from *Disposal and Storage of Spent Nuclear Fuel — Finding the Right Balance*

The 1998 target date for beginning repository operations has repeatedly slipped: from 1998 to 2003, and then to 2010. Recently, the 2010 projected start date has been made questionable by budget constraints, and 2015 has been mentioned as a possible new target date. These delays, along with the absence of a centralized federal storage facility for commercial spent fuel, raise the prospect that much more commercial spent nuclear fuel will require storage for much longer time periods at the utilities than first anticipated. As a result, nuclear utilities, with the support of many of their public utility commissions, have pushed for legislation to require the DOE to develop a federal centralized storage facility — located at or near Yucca Mountain — that could begin accepting commercial spent nuclear fuel in 1998 or soon thereafter. These proposals portend a change in the focus of the federal waste management program from disposal to storage.

With the spent fuel stockpile currently at 32,000 MTU and growing at 2000 MTU per year, it would take as much as 30 years to remove the inventory from all of the individual reactor sites. *Even if there is a centralized facility to accept fuel soon, much of the spent fuel will still remain at reactor sites for decades;* there is no quick way of completely removing the spent fuel.

The Board sees technical benefits in having centralized storage; however, most of these advantages accrue later in time (around 2010), after reactors begin to shut down in appreciable numbers. The benefits of centralized storage are greatest if the facility is located at an *operational* repository. *The Board sees no* *technical reason to move spent fuel to a centralized storage facility at this time. The methods now used to store spent fuel at reactor sites are safe and are likely to remain safe for decades to come.*

The waste ultimately must be disposed of; storage is not an alternative in the long run. The Board believes that current efforts to develop a repository should be continued. Developing a storage facility at Yucca Mountain now, prior to a site-suitability determination, may seriously jeopardize the nation's repository development program. First, limited resources likely will be diverted from the site-characterization program to support storage facility and transportation infrastructure development. Second, having spent fuel transported to and stored at Yucca Mountain may be perceived as prejudging the suitability of the site, thereby compromising the credibility of the entire waste management program.

If the recent progress in site characterization is maintained, there should be sufficient data to make a credible determination of Yucca Mountain's suitability for disposal within five years. It makes sense for the DOE's efforts to remain focused on site characterization until the suitability of the Yucca Mountain site is determined. If the site is found suitable, a centralized storage facility can then be developed there. Compared to taking immediate action on developing a storage site, this course entails a delay of at most five years. Since much spent fuel will remain at reactor sites for decades in any case, the impact of such a delay on at-reactor storage is relatively small. On the other hand, the potential effect on repository development and the viability of disposal could be substantially adverse.

Recommendations

1. Developing a permanent disposal capability should remain the primary national goal and, for the next several years, determining the suitability of the Yucca Mountain site should remain the primary objective of the DOE's waste management program. Assigning the Office of Civilian Radioactive Waste Management any significant new activities at this time could compete for funding and other resources with site-characterization and repository development efforts at the Yucca Mountain site.

2. The Board recommends that during the next several years *generic* planning for a centralized storage facility and for a supporting transportation infrastructure begin at a funding level modest enough to avoid competition with the repository program. From a technical, operational, and fiscal perspective, 2010 is the key milestone for storage. Therefore, plans should be made to have this storage facility operating at full capacity (able to accept 3,000 metric tons/year for 30 years) by about 2010. This will allow the federal government to remove the backlog of spent fuel from those plants already shut down and to empty the pools at other plants as shutdowns occur.

3. The *construction* of a federal centralized storage facility should be deferred until after a decision has been made about the suitability of the Yucca Mountain site for repository development. If Yucca Mountain proves suitable, the centralized storage facility should be located there.

4. The Board recommends developing storage *incrementally* by limiting the amount that can be transported to Yucca Mountain until repository construction has been authorized by the NRC. This will address the potential risks associated with linking storage to the earlier milestone of site suitability.

5. The Board also recommends reauthorizing limited-capacity backup storage, similar to the one previously authorized by the Nuclear Waste Policy Act, at an existing federal nuclear facility. *Actual development* of the backup facility should begin only if a clear need for the facility is established. Its operation should be phased out once the operation of a large centralized storage facility commences.

6. Because siting a centralized storage facility may be extremely difficult without a viable disposal program, if the site at Yucca Mountain proves unacceptable for repository development, the Board recommends that other potential sites for *both* disposal and centralized storage be considered.