U.S. NUCLEAR WASTE
TECHNICAL REVIEW BOARD

Report to
The U.S. Congress
and
The Secretary of Energy

January 1, 2004, to December 31, 2004

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
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May 2005

The Honorable J. Dennis Hastert
Speaker of the House
United States House of Representatives
Washington, DC 20515

The Honorable Ted Stevens
President Pro Tempore
United States Senate
Washington, DC 20510

The Honorable Samuel W. Bodman
Secretary
U.S. Department of Energy
Washington, DC 20585

Dear Speaker Hastert, Senator Stevens, and Secretary Bodman:

The Nuclear Waste Technical Review Board submits this *Report to The U.S. Congress and The Secretary of Energy* in accordance with provisions of the Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203, which requires the Board to report its findings and recommendations to Congress and the Secretary of Energy at least twice a year.

Congress created the Board to evaluate the technical and scientific validity of activities undertaken by the Secretary of Energy related to implementing the Nuclear Waste Policy Act (NWPA) of 1982. In this report, the Board summarizes its major activities from January 1, 2004, through December 31, 2004.

During the period covered by this report, the Board focused on the Department of Energy's (DOE) efforts to develop a system for accepting, transporting, and handling high-level radioactive waste and spent nuclear fuel before disposal of them in the repository proposed for Yucca Mountain in Nevada. In addition, the Board continued its evaluation of how the waste packages might perform in the proposed repository. Finally, the Board considered areas where the DOE could improve its understanding of how radionuclides might move through the unsaturated and saturated zones. Correspondence and related materials from the Board to the DOE on these and other issues are in the appendices to the report.

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Also in the appendices are the Board's *Strategic Plan for Fiscal Years (FY) 2004-2009*, an evaluation of the Board's performance in 2004, and the Board's *Performance Plan for FY 2005*. The Board's *Performance Plan for FY 2006* is under review; a revised plan will be posted soon on the Board's Web site.

The Board hopes that the information provided in this report will be useful as important decisions are made on managing the nation's spent nuclear fuel and high-level radioactive waste.

Sincerely,

B. John Garrick
Chairman

NUCLEAR WASTE TECHNICAL REVIEW BOARD 2004

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Executive Summary

In 1987, the U.S. Nuclear Waste Technical Review Board (Board) was created as an independent federal agency by Congress in the Nuclear Waste Policy Amendments Act. The Board was charged with evaluating the technical and scientific validity of the U.S. Department of Energy's (DOE) efforts to develop a system for disposing of high-level radioactive waste (HLW) and spent nuclear fuel (SNF). The Board is required to report its findings and recommendations to Congress and the Secretary of Energy at least twice a year. This document describes activities undertaken by the Board between January 1, 2004, and December 31, 2004.

During 2004, the Board's review of the DOE's technical and scientific work focused on three areas: the susceptibility of the Alloy 22 waste package to deliquescence-induced localized corrosion; the design and development of a transportation system that might move HLW and SNF from locations where the material currently is stored to the proposed repository site at Yucca Mountain in Nevada; and key elements of the natural system that are expected to play a role in isolating and containing radioactive waste for many thousands of years.

In the fall of 2003, the Board issued two letters and a report, stating that under the conditions of the DOE's high-temperature repository design, concentrated calcium chloride deliquescent brines would likely lead to widespread corrosion of the Alloy 22 waste package. Stimulated by the Board's analysis and conclusions, the DOE undertook new studies and investigations. The results of those efforts were discussed at a Board meeting in May 2004. Based on the new information provided to the Board at that meeting by the DOE and others, the Board revised its earlier position, stating that calcium chloride was unlikely to be present at significant levels in the repository tunnels where the waste packages might be emplaced. Thus, calcium chloride deliquescence-induced localized corrosion would not be widespread on the Alloy 22 waste package. These same investigations, however, subsequently revealed that a mixture of sodium and potassium nitrates and chlorides, which is highly deliquescent, might pose potential corrosion problems at high temperatures. The Board continues to monitor the DOE's ongoing corrosion studies closely.

As the DOE's efforts to design and develop a transportation system that might move HLW and SNF to Yucca Mountain intensified, so did the Board's review activities. The Board held two meetings devoted exclusively to the issue, and at two other meetings, heard presentations from the DOE about its work in this area. The Board noted in a series of letters to the DOE that progress had been made in producing more-detailed planning documents. Nonetheless, the Board believes that the DOE needs to do a better job of integrating its transportation planning effort and should place a higher priority on developing contingency plans for moving radioactive waste by legal-weight trucks if the construction of its proposed rail spur out of Caliente, Nevada is delayed. The DOE's response so far to the Board's recommendations has not addressed Board concerns adequately. This is particularly true with respect to considering transportation planning in the context of an integrated waste management system and interacting with key stakeholders, such as nuclear utilities and railroads, whose input is essential to developing effective technical approaches.

Based on information gathered at a two-day meeting in March 2004, the Board identified six aspects of the natural system where additional research could substantially improve the DOE's fundamental understanding of the roles they play in isolating and containing radioactive waste: hydraulic properties of major block-bounding faults; spatial distribution and composition of the saturated alluvium; matrix diffusion; colloid-facilitated transport; active fracture modeling; and boundary fluxes in the Yucca Mountain site-scale saturated-zone model. The DOE informed the Board that it is not prepared to undertake the recommended research at this time. The Board believes that the DOE has not presented a strong technical argument about why those investigations are not warranted, especially in light of the Court of Appeals decision, which raises the possibility that the compliance period in a new EPA standard might extend to the time of peak dose.

Finally, the Board is encouraged by the DOE's efforts in making its earthquake ground-motion estimates more realistic and in completing an aeromagnetic survey that could shed light on igneous activity in the Yucca Mountain area.

Notwithstanding the progress that the DOE has made in selected areas, the Board believes that several issues still require continued or additional attention: the integration, design, and operation of elements of the waste management system; an improved understanding and a clear explanation of the likely conditions inside repository tunnels after repository closure; unresolved corrosion issues related to deliquescent brines; and improvements in the modeling of volcanic consequences, taking into account compressible flow, waste mobilization, and interaction of magma with the waste package.

Board Activities

The U.S. Nuclear Waste Technical Review Board (Board) was established by Congress in the Nuclear Waste Policy Amendments Act (NWPAA) (U.S. Congress 1987). The Act requires the Board to evaluate the technical and scientific validity of the work undertaken by the U.S. Department of Energy (DOE) to develop a geologic repository system for disposing of high-level radioactive waste (HLW) and spent nuclear fuel (SNF) produced by the nation's nuclear defense complex and commercial nuclear power plants. The results of the Board's evaluation, along with its recommendations, are reported at least twice yearly to the Congress and to the Secretary of Energy.

Between January 1, 2004, and December 31, 2004, the period covered by this report, the Board focused its attention on the DOE's efforts to develop the system needed to accept, transport, and handle HLW and SNF before disposing of the wastes in the proposed repository located at Yucca Mountain in Nevada. In addition, the Board continued its evaluation of how the waste packages might perform if they were emplaced in the proposed repository. Finally, the Board considered areas where the DOE could improve its understanding of how radionuclides might move through the unsaturated and saturated zones.

I. Background

On July 23, 2002, President George W. Bush signed House Joint Resolution 87 (U.S. Congress 2002), sustaining his recommendation of Yucca Mountain in Nevada as the presumptive site for the nation's first HLW and SNF repository and authorizing the DOE to file an application with the U.S. Nuclear Regulatory Commission (NRC) for a license to construct the facility. Over the next 18 months, the DOE accelerated its efforts to prepare a license application, stepped up its work to design the surface and subsurface repository structures, and initiated efforts to create a system for transporting waste from current storage sites to the proposed repository. Among the concrete milestones achieved by the DOE was the publication on April 8, 2004, of a *Record of Decision* that adopted the "mostly rail" transportation scenario and announced that a branch rail line would be constructed from Caliente, Nevada, to Yucca Mountain (DOE 2004a). On the same day, the DOE published a notice in the *Federal Register* that it would prepare an environmental impact statement evaluating the alignment, construction, and operation of that rail line (DOE 2004b).

In July 2004, the U.S. Court of Appeals for the District of Columbia Circuit handed down its decision on a series of lawsuits brought by the State of Nevada against the DOE, the NRC, the U.S. Environmental Protection Agency (EPA), and President Bush. The Court rejected the State's challenges to the site-recommendation process. With one exception, the Court also sustained EPA's Yucca Mountain-specific environmental standard (40 CFR 197), the NRC's Yucca Mountain-specific licensing regulation (10 CFR 63), and the DOE's site-suitability guidelines (10 CFR 963).

The Court, however, ruled in the State's favor on a challenge to the part of the EPA's standard dealing with the compliance period, which specifies the length of time a repository must satisfy established performance requirements. The Court held

that the EPA had ignored congressional instructions by failing to follow the advice of a panel established by the National Academy of Sciences pursuant to Section 801 of the Energy Policy Act (U.S. Congress 1992). Notwithstanding the panel's recommendation that, within the limits imposed by the long-term stability of the geologic environment, "compliance with the standard should be measured at the time of peak dose, whenever that occurs (National Research Council 1995)," the EPA chose 10,000 years as the compliance period. The Court therefore vacated that part of the EPA's standard along with the derivative part of the NRC's licensing regulation, 10 CFR 63.

In August 2004, an NRC Atomic Safety and Licensing Board (ASLB) concluded that the DOE had not met its regulatory obligation to make all of its documentary material available on the Licensing Support Network (LSN). The ASLB therefore revoked the DOE's certification that it had fulfilled its duties and had satisfied the requirements for placing documents on the LSN (PAPO 2004). The decision was noteworthy because NRC regulations prevent the DOE from submitting a license application until at least six months after LSN certification has taken place.

Because of these setbacks and other factors, the DOE announced in November 2004 that it would not be able to meet its schedule for tendering a license application to the NRC by the end of December.

II. Findings and Recommendations

A. Waste Management System

The DOE is responsible for developing a waste management system. The system must be designed to accept waste at nuclear power plants, DOE defense complexes and other sites; select and procure a variety of casks, for transporting HLW and SNF to a repository site; handle and store, perhaps for extended periods, the waste at a repository site; and perform waste emplacement operations underground. The Board strongly believes that designing the waste management system in a way that effectively integrates its component elements is critical. By extension, the Board also believes that it has a responsibility to evaluate the entire waste management system to understand how the various pieces fit together.

1. Transportation

Until recently, the DOE had undertaken very few activities related to transportation, one of the central elements of the waste management system. Consequently, the Board's review in this area was, by necessity, limited. As the DOE began to devote more attention and resources to developing national and Nevada-specific transportation systems the Board's involvement in the area increased commensurately. Rather than focusing simply on the transportation system, however, the Board's review of the DOE's activities in this area has sought to integrate transportation with waste acceptance at reactor sites; the design, procurement, and functionality of casks; the handling and storage of HLW and SNF at the proposed repository site; and repository operation and design.

Last year, the Board held two meetings dedicated to reviewing the front end of the waste management system, that is, the part that comes into play before emplacing the HLW and SNF underground, and explored this issue in two other meetings. On January 21, 2004, the Board's Panel on the Waste Management System met in Las Vegas, Nevada (NWTRB 2004d). The Board heard from representatives of the nuclear industry, cask vendors, the trucking and railroad industries, and state governments. In addition, representatives from six Nevada counties and the State of Nevada made presentations. In their presentations, those individuals articulated two common themes. First, although there does not appear to be any technical impediment to the safe and secure transportation of HLW and SNF, the DOE has just begun interacting with interested and affected parties. Important institutional issues, such as emergency planning preparedness, still need to be resolved. Second, the DOE's strategic planning and system-design efforts are just starting. If the DOE wants to have a system in place for transporting HLW and SNF to Yucca

Mountain by December 2010, those efforts must be accelerated.*

The Board also was briefed by the DOE's senior manager in charge of developing the transportation systems that might be used to move waste to Yucca Mountain. He discussed the newly released transportation strategic plan. He also described how the DOE has organized transportation planning into five project elements: a fleet acquisition project, a fleet management facility project, an operational infrastructure development project, an institutional project, and a Nevada transportation project. He explained the DOE's rationale for selecting as its preferred option the Caliente rail route and its choice of the Carlin rail route as a backup. Finally, he provided detail about the DOE's interactions with interested and affected parties, especially state regional groups, such as the Southern States Energy Board and the Western Interstate Energy Board.

The Board heard as well from four other DOE managers and a representative from a nuclear utility who discussed the lessons they learned from moving radioactive waste. The DOE managers related their experiences, including transporting transuranic-contaminated waste from DOE sites to the Waste Isolation Pilot Plant (WIPP), moving of foreign research reactor fuel to the DOE's Savannah River National Laboratory, and shipping SNF stored at the West Valley Demonstration Project to the DOE's Idaho National Laboratory. The utility manager described how SNF was shipped from one nuclear power plant to another. These individuals noted that a number of lessons learned, ranging from communicating with the public to establishing emergency response network, could help the DOE in its transportation planning and design activities.

The subject of transportation planning arose again at the Board's May 18, 2004, meeting in Washington, D.C. (NWTRB 2004a). At that time, the DOE's senior manager in charge of developing transportation systems informed the Board about what had transpired during the previous three months. In particular, he discussed the DOE's *Record of Decision* to use mostly rail for transporting waste to Yucca Mountain, explained the DOE's decision to select the Caliente route, and presented timelines that laid out key milestones for each of the five transportation projects.

Board Observations

In a March 29, 2004, letter to the DOE (Abkowitz 2004), the Board observed that effective transportation planning is a large and ambitious task. Although the DOE has made a commendable start with the publication of its transportation strategic plan, much more work is needed. The strategic plan lacks details and could benefit from the creation of a Gantt chart (or its equivalent) that identifies, among other things, the relationship among key activities and a critical path from which to establish priorities and schedules. The Board also emphasized the importance of the DOE's interacting with a wide range of interested and affected parties, including stakeholders at all levels of government. Such exchanges are essential for understanding cask design and procurement requirements, transport logistics, and infrastructure interfaces.

In addition, the Board expressed concern that the DOE is underestimating the role that trucks might play in transporting HLW and SNF, even in a system that relies primarily on rail. Moreover, it was unclear to the Board whether the DOE is devoting enough attention and resources to developing emergency preparedness capabilities in communities along potential transportation routes to Yucca Mountain. The WIPP experience suggests that considerable time and effort are needed. Finally, the Board encouraged the DOE to draw upon the lessons learned transporting SNF within the nuclear weapons complex. Those lessons have clear applicability if waste is shipped to Yucca Mountain.

In a July 28, 2004, letter to the DOE (Duquette 2004) about the May 18, 2004, meeting, the Board commended the DOE for "making real progress" in planning its transportation system.

* At the time the letter was written, the DOE had sought to begin operations at Yucca Mountain by December 2010. As of December 31, 2003, that milestone had not been officially changed.

DOE Responses

In a May 28, 2004, letter (Chu 2004a), the DOE responded to the Board's comments in the March 29, 2004, letter. It noted that the questions that the Board had raised were important and that it was incorporating many of the Board's comments and concerns into its planning efforts. The DOE also indicated that its presentation at the Board's May 18, 2004, meeting addressed the specifics in the Board's March letter. In a January 26, 2005, letter (Chu 2005a), the DOE stated that it appreciated the Board's recognition that progress was being made in developing a transportation system.

Transportation also was the subject of a second meeting in 2004 of the Board's Panel on the Waste Management System, this one held in Salt Lake City on October 13–14, 2004 (NWTRB 2004f). On the first day, the Board received an update on the DOE's efforts from the senior official in charge of transportation. He noted that work-breakdown structures had been established for the four transportation projects: institutional, operations planning, fleet acquisition; and Nevada rail line development. He paid particular attention to work that had been carried out in the area of fleet acquisition. Meetings had been held with cask vendors, and their reports on current cask capabilities had been received. Based on those reports, the DOE concluded that 40 percent of commercial SNF could be shipped in casks that currently hold Certificates of Compliance from the NRC. Modifications could be made to those certificates so that 90 percent of commercial SNF could be accommodated. Consequently, few completely new cask designs will be needed. The DOE also met with representatives of the rail-car manufacturing industry and obtained their views on how to proceed with rail-car design, manufacture, and testing.

The Board heard a presentation by a scientist from Sandia National Laboratories (SNL) on transportation risk modeling, which focused on the RADTRAN transportation risk model. RADTRAN was first developed for the NRC in the late 1970's and has been modified and improved. According to the scientist, it is the transportation risk model that enjoys the broadest acceptance. A second presentation described plans for assessing transportation security risks.

Two representatives from the NRC also made presentations. The first described the NRC's role in regulating the transportation of radioactive materials. The second detailed the NRC's plans for conducting the Package Performance Study (PPS), which would subject a full-scale cask to "realistically conservative" accident conditions. The objective of the PPS is to evaluate the adequacy of models of cask performance that have been developed over the years. Finally, the Board heard two pairs of presentations—one by the DOE and the other by representatives of corridor states—on route selection and emergency response preparedness.

On the second day of the meeting, the Governor of Utah, The Honorable Olene S. Walker, spoke to the Board about the State's views on the transportation of SNF. A consortium of utilities are seeking a license from the NRC to construct a centralized SNF storage facility, the Private Fuel Storage Facility (PFS), approximately 50 miles from Salt Lake City. Governor Walker told the Board why the State is opposing that license. She discussed the State's concerns that the NRC might not complete its full-scale cask testing before SNF is shipped to PFS. She also expressed concern that measures for ensuring effective response in case of a transportation accident might not be fully implemented before SNF is shipped to PFS. The Chairman of the Board of PFS described the history of the project and the status of the his company's efforts to secure a construction license from the NRC. He explained that his company has been working with the railway industry to develop safety standards that would guide the design of new types of rolling stock to be used in any shipping campaign to PFS.

Finally, a representative from the Western Interstate Energy Board discussed how his organization developed a plan for informing interested members of the public about the issues involved in transporting HLW and SNF. In particular, he indicated that it is important to recognize how perceptions of risk affect the public's thinking about the transportation of radioactive materials.

Furthermore, he noted that strategies for communicating with the public will need to take those perceptions into account.

Board Observations

In a December 1, 2004, letter to the DOE (Garrick 2004b), the Board commended the DOE on its effort in developing a systematic approach to transportation planning. The detailed timelines, which identify key interdependencies among activities, represented a major advance over what the DOE had presented at earlier meetings. Because a successful transportation plan requires intensive interactions, however, the Board encouraged the DOE to expand further its exchanges with the railway industry and the utilities. The Board commented that the DOE needs to think about which specific implementing organizations would have responsibility for what specific aspects of transportation.

The Board noted some areas of the DOE's approach to transportation risk assessment that might be improved. The current version of RADTRAN employs deterministic models and includes several conservative assumptions. The Board was pleased to learn that an upcoming version of RADTRAN will have an enhanced capability to perform uncertainty analyses. This additional capability will make the results more realistic and consistent with the Board's preferred risk-based approach.

The Board observed that the DOE's approach to transportation security risk assessment appears to be organized appropriately. The Board, however, remarked that determining the probabilities of disruptive events is very difficult and urged the DOE to develop and use realistic scenarios for enhancing the technical basis of the overall analysis. The Board held that the risk assessment results, once available, should be merged into an integrated all-hazards risk management approach.

The Board was concerned that in interacting with corridor states and communities on emergency planning preparedness, the DOE is concentrating too much on funding formulas and not enough on ensuring adequate responses. The Board maintained that the DOE should define what constitutes a minimum acceptable level of emergency response as well as a method for verifying that the capability exists.

The Board also urged the DOE to decide whether it will use dedicated trains to move HLW and SNF to Yucca Mountain. Although it was clear from presentations that corridor states do not fully agree on routing criteria, the Board urged the DOE to persist in its effort to involve those parties in its decisions on routing. The Board especially urged the DOE to ensure that the views of tribal groups are adequately represented.

Finally, the Board repeated two observations made several times in the past. First, the DOE needs to pay more attention to the role trucks might ultimately play in the transportation system. In particular, contingency plans need to be developed for higher levels of truck use in case a rail line from Caliente to Yucca Mountain is not built or is delayed beyond the initiation of the shipping campaign. Second, the DOE's integration of the transportation program needs to be improved. The Board has not seen convincing evidence that the DOE has harmonized fully cask design, fleet acquisition, waste acceptance, and operational practice.

DOE Responses

In a February 1, 2005, letter (Chu 2005b), the DOE responded to the Board's findings and recommendations that followed the meeting in Salt Lake City. The DOE explained that the Office of National Transportation (ONT) within the Office of Civilian Radioactive Waste Management will be the primary implementing organization for the transportation system. The DOE added that it is developing a logistical model (subsequently called the Total System Model [TSM]) with the help of SNL. The model will enable the DOE to identify important logistical and operational interdependencies and thus will aid the DOE in making decisions such as the one on dedicated trains.

The DOE reiterated its view that it has a robust and proactive institutional program that is working with a broad range of parties to develop a

transportation system. It noted that it has fully funded the institutional project to support public information and public involvement. It stated that its approach is to work initially with various groups that it believes are "the correct ones to provide unbiased information to their constituents."

The DOE took exception to the Board's statement that the current version of RADTRAN employs deterministic models. Uncertainty analyses have been performed using that version since the late 1990's. Although external users have not been able to access this capability for about a year, this is a temporary situation that will likely be rectified by January 2006. The DOE indicated that it would consider an all-hazards risk-management approach, but it noted that it may not be possible to do so because the likelihood of a terrorist act cannot be ascertained.

The DOE stated that it already had articulated in policy documents that its minimum level of emergency response is that of improving awareness of the special characteristics of shipments that will be made under the Nuclear Waste Policy Act (NWPA) (U.S. Congress 1982). Further, the DOE noted that states and communities already have the capability to respond to accidents involving materials that pose a higher risk of immediate death or injury than does HLW or SNF. It committed to addressing the incremental level of preparedness needed to respond to the risks associated with radioactive materials through the use of additional resources. That course of action is mandated by Section 180(c) of the NWPA. But in the final analysis, the DOE maintained, state, local, and tribal governments are responsible for certifying, evaluating, and maintaining emergency-preparedness plans. Finally, the DOE stated that its *Radioactive Materials Transportation Practices Manual* (DOE 2002), whose development was reviewed by external parties, specifies what actions need to be taken under normal conditions as well as when an accident happens or when a security threat arises.

The DOE described how decision-aiding models are being developed to ensure that routing decisions have a sound technical basis. It noted that ONT is training state and tribal decision-makers to use those models. Moreover, ONT will be organizing workshops at the April meeting of the Transportation External Coordination Working Group on how to use the models. The DOE realizes that it needs to do more to involve Tribal governments in its routing decisions and indicated that it intends to do so.

The DOE maintained that it already is placing sufficient emphasis on the trucking transportation mode and that it has developed contingency plans in case the rail branch from Caliente to Yucca Mountain is delayed. The DOE also stated that it would be pleased to discuss the status of its transportation program's integration activities in greater detail at future Board meetings. The DOE, however, held that its systems are fully integrated and cited several examples to support that position.

2. *Waste Handling and Storage*

Other elements of the waste management system are facilities for handling and storing HLW and SNF at the proposed repository site. At the January 20, 2004, meeting of the Board's Panel on the Engineered System in Las Vegas (NWTRB 2004c), an official involved in the DOE's engineering design efforts presented plans for constructing those facilities. The plans identified several structures that would be used to receive and handle the fuel arriving at Yucca Mountain: a transportation cask-receipt facility, a canister-handling facility, two dry-transfer facilities, and several external buffer zones. These structures and interfacility transportation systems would be built in two phases at a pace that largely would be determined by the program's future funding profile.

Further, the official described the current DOE plans for constructing facilities at which SNF would be temporarily stored. At the start of operations, space to store 1,000 MT of SNF would be built inside the Aging Facility. In addition, current plans call for building a facility to store an additional 20,000 MT of SNF in four 5,000-MT modules. This facility would be separate from the Aging Facility. If needed, however, three additional modules of 5,000 MT and one module of 4,000 MT could be built at other locations that

have been identified. Those locations also would be outside of the Aging Facility.

In addition, the official informed the Board that as part of the DOE's efforts to prepare a license application, a preclosure safety analysis has been carried out to evaluate the occupational and offsite risks of operating the handling and storage facilities that it proposes to build. The risk to the facilities posed by aircraft also is being analyzed. Beyond indicating that the risk is below regulatory limits, the DOE discussed the results of these analyses only in very general terms.

Finally, the official described changes that had been made to the design of the subsurface facilities, including a revised ground-support system for the emplacement tunnels and a return to a rail system for the waste package transporter. The new ground-support system would use 3-millimeter-thick perforated sheets of stainless steel, installed in a 240° arc around the upper two-thirds of the tunnel. The sheets would be set in place using 3-meter-long friction rock bolts, also made of stainless steel.

Board Observations

In an April 5, 2004, letter to the DOE (Latanision 2004), the Board asked the DOE to explain better its technical justification for constructing storage capacity for 40,000 MT of SNF. In particular, the Board observed that a large surface-facility area with a pad for extended surface aging of SNF could affect the analysis of the aircraft-crash hazard. The Board also noted that the use of stainless steel components in the new ground-support system is highly unconventional and expensive. It asked the DOE to detail the technical basis for its choice and to describe planned inspection and maintenance activities for both the first 100 years of repository operation and the subsequent 200 years.

DOE Responses

In a July 21, 2004, letter (Chu 2004b), the DOE responded to the Board's comments on the design of the handling and storage facilities. It gave two reasons for its decision on how much temporary SNF storage should be constructed. First, the facilities would provide sufficient capacity to allow efficient loading of the emplacement drifts with the required combination of DOE waste and commercial SNF to meet thermal management goals. Second, the facilities would allow the DOE to stage SNF and HLW so that the rates of waste receipt and emplacement can be decoupled if necessary. The DOE also indicated that it is still in the process of finalizing its aircraft-hazard analyses.

The DOE also responded to the Board's concerns about the new ground-support system. It detailed the value engineering process that was used. In particular, the DOE laid out five criteria—relevant to both preclosure and postclosure performance—that were incorporated into its evaluations. It also listed alternative ground-support options that it considered. In addition, the DOE described the maintenance regime that would be followed for the first 100 years of repository operation. Tunnels would be monitored, perhaps using remote-control video cameras. If problems arise, remediation might be undertaken, depending on the specific circumstances. At this time, the DOE stated, no monitoring and maintenance program needs to be developed for the subsequent 200-year period. Finally, the DOE observed that although the initial cost of the stainless steel sheets is higher than the cost of standard carbon-steel components, the added cost is outweighed by the cost and potential worker-safety issues that would be associated with moving waste packages after their emplacement to maintain a less robust ground-support system.

The full Board held a meeting on September 20, 2004, in Las Vegas (NWTRB 2004b). At that meeting, the official in charge of the DOE's engineering efforts updated the Board on its design of the surface facilities at the proposed repository site. He provided additional information about the preclosure-safety analyses that are being conducted. In particular, the DOE official identified event sequences that appear to be the major contributors to risk: a drop of an individual commercial SNF assembly, a collision of an individual commercial SNF assembly with the Fuel Handling Facility or the Dry Transfer Facility, and a dropping and breach of a transportation cask containing commercial SNF, HLW, or spent

naval reactor fuel. In the course of the presentation, the possibility was raised that SNF might be handled as many as four times from the time it arrives at the proposed repository site to its emplacement underground.

Board Observations

In a November 30, 2004, letter to the DOE (Garrick 2004a), the Board recommended that the DOE should analyze ways to minimize the number of times fuel assemblies are handled. It encouraged the DOE to evaluate how the aging of SNF on the surface would contribute to the development of a clearly articulated thermal management strategy.

DOE Responses

In a March 31, 2005, letter (Garrish 2005), the DOE stated that it agreed with the Board's assessment of the importance of systematic integration of waste management activities for optimizing the system as a whole. It described two approaches it is taking for ensuring that integration. The first is an "upper-tier" approach, known as the TSM. The TSM tracks waste shipments from the waste generating and storage sites through emplacement. The TSM also provides logistical information about waste stream movements and the system resources required for accomplishing those movements. The second, or "lower-tier," approach is a suite of detailed models and studies focused on the throughput capability of each of the individual waste handling facilities.

B. Isolation and Containment of Radioactive Waste in the Proposed Repository

Before the DOE can dispose of HLW and SNF in a repository, it must demonstrate the "reasonable expectation" that the waste will be isolated and contained so that expected doses that affected populations are exposed to are below regulatory limits. Over the years, the Board has devoted much of its attention to evaluating the scientific and technical validity of the DOE's projections of repository performance. In 2004, the Board continued to probe that issue, recognizing the possibility that a new standard might be adopted that sets the compliance period at the time of peak dose.

1. Engineered System

At the January 20, 2004, meeting of the Board's Panel on the Engineered System in Las Vegas (NWTRB 2004c), an official involved in developing the DOE's engineering plans described recent changes made to the design of the subsurface facilities. One of the revisions involves increasing the radius of the turnouts of the emplacement tunnels. The change was prompted, in part, by a desire to reduce dose rates in the main access tunnels.

Board Observations

In a April 5, 2004, letter to the DOE (Latanision 2004), the Board noted that the increase in turnout radius would affect postclosure waste-package temperatures, particularly the temperatures of packages close to the turnouts. Moreover, the change was likely to exacerbate "cold trap" effects. Consequently, the Board recommended that the DOE revise its calculations of temperature and relative humidity to reflect the design changes.

DOE Responses

In a July 21, 2004, letter (Chu 2004b), the DOE addressed the Board's observations and recommendation. The DOE stated that, within the emplacement tunnels, relative humidity would fall and that temperatures also would decline, albeit by a rather small amount. The DOE indicated that those changes have been evaluated and that a report documenting them would be completed in the near future.

In a series of letters and in a major report issued in the fall of 2003 (Corradini 2003b, 2003c; NWRTB 2003b), the Board addressed the issue of whether deliquescence-induced localized corrosion of the waste packages would take place if the DOE implemented its current high-temperature repository design. Basing its findings and recommendations on information provided by the DOE, the Board concluded the following:

- Project data show that initiation of crevice corrosion in the waste package material, Alloy 22, during the thermal pulse would be likely in calcium or magnesium chloride brines (with or without the presence of potential nitrate inhibitors) formed by deliquescence at temperatures well below the peak temperature on the waste package surface expected in the DOE's proposed repository design.

- Crevice corrosion initiated during the thermal pulse would be likely to propagate during the remainder of the thermal pulse and propagation also would be likely to continue even after the thermal pulse has passed.

- Localized crevice-corrosion processes are particularly insidious because initiation is difficult to predict and propagation rates can be very rapid.

- The DOE has not demonstrated that conditions are present to ensure that the proposed vaporization and capillary barriers to water seepage into the tunnels would be pervasive.

The seriousness of these corrosion concerns led the Board to urge the DOE to reexamine its current high-temperature repository design because "high temperatures…will result in perforation of the waste packages with possible release of radionuclides." The Board also stated its belief that total system performance assessment should not be used to dismiss these corrosion concerns.

Because of the far-ranging nature of the Board's letters and report, the Board invited the DOE, the NRC, the electric utility industry, and the State of Nevada to a two-day meeting to explore these corrosion issues in depth. That meeting was held on May 18–19, 2004, in Washington, D.C. (NWTRB 2004a).

At the meeting, the discussion of deliquescence-induced corrosion began with the Board presenting its views on the evolution of the environments on the waste-package surface and on its interpretation of the corrosion data gathered both by the DOE and by the NRC's Center for Nuclear Waste Regulatory Analyses (CNWRA). Two representatives of the CNRWA and two representatives from the NRC then made presentations on the near-field chemical environment, factors influencing uniform and localized corrosion, and the effect of corrosion on overall repository performance. In the first talk, the CNWRA presenter concluded brines forming at high temperatures due to deliquescence may have concentrations of oxyanions (NO_3^- and SO_4^{2-}) high enough to mitigate or inhibit localized corrosion of the waste package. In the next talk, a second CNWRA scientist presented data indicating that the minimum nitrate to chloride molar concentration ratio necessary to inhibit localized corrosion is in the range of 0.1 to 0.2 and is slightly dependent on chloride concentration, temperature, and metallurgical condition. In the third presentation, the NRC representatives observed that although a high-temperature deliquescence environment could occur, waste packages could be passivated by inhibitors. Moreover, the release of radionuclides could be limited because of the limited amount of calcium and magnesium chloride and because of the limited exposed surface area.

Individuals working for the Electric Power Research Institute (EPRI) also spoke to the Board. They presented a decision tree that listed six questions. In EPRI's view, each of the six questions would have to be answered affirmatively before it would be possible to reach the conclusion that the Board's deliquescence-induced corrosion scenario was of concern.

The thrust of the EPRI presentation was that none of the six questions could be answered affirmatively. First, it was highly unlikely that pure divalent-cation chloride deliquescent brines will form. Dust from the tunnel walls as well as dust blown in from the outside contains only a small fraction of soluble chlorides. Calcium chloride would form a mixed-anion brine, while the magnesium chloride would react with silicates to remove the magnesium from the brines as a solid precipitate. Second, even if calcium and magnesium brines were to form, they would not be stable or persistent. Third, even if the brines were stable or persistent, the chemical conditions needed to initiate localized corrosion would not exist because minerals in the dust would neutralize the acidity in the brines and corrosion-

inhibiting oxyanions in the brines would greatly exceed the concentration of chlorides.

Fourth, even if corrosive brine were to form and persist, localized corrosion would not initiate. Fifth, not only would the inhibitors in deliquescent solutions overwhelm the aggressive chloride ions, but the dust and salt deposits also would not support initiation because of inadequate separation between anodic and cathodic reaction sites and lack of localized acidification. Sixth, even if the packages were locally penetrated, the releases would not exceed regulatory compliance criteria.

The DOE also prepared a multiprong response to the Board's letters and report. Its presentation began with a discussion of the thermal hydrologic environment and thermal seepage. One scientist addressed the Board's conclusion that the vaporization and capillary barriers would not be pervasive throughout the tunnels. He examined reasons behind the Board's claim but maintained that they are not persuasive. He stated that the underlying conceptual models had been validated against test data. Thus, he concluded that all lines of evidence support the view that no seepage into the tunnels would take place when the tunnel wall temperature exceeds 96°C.

The key conclusion of a second presentation by another DOE scientist was that two conditions must be present for calcium chloride to form brine from salts in tunnel dusts and that none of the salts in tunnel dusts satisfy both conditions. Similarly, the presentation's conclusion was that three conditions must hold for magnesium chloride to form brine from salts in tunnel dust but that these conditions would not be found at Yucca Mountain. The scientist further maintained that the presence of either calcium-chloride or magnesium-chloride salts in dust that might blow in from the outside is very unlikely. Those minerals exist on the earth's surface at very few places and, even then, their occurrence appears to be ephemeral. Finally, the DOE presenter also stated that, even if for some unexpected reason, calcium-chloride and magnesium-chloride salts should be present, they would transform rapidly into nondeliquescent phases because of their instability at high temperatures.

A presentation by a DOE corrosion consultant touched on the question of corrosion resistance of the waste package. Responding directly to the Board's concerns about deliquescence-induced localized corrosion, he held that such a phenomenon will not arise if the nitrate-to-chloride ratio is greater than 0.5. Moreover, he noted that the inhibiting effect of nitrate persists up to 160°C. He suggested, however, that there is a potential for corrosion of Alloy 22 during the relatively short period beginning 700 years after repository closure and extending roughly another 700 years. During that period, average temperature on the drift walls would be between 96°C and 105°C, and dripping and seepage into the tunnels might be possible. If the nitrate-to-chloride ratio dropped far enough, sodium chloride could initiate localized corrosion. However, even then, it would be necessary to evaluate the initiation, propagation, stifling, and arrest of the corrosion process before reaching any conclusions about how significant the consequences might be. Nonetheless, the DOE strongly believes that corrosion of the waste packages due to calcium chloride would not be widespread nor would it necessarily result in large releases of radionuclides to the environment.

Board Observations

In a July 28, 2004, letter to the DOE (Duquette 2004), the Board noted that its previous letters and report on deliquescence-induced localized corrosion had been based particularly on the Project's corrosion tests carried out in aqueous environments rich in calcium chloride, environments which the Project subsequently found are not representative of those found within the proposed repository. Those test results indicated that corrosion would take place when the temperature ranges from 140°C to 160°C. At those temperatures, the mitigating effects of nitrate might not be sufficient to inhibit the corrosion process fully.

In this letter, the Board concluded, based primarily on information presented at its May 2004 meeting, that dusts accumulating on waste-package surfaces would not be likely to contain significant amounts of calcium chloride and that significant amounts of calcium chloride would not be likely to evolve during the thermal pulse.

Thus, localized corrosion induced by deliquescence of calcium chloride would be unlikely.

The Board noted, however, that the May meeting did raise some new questions about the corrosion-resistance of Alloy 22. The Board urged the DOE to investigate further the possibility that sodium chloride could cause corrosion in environments where the nitrate-to-chloride ratio is low. In addition, the recent discovery of ammonium ions and their implication for corrosion needed to be explained. Finally, data presented by the State of Nevada suggested that nitrates could aggressively cause corrosion in some circumstances. The DOE might find it worthwhile to review existing corrosion data to determine whether its analyses have properly bounded the nitrate-containing environments that reasonably might be expected at Yucca Mountain. In general, the Board advised the DOE that it needed to ensure that its corrosion tests are carried out in environments that closely approximate the conditions to which the waste package will be exposed and in environments that reasonably bound those conditions. It was unclear to the Board how well the DOE had characterized those environments.

The Board also observed in its July 28, 2004, letter, that at the May meeting the DOE also presented a detailed explanation of why it had high confidence in its view that there would be no seepage during the period when repository rocks are above boiling and only limited seepage at lower temperatures. After reviewing the DOE's explanation, the Board continued to question the pervasiveness of both the vaporization and the capillary barriers. The Board based its position on a number of uncertainties that have persisted related to the expected repository tunnel environments. The Board suggested that the DOE should address those uncertainties to establish a more solid technical basis for predicting the performance of the vaporization and capillary barriers.

DOE Responses

In a January 26, 2005, letter (Chu 2005a), the DOE responded to the Board's comments. The DOE noted the Board's agreement with the claim that calcium-chloride-type deliquescent brines are unlikely to exist at Yucca Mountain. The DOE also stated that understanding better the corrosion behavior of Alloy 22 at high temperature in the presence of other chloride brines and varying amounts of inhibitors is important. The DOE remarked that sodium chloride-sodium nitrate-potassium nitrate deliquescent brines can boil at maximum temperatures of approximately 200°C. Although the DOE has not found significant corrosion under those conditions, it is continuing to analyze the situation.

The DOE explained the steps it is taking to ensure that its corrosion tests are carried out in appropriate environments. It detailed what it believes are the expected waste-package environments for the first 10,000 years after the repository is closed. Finally it described work that is under way to evaluate corrosion. Those investigations vary the amount and composition of dust on waste package surfaces as well as the volume of brine and quantities of dissolved salts. The studies also are designed to assess the deliquescence-related properties of ammonium salts and the effects of any chloride-containing silicate minerals or minerals containing hydroxide, which can replace chloride. The DOE indicated that it is working to document the technical basis for excluding localized corrosion of the waste package because of the deliquescence of dust constituents.

The DOE addressed the concerns raised by the Board about the possibility of concentrated sodium brines causing corrosion when temperatures fall between 96°C and 105°C. The DOE maintained that, if the drip shields are intact, brines can form only by deliquescence. In that case, however, the nitrate-to-chloride ratio would be high enough that corrosion would be inhibited. If the drip shield were to fail, brines also could form as a result of seepage. Although the nitrate-to-chloride ratio would be lower than in the deliquescent case, no localized corrosion has been observed at low temperatures when the ratios ranged from 0.05 to 0.5. The DOE also explained its preliminary thinking about why ammonium ions are present and what the effects of their presence might be.

Finally, the DOE reiterated its view that the capillary barrier would be pervasive. It suggested that a wide range of tests and models support that view. The DOE noted, however, that direct

empirical evidence of the pervasiveness of the vaporization barrier did not exist. The DOE indicated that if such data were needed to sustain the DOE's repository safety case, it might be gathered in the future to improve confidence in vaporization barrier's effectiveness.

(The DOE repeated many of its earlier comments dealing with its material testing program in a March 31, 2005, letter [Garrish 2005]. That letter was written in response to a November 30, 2004, Board letter [Garrick 2004a], which commented on DOE presentations made at the Board's September 20, 2004 meeting.)

2. *Natural System*

At a meeting on March 9–10, 2004, of the Panel on the Natural System in Las Vegas (NWTRB 2004e), the Board heard a series of talks on fluid flow and radionuclide transport in the unsaturated and saturated zones. On the first day, a scientist from the Desert Research Institute (DRI) discussed how alluvial fans might provide insights into climate changes that occurred thousands of years ago. A second investigator from DRI explained how the climate record found at Devil's Hole could be used to characterize four climate states that are likely to arise over the next 400,000 years. A researcher from the U.S. Geological Survey (USGS) described methods that have been used to infer the long-term behavior of the unsaturated zone hydrogeologic system. Another USGS scientist provided an account of the evolution of the conceptual model for the unsaturated zone at Yucca Mountain. A former member of CNWRA's technical staff maintained that, based on the studies of the northern Mexican Peña Blanca natural analogue site, secondary minerals formed from the thermodynamically unstable SNF are likely play a significant role in controlling release of radionuclides to the environment. A scientist from Los Alamos National Laboratory (LANL) detailed the DOE's plans for investigating the Peña Blanca site further.

An investigator from Lawrence Berkeley National Laboratory (LBNL) explained how the DOE has developed and empirically tested its model of unsaturated-zone flow and transport. A second LBNL researcher explained model results for unsaturated-zone radionuclide transport both in solution and facilitated by colloids. Another LANL scientist described how the unsaturated-zone flow-and-transport model is being abstracted for use in the performance assessment that the DOE is preparing to support its license application. Finally, a senior DOE official presented information about the expected travel time of a water molecule in the unsaturated zone, even though he maintained that the calculation is not a meaningful parameter in the DOE's risk assessment calculations nor is it required to assess the performance of the proposed repository.

On the second day, the Board heard from seven more scientists about issues dealing with the saturated zone. A third USGS researcher discussed progress made on developing the Death Valley regional flow model as well as planned future efforts. A consultant to Inyo County in California, where Death Valley is located, explained some of the conceptual and methodological challenges confronting any hydrogeologic modeler and that those challenges significantly reduce his confidence in performance assessment projections. An investigator described the saturated-zone model that CNWRA was creating to aid the NRC's evaluation of a possible DOE license application. A third LANL scientist presented the DOE's conceptual model of flow and transport in the saturated zone. A fourth USGS researcher detailed how the DOE is independently validating flow paths and independently constraining flow rates in its conceptual model. A member of the SNL technical staff discussed three key processes in the saturated zone: matrix diffusion, sorption, and colloid-facilitated transport. Finally, another SNL scientist explained how the saturated-zone model is being abstracted for use in the performance assessment the DOE is preparing to support its license application.

Board Observations

In a May 3, 2004, letter to the DOE (Parizek 2004), the Board made several observations and advanced several recommendations. To begin with, the Board held that evidence is available suggesting that the natural system could provide an effective barrier to the migration of radionu-

clides. However, key hydrogeologic features and processes are not presently well understood. A better and more realistic understanding of those features and processes would allow the DOE to take full credit for whatever performance the natural system provides.

The Board then identified three high-priority areas that it believes ought to be the focus of additional studies. First, the hydraulic properties of major block-bounding faults need to be investigated in the field because those faults could substantially influence flow and transport. Second, characterization of the spatial distribution and composition of the saturated alluvium could increase understanding of groundwater flow and other factors important to radionuclide transport along Fortymile Wash south of Yucca Mountain. Third, a better empirical basis for predicting matrix diffusion would increase confidence in the DOE's estimates of radionuclide transport times. In addition, the Board identified three other areas—colloid-facilitated transport, active fracture modeling, and boundary fluxes on the Yucca Mountain site-scale saturated-zone model—that have substantial unresolved uncertainties that need to be addressed.

The Board also reiterated its view that multiple lines of evidence and argument can be used to supplement and evaluate the conceptual understanding of the natural systems at the site, the models used to represent those concepts, and the scenarios predicted by those models. The Board pointed particularly to the studies being carried out at Peña Blanca as an example of productive mustering of multiple lines of evidence. The Board cited as well the possibility of collecting isotopic data from discrete zones in the flow path from Yucca Mountain to constrain saturated-zone model projections.

DOE Responses

In a September 10, 2004, letter (Chu 2004c), the DOE responded to the Board's observations and recommendations. It agreed that some aspects of fluid flow and radionuclide transport are uncertain. It stated that those uncertainties had already been incorporated into the performance assessment being prepared, although some conservative approximations have been used. In its view, this approach is acceptable in a licensing analysis. The DOE held that the present level of understanding of key hydrogeologic processes is adequate to support a license application. The DOE note, however, that, as part of its long-term Science and Technology Program, it plans further investigation of key conservatisms in the natural system. Those investigations could enhance understanding of repository performance.

The DOE did not accept the Board's recommendation to conduct large-scale hydraulic tests of the major faults before submitting a license application, although it stated that such tests would be included in its performance confirmation plans. Instead, the DOE explained how it was using modeling studies and other investigatory tools to gather information about key variables and parameters associated with those faults. In its view, those approaches have generated a level of understanding that is adequate for incorporating into the performance assessment the relevant effects of faults on groundwater flow and rates of radionuclide transport as well as the uncertainties associated with those effects.

With respect to the Board's recommendation dealing with the saturated-zone alluvium, the DOE reminded the Board that work at the Alluvial Testing Complex was halted because of a dispute with the State of Nevada over water withdrawal at the Yucca Mountain site. Although some tests had been conducted before the dispute arose, the DOE indicated that work on the alluvium would be undertaken in the future only as part of its Performance Confirmation Program. The DOE noted, however, that Nye County has plans to investigate the geometry of the alluvium-tuff interface as part of its Early Warning Drilling Program.

The DOE recounted the investigations already carried out to predict matrix diffusion, including liquid release and tracer tests between Alcove 8 and Niche 3. In the DOE's view, the results obtained from those studies support conceptual models of unsaturated zone flow and transport and confirm that numerical approaches used in the models adequately represent physical processes controlling unsaturated-zone flow. Similarly, work carried out in laboratories and at

the C-well complex provides a basis for quantifying the effect of matrix diffusion on radionuclide migration through the fractured tuff of the saturated zone. The DOE informed the Board that three additional projects on the subject of matrix diffusion are under way.

The DOE indicated that it already had conducted a number of studies on colloid-facilitated transport. Those results lead it to believe that most colloids will be filtered by the volcanic rock and the alluvium and that only a small percentage will remain mobile during migration in the saturated zone. The DOE acknowledged that there are uncertainties associated with colloid-retardation factors but maintained that the uncertainties have been accounted for.

The DOE recognized that field data are relatively sparse and only indirectly support the active fracture model, which is important for calculations of unsaturated-zone flow and transport. Nonetheless, the DOE described the approach it has taken in its performance assessments to overcome that lack of data. In its view, that approach yielded a robust representation of the relevant phenomena. The DOE indicated that experiments would be conducted over the next 18 months to validate the active-fracture model.

The DOE stated that it is revising one of its core technical documents to update the hydrologic framework model and boundary fluxes. The analysis also will include additional evaluation of alternative conceptual models. Moreover, other work initiated recently seeks to optimize the interface between site and regional groundwater models and will incorporate up-to-date versions of each.

Finally, the DOE agreed with the Board that multiple lines of evidence could be used to supplement and evaluate conceptual understanding of the natural system at Yucca Mountain. The DOE noted that work at Peña Blanca could provide important information. It further stated that isotopic data have been used to estimate advective transport times of unretarded species in the tuff and alluvial aquifers and to establish bounds on the magnitude and timing of the recharge in the saturated zone at the regional scale.

3. Seismic Issues

Yucca Mountain is located in an area that has experienced earthquakes in the past. Over the years, the Board has followed closely the technical work undertaken by the DOE to address seismic issues. In February 2003, two Board panels met jointly to consider, among other things, the technical basis for using particular ground-motion parameters in preclosure and postclosure seismic design and analysis (NWRTB 2003a). In a June 27, 2003, letter to the DOE (Corradini 2003a), the Board reached the following conclusion: In estimating very-low-probability ground motions, the DOE had derived earthquake ground motions that lack physical realism and are outside the limits of existing worldwide seismic records and experience, particularly when the Yucca Mountain source and site conditions are taken into account. The Board urged the DOE to develop a strategy for bounding its overly conservative estimates. In an October 8, 2003, letter (Chu 2003), the DOE committed to addressing this problem. During 2004, the Board heard two presentations about the DOE's progress in this area.

At the Board meeting held on May 18–19, 2004, in Washington, D.C. (NWTRB 2004a), a Bureau of Reclamation scientist working on Yucca Mountain seismic issues indicated that the DOE had decided to evaluate bounding ground motions using site-specific physical arguments. He went on to describe a variety of approaches that the DOE is either taking or would take in the future. In a July 28, 2004, letter to the DOE (Duquette 2004), the Board expressed its approval of the types of investigations and analyses that the DOE had proposed and suggested that the DOE commission a peer review of the results.

At the Board meeting held on September 20, 2004, in Las Vegas (NWTRB 2004b), the same Bureau of Reclamation scientist told the Board about observations of rocks at Yucca Mountain that, although more than 10,000,000 years old, have not been deformed by extreme earthquake ground motion (shaking). He also described testing and modeling studies to assess the level of ground motion that would have been needed to cause deformation, had it been observed. These results are being applied to limit ground-motion estimates in the performance assessment that the DOE is prepar-

ing to submit as part of its license application. In a November 30, 2004, letter to the DOE (Garrick 2004a), the Board encouraged the DOE to continue its efforts to develop realistic estimates of ground motions. Further, recognizing that some work in this area is likely to be carried out under the auspices of the long-term Science and Technology Program, the Board reminded the DOE about how important it will be to integrate the various research strands. Finally, the Board repeated its suggestion that all this work be subject to independent external peer review.

C. The Board's Assessment of Progress in 2004

On the basis of information presented by the DOE at meetings in 2004, the Board believes that progress has been made in several areas on which the Board commented in its letters to the DOE. For example, a key corrosion issue raised by the Board in 2003 was addressed by DOE data and analyses, indicating that tunnel conditions during the thermal pulse will likely not lead to the initiation of localized corrosion of the waste packages due to deliquescence of calcium chloride. The Board is encouraged by the DOE's efforts in making its earthquake ground-motion estimates more realistic and in completing an aeromagnetic survey that could shed light on igneous activity in the Yucca Mountain area. The DOE also appears to have made headway in developing a systematic approach to planning the transportation of SNF and HLW.

Among the issues on which the Board has commented that it believes require continued or additional attention are (1) the integration, design, and operation of elements of the waste management system; (2) a better understanding of the waste-isolation characteristics and behavior of the natural components of the repository; (3) an improved understanding and a clear explanation of the likely conditions inside repository tunnels after repository closure; (4) unresolved corrosion issues related to deliquescent brines; (5) resolution of discrepancies among chlorine-36 studies; (6) improvements in the modeling of volcanic consequences, taking into account compressible flow, waste mobilization, and interaction of magma with the waste package; and (7) work undertaken by the long-term Science and Technology Program.

D. The Board's Assessment of DOE Responses

Above, the Board identified areas where progress had been made on two issues it first raised in 2003: the resolution of a specific corrosion concern and the development of more realistic information on the seismic threat to the repository. The DOE's investigations into the first issue resulted in new insights and prompted new areas of inquiry that significantly strengthened the technical basis for its position on whether calcium chloride deliquescent brines would cause widespread corrosion of the Alloy 22 waste package. These same investigations, however, subsequently revealed that a mixture of sodium and potassium nitrates and chlorides, which is highly deliquescent, might pose potential corrosion problems at high temperatures. The Board looks forward to reviewing this line of study in greater detail in the coming months.

The DOE responded positively to the Board's recommendations dealing with ground-motion estimates. Some studies have been completed, and others are being prepared. The DOE publicly discussed its new work and engaged in a constructive dialogue on it with the Board. Significant steps have been taken, and the Board is encouraged by the DOE's actions to date in the seismic area.

The Board questions the DOE's response to the Board's recommendations in 2004 in two other areas. The Board believes that the DOE has not presented a strong technical argument about why further investigations into elements of the natural system are not warranted, especially in light of the Court of Appeals decision, which raises the possibility that the compliance period in a new EPA standard might extend to the time of peak dose.

The DOE's response so far to the Board's recommendations for developing a transportation system also has not addressed Board concerns adequately. This is particularly true with respect to considering transportation planning in the context

of an integrated waste management system and interacting with key stakeholders, such as nuclear utilities and railroads, whose input is essential to developing effective technical approaches.

III. Other Board Activities

A. Field Trip to Yucca Mountain

Board members and staff were among the 24 participants in a Yucca Mountain hydrogeology field excursion on March 11, 2004. The purpose of the 13-hour trip was to examine the characteristics of the rock and sedimentary units that comprise the unsaturated and saturated zones of Yucca Mountain and vicinity, with particular attention to the rock characteristics that control fluid flow and radionuclide transport from the proposed nuclear waste repository at Yucca Mountain to the accessible environment.

Each stop addressed one or more aspects of the site hydrogeology relevant to fluid flow and radionuclide transport. At the Sample Management Facility, trip participants observed the intact sedimentary core of alluvial materials recovered by a novel sonic drilling method from Fortymile Wash. In Fortymile Wash, itself, the group stopped to observe the character and architecture of sedimentary deposits at the land surface, which helped the Board to gain a greater understanding of the nature of saturated-zone flow and radionuclide transport at depth in the alluvial deposits. At the Nye County Early Warning Program drill pad 10, trip participants discussed differing geologic interpretations of rock samples from drilling and the implications for radionuclide transport of the uncertainty associated with the location where saturated flow transitions from volcanic rocks into alluvial rocks. At a stop on top of Yucca Mountain, Board members engaged DOE scientists in discussions of volcanic hazards posed to the proposed repository. Another stop gave the group an opportunity to examine the exposed sequence of volcanic rock strata comprising the unsaturated zone at Yucca Mountain and to discuss factors controlling the occurrence and size of lithophysal cavities in volcanic rocks at Yucca Mountain. At a stop in Raven Canyon, trip participants observed surface outcrops of volcanic rocks that lie buried at depth in the saturated-zone flow field and discussed the phenomenon of matrix diffusion of radionuclides from rock fractures into rock matrix.

Writing to the DOE after the panel meeting and field excursion, the Board remarked as follows (Parizek 2004).

> Observations during our field trip to Yucca Mountain demonstrated two things in particular: (1) better understanding of the behavior of the natural barriers at Yucca Mountain is challenging because of the complexity of the geologic system, and (2) based on recent progress in characterizing the natural system, enhanced understanding of the natural system is attainable.

B. International Activities

In 2004, the Board continued its past practice of interacting with and visiting nuclear waste management programs abroad. The Board maintains international contacts because they often provide insights that are pertinent to the Board's scientific and technical oversight responsibilities. In addition, learning about efforts being carried out in other countries may suggest approaches and perspectives that might be incorporated by the Yucca Mountain Project.

In April 2004, the Board hosted a visit from a representative from Nirex (the British radioactive waste management company) and the then newly formed Citizens Committee on Radioactive Waste Management. The discussion focused on how technical and non-technical issues have affected the course of waste management programs in both the United States and the United Kingdom. Updates were exchanged on the status of the radioactive waste management programs in the two countries.

In May 2004, the Board hosted a meeting and lunch with members of the French Parliament and their staff and a representative from the Nuclear Counselor's Office of the French Embassy. The purpose of their trip was to collect information

and form impressions on how to construct a new law on HLW management and disposal that they planned to begin drafting at the end of 2004.

In addition, the Board undertook two international trips in 2004. On June 7–11, 2004, a small delegation of the Board met with representatives of the Swedish and Finnish nuclear waste disposal programs and visited most of their facilities. The visit included meetings with elected representatives from two municipalities; a tour and discussion with the crew of the M/S Sigyn, the ship for transporting spent fuel; tours of their repositories for intermediate and low-level waste; visits to possible or proposed sites for deep geologic disposal and surface and underground research facilities; a tour of Sweden's canister research laboratory and central long-term storage facility for SNF; discussions with the leadership and scientists/engineers involved in managing and researching disposal methodologies; and talks with Sweden's regulatory authorities.

On November 15–18, 2004, a delegation of the Board made its first visit to Spain to gain information about the country's efforts to manage its radioactive waste. The delegation met with officials from the National Waste Management Company, the Ministry of Industry, Tourism and Commerce, and the Nuclear Safety Council. The Board toured dry-storage facilities for spent fuel at the Trillo nuclear power plant and storage facilities for low- and intermediate-level waste at El Cabril.

In 2004, the Board also participated in two events that formalized its interactions with comparable peer-review groups abroad. In January, 2004, the Nuclear Energy Agency of the Organization for Economic Cooperation and Development hosted a meeting of chairmen of independent nuclear waste technical review bodies. A representative of the Board attended, along with chairmen from the following organizations.

- France: Commission Nationale d'Evaluation
- Germany: RSK-VE
- Japan: Atomic Energy Commission High-Level Radioactive Waste Disposal Expert Subcommittee
- Sweden: National Council on Nuclear Waste
- Switzerland: Arbeitsgruppe des Bundes für die Nukleare Entsorgung

The intent of the group is to meet regularly to discuss shared issues that have emerged in their respective countries concerning the management and disposal of SNF and HLW. The meetings will provide the organizations with a venue for discussing contentious topics and acquire contacts and information to help their organizations carry out their missions better. A second meeting, which the Chairman of the Board attended, was held in October, 2004.

IV. The Board in Transition

During 2004, the Board underwent a major transition as long-serving members either resigned or reached the end of their appointed terms. On January 15, 2004, Dr. Paul Craig informed President George W. Bush that he intended to resign effective January 19, 2004. President William J. Clinton appointed Dr. Craig to the Board on January 30, 1997. On May 21, 2004, Dr. Daniel Bullen informed the President that he intended to resign effective May 24, 2004. President Clinton appointed Dr. Bullen to the Board on January 17, 1997.

On September 10, 2004, President Bush appointed seven new members to the Board. He named as Chairman, Dr. B. John Garrick, an executive consultant on the application of the risk sciences to complex technological systems. In addition, on the same day, the President appointed as members of the Board Dr. William Howard Arnold, an independent consultant with expertise in nuclear project management; Dr. Daryle H. Busch, professor of chemistry at the University of Kansas; Dr. George M. Hornberger, professor of environmental sciences at the University of Virginia; Dr. Andrew C. Kadak, a professor in the Nuclear Engineering Department of the Massachusetts Institute of Technology; Dr. Ali Mosleh, a professor in the Reliability Engineering Program at the University of Maryland; and Dr. Henry Petroski, professor

of civil engineering and history at Duke University. As part of their orientation process, some of the new Board members visited the Yucca Mountain site in September, 2004.

Rotating off the Board in September 2004 as their terms expired were three members: Dr. Norman L. Christensen, Dr. Priscilla P. Nelson, and Dr. Richard R. Parizek. All those members had been appointed by President Clinton in early 1997.

Each of the five members leaving the Board in 2004 brought considerable expertise and extensive experience to the Board's task of evaluating the technical and scientific validity of the DOE's waste-disposal activities. During the time they served, each made important and valuable contributions to the Board's technical review.

V. Evaluation of the Board's Performance During 2004

The Board believes that measuring its effectiveness by directly correlating Board recommendations with improvements in the technical and scientific validity of the DOE's activities would be ideal. However, the Board cannot compel the DOE to comply with its recommendations. Consequently, a judgment about whether a specific Board recommendation had a positive outcome may be (1) subjective or (2) an imprecise indicator of Board performance because implementation of Board recommendations is outside the Board's direct control. Therefore, to assess how well it met its performance goals in a given year, the Board has developed the following measures.

- Did the Board undertake the reviews, evaluations, and other activities needed to achieve the goal?

- Were the results of the Board's reviews, evaluations, and other activities communicated in a timely, understandable, and appropriate way to Congress and the Secretary of Energy?

If both measures are met in relation to a specific goal, the Board's performance in meeting that goal is judged effective. If only one measure is met, the performance of the Board in achieving that goal is judged minimally effective. Failing to meet both performance measures without sufficient and compelling explanation will result in a judgment that the Board has been ineffective in achieving that performance goal.

The Board will use the evaluation of its performance from the current year together with its assessment of current or potential key issues of concern related to the DOE program to develop its annual performance objectives and performance-based budget request for subsequent years.

On the basis of the evaluation described above and consistent with the performance measures described in the Board's *Performance Plan for FY 2004*, the Board's performance for FY 2004 was found to be effective overall. However, the Board was not able to review the DOE's performance assessment results in 2004. Consequently, performance goals related to reviewing that important aspect of the DOE program were partially met or deferred. Several other performance goals were not possible to meet fully because the DOE did not undertake activities in those areas in 2004. When that is the case, it is noted in the performance evaluation of the specific goal. A detailed evaluation of the Board's performance for FY 2004 is in Appendix H.

The Board's *Performance Plan for FY 2005* is in Appendix I. In past years, the Board's performance plan for the next fiscal year had been included in the summary report. The Board's *Performance Plan for FY 2006* is, however, currently in review. When the review is completed, the revised plan will be posted on the Board's Web site: www.nwtrb.gov. The Board's *Strategic Plan for 2004–2009* is included in Appendix G. In the coming months, the Board's strategic plan

Abbreviations and Acronyms

Board	U.S. Nuclear Waste Technical Review Board
CNWRA	Center for Nuclear Waste Regulatory Analyses
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
HLW	high-level radioactive waste
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LSN	Licensing Support Network
MT	metric tonnes
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act of 1982
NWPAA	Nuclear Waste Policy Act Amendments of 1987
NWTRB	U.S. Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
ONT	Office of National Transportation
SNF	spent nuclear fuel
TSM	Total System Model
TSPA	Total System Performance Assessment
USGS	U.S. Geological Survey
WIPP	Waste Isolation Protection Plant

Glossary

The following list was compiled to help readers understand some of the terms used in this report.

aging facility Commercial spent nuclear fuel (SNF) arriving at the repository that cannot be loaded into waste packages is placed in site-specific casks and moved to the Aging Facility. Aging is needed to allow thermally hot commercial SNF to cool to meet the thermal limits for emplacement. Aging is also needed to temporarily hold commercial SNF that cannot proceed through normal repository processes and emplacement operations because the necessary facilities are unavailable.

Alloy 22 A nickel-chromium-molybdenum alloy proposed for use as the material of construction for the waste package's outer wall.

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

anodic reaction site A site where oxidation reactions (reactions involving the loss of electrons) take place.

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

brine A concentrated solution of one or more salts in water.

calcium chloride A highly deliquescent salt with the chemical formula $CaCl_2$.

capillary barrier Term used by the DOE to denote a contact in the unsaturated zone between a geologic unit containing relatively small diameter openings and a unit containing relatively large diameter openings.

cathodic reaction site A site where reduction reactions (reactions involving the gain of electrons) take place.

Certificate of Compliance A certification, by the U.S. Nuclear Regulatory Commission, that a package used for shipping radioactive materials meets the applicable requirements of the Commission.

colloid A suspension of very fine-grained material.

corrosion A destructive attack of a material by chemical or electrochemical interaction with its environment.

crevice corrosion Localized corrosion of a metal surface at or near an area that is shielded from full exposure to the bulk environment because of proximity between the metal and the surface of another material.

deliquesence The absorption of atmospheric water vapor by a solid salt to the point where the salt dissolves into a saturated solution.

dose see **radiation dose**

Environmental Impact Statement (EIS) A detailed written statement to support a decision to proceed with major Federal actions affecting the quality of the human environment. Required by the National Environmental Policy Act (NEPA), the environmental impact statement describes: the environmental impact of the

proposed action; any adverse environmental effects which cannot be avoided should the proposal be implemented; alternatives to the proposed action *(although the Nuclear Waste Policy Act, as amended, precludes consideration of certain alternatives);* the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity; and any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented. Preparation of an environmental impact statement requires a public process that includes public meetings, reviews, and comments, as well as agency responses to the public comments.

fluid flow The movement of water from one location to another.

Gantt chart A tool for planning and analyzing projects consisting of timelines that display the timing, duration, and sequencing of the project.

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

ground motion Vibratory ground motion produced by an earthquake.

high-level radioactive waste Highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in concentrations above levels specified in regulations. Any other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines requires permanent isolation by disposal in a geologic repository.

hydrogeology The science dealing with subsurface water and with related geologic aspects of surface water.

license application A document submitted to the Nuclear Regulatory Commission containing general information and a safety analysis for certain nuclear facilities such as a nuclear power plant, a geologic repository, and a spent-fuel storage facility. A license application must be approved before the facility is constructed and before it can be operated.

Licensing Support Network (LSN) Refers to an electronic information retrieval and distribution system to support the licensing process, as required by the Nuclear Regulatory Commission in 10 CFR Part 2, Subpart J. This system must be certified by the Commission at least six months before the Department of Energy submits a repository license application. The Department has worked with the Commission and the Commission-sponsored stakeholder group to develop an acceptable system that will be used for document discovery by all participants in the repository licensing hearings.

magnesium chloride A highly deliquescent salt with the chemical formula $MgCl_2$.

matrix diffusion The migration of higher concentrations of dissolved chemicals from more permeable zones to less permeable zones having lower concentrations of the same dissolved chemicals.

multiple lines of evidence Varied methodological approaches used to infer the behavior of the repository system (or its major components) for extended time periods. Examples include analogues, simplified calculations, and arguments based on defense-in-depth.

near field A zone that typically extends one diameter outward from the tunnel wall. In that zone, coupled thermal, hydrological, mechanical, and chemical processes are expected to occur.

nitrate The anion NO_3, often used as a way to designate a salt containing nitrate.

Nuclear Waste Policy Act The federal statute enacted in 1982 that established the Office of Civilian Radioactive Waste Management and defined its mission to develop a federal system for the management and geologic disposal of commercial spent nuclear fuel and other high-level radioactive wastes, as appropriate. The Act

also specified other federal responsibilities for nuclear waste management, established the Nuclear Waste Fund to cover the cost of geologic disposal, authorized interim storage until a repository is available, and defined interactions between federal agencies and the states, local governments, and Indian tribes.

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

oxyanion A negatively charged polyatomic ion that contains oxygen.

peak dose The maximum dose rate projected to occur after the closure of the repository.

peer review A documented critical review performed by those who are independent from individuals who performed the work but have technical expertise at least equivalent to those who performed the original work.

performance assessment A complex computer-based analysis that predicts the behavior of an entire repository system under a given set of conditions.

postclosure The period of time after the closure of the geologic repository.

preclosure The period of time before and during the closure of the geologic repository.

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

radionuclide transport The movement of radioactive materials through rock formations, most typically in water.

radionuclide An atomic nucleus that is radioactive.

RADTRAN A computer code for transportation risk assessment for radioactive materials developed at Sandia National Laboratories. It combines demographic, routing, transportation, packaging, and materials data with meteorological data and health physics data to calculate expected radiological consequences of incident-free radioactive materials transportation and associated accident risks.

repository see **geologic repository**

saturated zone The part of the Earth's crust in which all empty spaces are filled with water.

seismic Pertaining to an earthquake or earth vibration.

spent nuclear fuel Uranium-containing rods that have been withdrawn from a nuclear reactor following irradiation. Some of the uranium atoms have undergone nuclear reactions producing fission products and transuranic elements that remain in the rods.

thermal pulse The period of approximately one thousand years immediately following repository closure, during which temperatures on the waste package surface can rise to more than 150°C according to the Department of Energy's current repository design.

Total System Model (TSM) This logistical tracks waste shipments from the waste generating and storage sites through emplacement. It also provides logistical information about waste stream movements and the system resources required for accomplishing those movements.

Total System Performance Assessment (TSPA) Analyses undertaken by the Department of Energy for assessing the ability of the potential repository at Yucca Mountain to provide long-term isolation and containment of radioactive wastes.

unsaturated zone Layers of rock in which some, but not all, of the empty spaces are filled with water.

vaporization barrier Term used by the DOE to denoted a phenomenon that limits downward flow of water to emplacement drifts by vigorous boiling in the superheated rock (i.e., rock temperature above boiling point of water).

waste management system All elements of the system involved in the management of radioactive wastes. (from DOE)

waste package The waste form, any fillers, and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.

References

Abkowitz, Mark. 2004. March 29 letter from Mark Abkowitz, Chairman, Panel on the Waste Management System, to Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, on the Board's reactions to presentations at the January meeting of the Panel on the Waste Management System.

Chu, Margaret S. Y. 2003. October 8 letter from Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, to Michael L. Corradini, Chairman, U.S. Nuclear Waste Technical Review Board, containing the DOE's responses to recommendations in the Board's June 27, 2003, letter.

_____. 2004a. May 28 letter from Margaret S. Y. Chu, Director, OCRWM, to Mark Abkowitz, Chairman, Panel on the Waste Management System, containing the DOE's responses to recommendations in the Board's March 29, 2004, letter.

_____. 2004b. July 21 letter from Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, to Ronald M. Latanision, Chairman, Panel on the Engineered System, containing DOE's responses to recommendations in the Board's April 5, 2004 letter.

_____. 2004c. September 10 letter from Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, to Richard N. Parizek, Chairman, Panel on the Natural System, containing the DOE's responses to recommendations in the Board's May 3, 2004, letter.

_____. 2005a. January 25 letter from Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, to B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, on DOE's responses to recommendations in the Board's July 28, 2004, letter.

_____. 2005b. February 1 letter from Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, to B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, containing the DOE's responses to recommendations in the Board's December 1, 2004, letter.

Corradini, Michael L. 2003a. June 27 letter from Michael L. Corradini, Chairman, U.S. Nuclear Waste Technical Review Board, to Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, on the Board's reactions to presentations at the February joint meeting of the Panel on the Natural System and the Panel on the Engineered System.

_____. 2003b. October 21 letter from Michael L. Corradini, Chairman, U.S. Nuclear Waste Technical Review Board, to Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, on the Board's comments on the data and analyses related to corrosion presented at the May Board meeting.

_____. 2003c. November 25 letter from Michael L. Corradini, Chairman, U.S. Nuclear Waste Technical Review Board, to Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, containing additional Board's comments on the data and analyses related to corrosion presented at the May Board meeting.

Department of Energy (DOE). 2002. *Radioactive Materials Transportation Practices Manual.* Office of Environmental Management. DOE M 460.2-1.

_____. 2004a. "Record of Decision on Mode of Transportation and Nevada Rail Corridor for the disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, NV." *Federal Register.* Vol. 69, No. 68. April 8, 2004; pp.18557-18565.

_____. 2004b. "Notice of Intent to Prepare an Environmental Impact Statement for the Alignment, Construction, and Operation of a Rail Line to a Geologic Repository at Yucca Mountain, Nye County, NV. *Federal Register.* Vol. 69, No. 68. April 8, 2004; pp. 18565-18569.

Duquette, David J. 2004. July 28 letter from David J. Duquette, Chairman, Executive Committee, to Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, on the Board's reactions to presentations at the May Board meeting.

Garrick, B. John. 2004a. November 30 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, on the Board's reactions to presentations at the September Board meeting.

_____. 2004b. December 1 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, on the Board's reactions to presentations at the October meeting of the Panel on the Waste Management System.

Garrish. Theodore J. 2005. March 31 letter from Theodore J. Garrish, Deputy Director, Office of Civilian Radioactive Waste Management to B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, on the DOE's responses to recommendations in the Board's November 30, 2004, letter.

Latanision, Ronald M. 2004. April 5 letter from Ronald M. Latanision, Chairman, Panel on the Engineered System, to Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, on the Board's reactions to presentations at the March Panel on the Engineered System meeting.

National Research Council. Committee for Technical Bases for Yucca Mountain Standards. 1995. *Technical Bases for Yucca Mountain Standards.* Washington, D.C.: National Academy Press.

Nuclear Waste Technical Review Board (NWTRB). 2003a. Panel on the Natural System and Panel on the Engineered System. Joint meeting; February 24, 2003; Las Vegas, Nevada (transcript of proceedings). Arlington, Virginia.

_____. 2003b. "An Evaluation of Key Elements in the U. S. Department of Energy's Proposed System for Isolating and Containing Radioactive Waste." U.S. Nuclear Waste Technical Review Board Technical Report. Arlington, Virginia.

_____. 2004a. Spring Board meeting; May 18-19, 2004; Washington, D.C. (transcript of proceedings). Arlington, Virginia.

_____. 2004b. Fall Board meeting; September 20, 2004; Las Vegas, Nevada (transcript of proceedings). Arlington, Virginia.

_____. 2004c. Panel on the Engineered System meeting; January 20, 2004; Las Vegas, Nevada (transcript of proceedings). Arlington, Virginia.

_____. 2004d. Panel on the Waste Management System meeting; January 21, 2004; Las Vegas, Nevada (transcript of proceedings). Arlington, Virginia

_____. 2004e. Panel on the Natural System meeting; March 9-10, 2004; Las Vegas, Nevada (transcript of proceedings). Arlington, Virginia.

_____. 2004f. Panel on the Waste Management System meeting; October 13-14, 2004, Salt Lake City, Utah (transcript of proceedings). Arlington, Virginia.

Pre-License Application Presiding Officer (PAPO). 2004. Memorandum and Order. August 31, 2004.

Parizek, Richard N. 2004. May 3 letter from Richard N. Parizek, Chairman, Panel on the Natural System, to Margaret S. Y. Chu, Director, Office of Civilian Radioactive Waste Management, on the DOE's participation at Panel on the Natural System meeting held January 20.

U.S. Congress. 1982. *Nuclear Waste Policy Act of 1982* (NWPA). 97th Congress, 2nd Session. Washington, D.C.: Government Printing Office.

_____. 1987. *Nuclear Waste Policy Amendments Act of 1987* (NWPAA). 100th Congress, 1st Session, 1987. Washington, D.C.: Government Printing Office.

_____. 1992. *Energy Policy Act.* 102nd Congress, 2nd Session. Washington, D.C.: Government Printing Office.

_____. 2002. *House Joint Resolution 87: Approving the Site at Yucca Mountain, Nevada, for the development of a repository for the disposal of high-level radioactive waste and spent nuclear fuel, pursuant to the Nuclear Waste Policy Act of 1982.* 107th Congress, 2nd Session; 2002. Washington, D.C.: Government Printing Office.

10 CFR 63 (Code of Federal Regulations). 2001. Title 10, *Energy*, Part 63, "Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain."

10 CFR 963 (Code of Federal Regulations). 2001. Title 40, *Energy,* Part 963. "Yucca Mountain Site Suitability Guidelines."

40 CFR 197 (Code of Federal Regulations). 1999. Title 40, *Protection of Environment,* Part 197. "Environmental Radiation Protection Standards for Yucca Mountain, Nevada."