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
Arlington, VA 22201-3367

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.

Telephone: 703-235-4473 Fax: 703-235-4495

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

Dr. Michael L. Corradini, Chairman[1]
University of Wisconsin
Madison, Wisconsin

Dr. B. John Garrick, Chairman[5]
Consultant
Newport Beach, California

Dr. Mark D. Abkowitz
Vanderbilt University
Nashville, Tennessee

Dr. Wm. Howard Arnold[5]
Consultant
Macatawa, Michigan

Dr. Daniel B. Bullen[3]
Iowa State University
Ames, Iowa

Dr. Daryle H. Busch[5]
University of Kansas
Lawrence, Kansas

Dr. Thure E. Cerling
University of Utah
Salt Lake City, Utah

Dr. Norman L. Christensen, Jr.[4]
Duke University
Durham, North Carolina

Dr. Paul P. Craig[2]
University of California, Davis, Emeritus
Davis, California

Dr. David J. Duquette
Rensselaer Polytechnic Institute
Troy, New York

Dr. George M. Hornberger[5]
University of Virginia
Charlottesville, Virginia

Dr. Andrew C. Kadak[5]
MIT
Cambridge, Massachusetts

Dr. Ronald M. Latanision
MIT
Cambridge, Massachusetts

Dr. Ali Mosleh[5]
University of Maryland
College Park, Maryland

Dr. Priscilla P. Nelson[4]
National Science Foundation
Arlington, Virginia

Dr. Richard R. Parizek[4]
Pennsylvania State University
State College, Pennsylvania

Dr. Henry R. Petroski[5]
Duke University
Durham, North Carolina

[1] Resigned January 12, 2004
[2] Resigned January 17, 2004
[3] Resigned May 24, 2004
[4] Until September 9, 2004
[5] Since September 10, 2004

Executive Staff

William D. Barnard	*Executive Director*
Joyce M. Dory	*Director of Administration*

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Victoria F. Reich	*Librarian*

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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."

Appendices

Appendix A
U.S. Nuclear Waste Technical Review Board Members

Michael L. Corradini, Ph.D.; Chairman

Dr. Michael L. Corradini was appointed to the U.S. Nuclear Waste Technical Review Board as Chairman on June 26, 2002, by President George W. Bush. Dr. Corradini resigned from the Board effective January 12, 2004.

Dr. Corradini is chairman of the engineering physics department of the University of Wisconsin–Madison. He brings to the Board expertise in nuclear and industrial safety. His research focuses on multiphase flow and heat/mass transfer, vapor-explosion phenomena, jet-spray breakup, and mixing dynamics, as well as on heat/mass transfer and chemical reactions involved in molten core-concrete interactions.

Dr. Corradini has 25 years of experience in nuclear engineering, including research and teaching. He was elected to membership in the National Academy of Engineering of the National Academy of Sciences in 1998. He is a Fellow of the American Nuclear Society and was a recipient of the 1990 Young Members Engineering Achievement Award. Dr. Corradini is a registered Professional Engineer.

Dr. Corradini has served as a consultant for the U.S. Nuclear Regulatory Commission's Advisory Committee on Reactor Safeguards and for the U.S. Department of Energy National Laboratories (Los Alamos National Laboratory, Oak Ridge National Laboratory, Idaho National Engineering Laboratory, Brookhaven National Laboratory). He also has participated in nationally and internationally sponsored research.

Dr. Corradini earned a bachelor of science degree in mechanical engineering from Marquette University in 1975. He received a master of science degree in nuclear engineering from the Massachusetts Institute of Technology (MIT) in 1976 and a Ph.D. in nuclear engineering from MIT in 1978. For the next three years, he was on the technical staff of Sandia National Laboratories, conducting research on severe reactor accidents. In 1981, Dr. Corradini joined the University of Wisconsin–Madison faculty. He became Associate Dean, Academic Affairs, of the College of Engineering in 1995. In 2001, he became chairman of the Department of Engineering Physics.

Dr. Corradini lives in Madison, Wisconsin.

B. John Garrick, Ph.D., P.E.; Chairman

Dr. B. John Garrick was appointed to the U.S. Nuclear Waste Technical Review Board as Chairman on September 10, 2004, by President George W. Bush.

Dr. Garrick is an executive consultant on the application of risk sciences to complex technological systems in the space, defense, chemical, marine, transportation, and nuclear fields. He served for 10 years (1994–2004), 4 years as chair, on the U.S. Nuclear Regulatory Commission's Advisory Committee on Nuclear Waste. His areas of expertise include risk assessment and nuclear science and engineering. A founder of the firm PLG, Inc., Dr. Garrick retired as President, Chairman, and Chief Executive Officer in 1997. Before PLG's acquisition and integration into a new firm, it was an international engineering, applied science, and management consulting firm.

Dr. Garrick was elected to the National Academy of Engineering in 1993, President of the Society for Risk Analysis 1989–90, and recipient of that Society's most prestigious award, the Distinguished Achievement Award, in 1994. He has been a member and chair of several National Research Council committees, having served as vice chair of the Academies' Board on Radioactive Waste Management and as a member of the Commission on Geosciences, Environment, and Resources. He recently chaired the National Academy of Engineering Committee on Combating Terrorism. Among other National Academy committees he has chaired are the Committee on the Waste Isolation Pilot Plant, the Committee on Technologies for Cleanup of High-Level Waste in Tanks in the DOE Weapons Complex, and the Panel on Risk Assessment Methodologies for Marine Systems. Other Academy committee memberships included space applications, automotive safety, and chemical weapons disposal. He is a member of the first class of lifetime national associates of the National Academies.

Dr. Garrick has published more than 250 papers and reports on risk, reliability, engineering, and technology, has written several book chapters, and was editor of the text, *The Analysis, Communication, and Perception of Risk*.

Dr. Garrick received his Ph.D. in engineering and applied science from the University of California, Los Angeles, in 1968. His fields of study were neutron transport, applied mathematics, and applied physics. He received an M.S. in nuclear engineering from UCLA in 1962, attended the Oak Ridge School of Reactor Technology in 1954–55, and received a B.S. in physics from Brigham Young University in 1952. He is a fellow of three professional societies: the American Nuclear Society, the Society for Risk Analysis, and the Institute for the Advancement of Engineering. He is a registered professional engineer in California.

Dr. Garrick lives in Laguna Beach, California.

Mark D. Abkowitz, Ph.D.

Dr. Mark D. Abkowitz was appointed to the U.S. Nuclear Waste Technical Review Board on June 26, 2002, by President George W. Bush.

Dr. Abkowitz is a professor of civil and environmental engineering at Vanderbilt University in Nashville, Tennessee, and is director of the Vanderbilt Center for Environmental Management Studies. He brings to the Board expertise in transportation, systems analysis, risk management, and applications of advanced information technologies.

Dr. Abkowitz has served on several national and international committees, including as chairman of the National Academy of Sciences Transportation Research Board Committee on Hazardous Materials Transport and as a member of the National Research Council Committee on Disposal of Transuranic Waste at the Waste Isolation Pilot Plant. Dr. Abkowitz also serves on the board of Visual Risk Technologies. He is the author of more than 70 journal publications and study reports.

Dr. Abkowitz has been inducted into Chi Epsilon and the National Society of Sigma Xi and is a member of the World Conference on Transportation Research Society. He received the Distinguished Service Award in 1996 from the Transportation Research Board.

Dr. Abkowitz received a bachelor of science degree in civil engineering from the Massachusetts Institute of Technology (MIT) in 1974. In 1976, he received a master of science degree in civil engineering from MIT. He was awarded a Ph.D. in civil engineering–transportation by MIT in 1980. From 1976 to 1980, he worked as a project manager and research investigator for the U.S. Department of Transportation. In 1980, he joined the civil engineering faculty of Rensselaer Polytechnic Institute. During a sabbatical in 1986–87, he served as a senior analyst to the U.S. Congress, Office of Technology Assessment. He joined Vanderbilt in 1987 as Administrative Director, Vanderbilt Engineering Center for Transportation Operations and Research.

Dr. Abkowitz lives in Nashville, Tennessee.

William Howard Arnold, Ph.D., P.E.

Dr. William Howard Arnold was appointed to the U.S. Nuclear Waste Technical Review Board on September 10, 2004, by President George W. Bush.

Dr. Arnold is a private consultant. He was president of Louisiana Energy Services until his retirement in 1996. Louisiana Energy Services was a partnership of Urenco, Duke Power, Fluor Daniel, Northern States Power, and Louisiana Power and Light, formed to build the first privately owned uranium-enrichment facility in the United States. Dr. Arnold had retired from Westinghouse Electric Corporation in 1989 after 33 years in a variety of positions.

From 1955 to 1961, Dr. Arnold was senior engineer and section manager for Westinghouse Commercial Atomic Power. He was responsible for reactor physics design of the first series of Westinghouse commercial reactors. He spent one year with NUS Corporation as a nuclear fuel management consultant. From 1961 to 1968, he was deputy engineering manager, operations manager, and program manager for the NERVA nuclear rocket project for Westinghouse Astronuclear Laboratory. In 1968–1970, Dr. Arnold was manager of the underseas weapons department for the Westinghouse Defense Center in Baltimore, Maryland, responsible for the Mk 48 torpedo. From 1972 to 1989, he held various positions with Westinghouse in the nuclear area, including engineering manager of the pressurized-water reactor systems division, general manager and president of the Nuclear International Division, and general manager of the Advanced Energy Systems Division. He also served as vice president of Westinghouse Hanford Company.

Dr. Arnold was elected to the National Academy of Engineering in 1974 and is a Fellow and past member of the Board of Directors of the American Nuclear Society. He has participated in several National Academy of Sciences studies, including chairing the 2003 study, titled "Improving the Scientific Basis for Managing DOE's Excess Nuclear Materials and Spent Nuclear Fuel."

Dr. Arnold received a bachelor's degree in chemistry and physics from Cornell University in 1951. In 1955, he was awarded a Ph.D. in experimental physics by Princeton University. He is a registered professional engineer in Pennsylvania.

Dr. Arnold resides in Macatawa, Michigan, and Coronado, California.

Daniel B. Bullen, Ph.D.

Dr. Daniel B. Bullen was appointed to the U.S. Nuclear Waste Technical Review Board on January 17, 1997, by President William Clinton.

Dr. Bullen is an associate professor of mechanical engineering, Department of Mechanical Engineering, at Iowa State University in Ames, Iowa. He brings to the Board special expertise in performance assessment modeling of radioactive waste disposal facilities, performance assessment of engineered barrier systems, radiolysis effects in spent-fuel dry casks in storage environments, radiation effects on materials, and materials degradation in severe service environments.

Dr. Bullen has been teaching since 1989, and he served as Nuclear Engineering Program Coordinator at Iowa State University from 1993 to 1996 and as director of the Iowa State University Nuclear Reactor Laboratory from 1993 to 2001. He has 12 years of industry experience in nuclear engineering and materials science. He has edited and reviewed articles for such professional publications as *Nuclear Technology*, *Journal of the American Ceramic Society*, *American Nuclear Society Transactions*, and *Encyclopedia of Chemical Technology*. He has written or co-written more than 70 technical publications and reports and has contributed to three books. He is a registered Professional Engineer in mechanical, metallurgical, and nuclear engineering. Dr. Bullen's honors and awards include Tau Beta Pi (National Engineering Honor Society), Phi Kappa Phi, Sigma Xi (Scientific Research Society), Alpha Nu Sigma (Nuclear Engineering Scholastic Honor Society), a Lilly Teaching Fellowship at the Georgia Institute of Technology (1991), and two Outstanding Professor awards. He has appeared in Who's Who in Science and Engineering, Who's Who in America, and Who's Who in the World.

Dr. Bullen is a member of ASM International; American Society of Mechanical Engineers; National Society of Professional Engineers; Minerals, Metals & Materials Society; and American Nuclear Society (ANS). He is an active member of the Education and Training Division and the Fuel Cycle and Waste Management Division of ANS and has served as Chairman of the Executive Committee of each division.

Dr. Bullen is an international consultant in radioactive waste management. As a consultant to Monitor Scientific, LLC, of Denver, Colorado, Dr. Bullen has provided technical expertise to the Japanese and Swedish nuclear waste management programs on issues related to waste package degradation, performance-confirmation monitoring, and long-term performance assessment.

In 1978, Dr. Bullen earned a bachelor of science degree in engineering science from Iowa State University. He was a research assistant at the University of Wisconsin–Madison while earning master of science degrees in nuclear engineering in 1979 and materials science in 1981 and a Ph.D. in nuclear engineering in 1984. He then worked for Lawrence Livermore National Laboratory as an engineer until 1986, when he became senior engineer for Science & Engineering Associates, Inc., in Pleasanton, California. In 1988, he became president of DG Engineering Associates, providing technical consulting services to Lawrence Livermore National Laboratory. Dr. Bullen moved to North Carolina State University in 1989 as an assistant professor of nuclear engineering and to the Georgia Institute of Technology in 1990 as an assistant professor of mechanical engineering. He moved to Iowa State University in 1992 as an associate professor of nuclear engineering.

Dr. Bullen lives in Ames, Iowa.

Daryle H. Busch, Ph.D.

Dr. Daryle H. Busch was appointed to the U.S. Nuclear Waste Technical Review Board on September 10, 2004, by President George W. Bush.

Dr. Busch is the Roy A. Roberts Distinguished Professor of Chemistry at the University of Kansas. He also is deputy director of the NSF Engineering Research Center, which has the title Center for Environmentally Beneficial Catalysis.

Before going to the University of Kansas, Dr. Busch was a member of the faculty at The Ohio State University, eventually becoming Presidential Professor in 1987. His research in basic transition metal coordination chemistry fathered modern macrocyclic ligand chemistry and created the molecular template effect. He was one of the founders of the subject of ligand reactions and an early researcher and proponent of bioinorganic chemistry. He first described the phenomenon called "preorganization" in 1970. His research is presently focused on homogeneous catalysis, bioinorganic chemistry, and orderly molecular entanglements, a part of supramolecular and nanochemistry.

Dr. Busch served on the board of directors and in various capacities on local and regional sections and committees of the American Chemical Society (ACS). He was president of the ACS in 2000, and a member of the Board of Directors in 1999–2001.

In addition to some 400 scientific publications, Dr. Busch holds 11 patents jointly with 5 major industrial companies and 2 universities. Recognition of his research includes the ACS Award for Distinguished Service in Inorganic Chemistry (1976); the ACS Award for Research in Inorganic Chemistry (1963); the John C. Bailar Medal of his alma mater, the University of Illinois (1978); the Dwyer Medal of the Royal Society of N.S.Wales, Australia (1978); the Izatt-Christenson International Award for Macrocyclic Chemistry (1994); and the Basolo Medal of Northwestern University (2003). In 2003, Dr. Busch was an honorary inductee into the Chemical Society of Japan. His teaching has been recognized by the University of Kansas Louis Byrd Graduate Educator Award (1996) and an Ohio State University Alumni Teaching Award (1980).

He was recently chairman of the Chemistry Section of the American Association for the Advancement of Science and served the International Union for Pure and Applied Chemistry as chairman of the Commission on Inorganic Nomenclature and as secretary of the Inorganic Chemistry Division Committee.

Dr. Busch received a bachelor's degree in chemistry from Southern Illinois University in 1951 and master's and Ph.D. degrees in chemistry from the University of Illinois in 1952 and 1954 respectively.

Dr. Busch resides in Lawrence, Kansas.

Thure E. Cerling, Ph.D.

Dr. Thure E. Cerling was appointed to the U.S. Nuclear Waste Technical Review Board on June 26, 2002, by President George W. Bush.

Dr. Cerling is Distinguished Professor of Geology and Geophysics and Distinguished Professor of Biology at the University of Utah. He brings to the Board expertise in terrestrial geochemistry. His research interests are in the study of geochemistry processes occuring at or near the Earth's surface and in the geological record of ecological change.

Dr. Cerling was elected to membership in the National Academy of Sciences in 2001. He is a fellow of the American Association for the Advancement of Science and of the Geological Society of America. He has been a visiting professor at Scripps Institution of Oceanography, Yale University, the University of Lausanne in Switzerland, the California Institute of Technology, and at the University of Cape Town in South Africa.

Dr. Cerling has served on numerous boards, panels, and committees, including the National Research Council-National Academy of Sciences Board of Earth Sciences and Resources, Geochemical Society Board of Directors, and the Nuclear Waste Group of the International Union of Geological Sciences. He also served on the Governor's Nuclear Waste Task Force, State of Utah, in 1981–83. In 1998, he received the University of Utah Distinguished Research Award.

In 1972, Dr. Cerling earned a bachelor of science degree in geology and chemistry from Iowa State University. In 1973, he received a master of science degree in geology from Iowa State University. In 1977, he was awarded a Ph.D. in geology by the University of California–Berkeley. From 1977 to 1979, Dr. Cerling worked as a research scientist at Oak Ridge National Laboratory. In 1979, he joined the faculty of the University of Utah.

Dr. Cerling lives in Salt Lake City, Utah.

Norman L. Christensen, Jr., Ph.D.

Dr. Norman L. Christensen, Jr. was appointed to the U.S. Nuclear Waste Technical Review Board on January 17, 1997, by President William Clinton.

Dr. Christensen is professor of ecology at the Nicholas School of the Environment and Earth Sciences at Duke University in Durham, North Carolina. He brings to the Board special expertise in biology and ecology. His research interests include the effects of disturbance on structure and function of populations and communities; comparative biogeochemical and community responses to varying fire regimes; use of remote sensing systems (such as synthetic aperture radar) to evaluate long-term changes in forest ecosystems; and pattern analysis of forest development following cropland abandonment as affected by environment, stand history, and plant demographic patterns.

Dr. Christensen has been teaching for more than 29 years and has more than 90 scientific articles and books to his credit. He has written widely on the importance of natural disturbance in the management of forests, shrublands, and wetlands, and he is interested in applying basic ecological theory and models to ecosystem management.

Dr. Christensen is the recipient of the 1977 Duke Endowment Award for Teaching Excellence, the 1991 Distinguished Teaching Award for Trinity College of Arts and Sciences at Duke, and the 1994 Distinguished Scholar-Alumni Award from California State University–Fresno. He was made a Fellow of the American Association for the Advancement of Science in 1993 and is a recipient of the National Park Service's A. Starker Leopold Award for distinguished service. Dr. Christensen has served on more than 25 national and regional panels and commissions and on the editorial boards of American Midland Naturalist, Journal of Vegetation Science, and Journal of Wildland Fire. He is currently vice president of the Ecological Society of American and Chairman of the National Commission on Science for Sustainable Forestry.

Dr. Christensen is a member of the American Association for the Advancement of Science, the British Ecological Society, the Ecological Society of America, Sigma Xi (Scientific Research Society), the Society of American Foresters, and the National Association of Environmental Professionals.

Dr. Christensen earned a bachelor's degree in biology from Fresno State College in 1968. He earned a master of science degree in biology from Fresno State College in 1970 and a Ph.D. in biology from the University of California–Santa Barbara in 1973. He began his teaching career as an assistant professor in the Department of Botany at Duke University in 1973. He became an associate professor in 1979 and was elevated to full professor in 1987. He was dean of the Nicholas School of the Environment from 1991 to 2001.

Dr. Christensen lives in Chapel Hill, North Carolina.

Paul P. Craig, Ph.D.

Dr. Paul P. Craig was appointed to the U.S. Nuclear Waste Technical Review Board on January 30, 1997, by President William Clinton.

Dr. Craig is Professor of Engineering Emeritus at the University of California, Davis, and is a member of the university's Graduate Group in Ecology. He brings to the Board special expertise and research interest in energy and environmental policy.

Dr. Craig has more than 21 years of teaching experience and more than 100 refereed publications to his credit. He is Chairman of the Sierra Club's National Global Warming and Energy Committee. He was a Lawrence Berkeley National Laboratory Participating Guest Scientist from 1976 to 1997 and again starting in 2002. He is a Fellow of the American Physical Society. Dr. Craig's awards include a John Simon Guggenheim Memorial Foundation Fellowship and a National Science Foundation Meritorious Service Award. He is a member of Phi Beta Kappa.

Dr. Craig earned a bachelor of science degree in mathematics and physics from Haverford College in 1954. He earned a Ph.D. in physics from the California Institute of Technology in 1959. He began his career as a staff scientist at Los Alamos National Laboratory in 1959 and moved to Brookhaven National Laboratory in 1962 as a physicist and a group leader. In 1971, he became deputy and acting director of the Office of Energy Research and Development Policy of the National Science Foundation, where he provided policy analysis support to the President's science advisor and to the Office of Management and Budget. Dr. Craig became director of the University of California Council on Energy and Resources in 1975 and professor of engineering at the University of California, Davis, in 1977. He received his emeritus standing in 1994.

Until his appointment to the Nuclear Waste Technical Review Board, Dr. Craig was a member of the National Academy of Sciences–National Research Council Board on Radioactive Waste Management.

Dr. Craig lives in Martinez, California.

David J. Duquette, Ph.D.

Dr. David J. Duquette was appointed to the U.S. Nuclear Waste Technical Review Board on June 26, 2002, by President George W. Bush.

Dr. Duquette is Department Head and a professor of materials science and engineering at Rensselaer Polytechnic Institute (RPI) in Troy, New York. He brings to the Board expertise in the physical, chemical, and mechanical properties of metals and alloys, with special emphasis on environmental interactions. His current research interests include the physical, chemical, and mechanical properties of metals and alloys, with specific reference to studies of cyclic deformation behavior as affected by environment and temperatures, basic corrosion studies, and stress-corrosion cracking.

Dr. Duquette is author or co-author of more than 200 scientific publications, primarily in environmental degradation of materials and electrochemical processing of semiconductor interconnects. Among the awards that he has received are the Willis Rodney Whitney Award from the National Association of Corrosion Engineers in 1990 and the Humboldt Prize from the Alexander von Humboldt Foundation in 1983. He has been elected an Honorary Member of Alpha Sigma Mu, the national metallurgical honorary society, and has received an Outstanding Paper Award from Acta Metrallurgica. He is a Fellow of the National Association of Corrosion Engineers and of the American Society for Metals and is also a member of the Minerals, Metals & Materials Society and of the Electrochemical Society.

Dr. Duquette spent more than five years as a member of a scientific review group that advised the Canadian government on disposal of high-level nuclear waste. He also has been a member of a panel that advised the United States government on container design and materials selection for disposing of nuclear waste.

Dr. Duquette received a bachelor of science degree from the U.S. Coast Guard Academy in 1961. From 1961 to 1965, he served as a commissioned officer in the U.S. Coast Guard. From 1965 to 1968, he was a research assistant in the Department of Metallurgy and Materials Science at the Massachusetts Institute of Technology (MIT). In 1968, he was awarded a Ph.D. in materials science by MIT. From 1968 to 1970, he worked as a senior research associate in the Advanced Materials Research and Development Laboratory of Pratt and Whitney Aircraft. Dr. Duquette joined the RPI faculty in 1970.

Dr. Duquette lives in Loudonville, New York.

George M. Hornberger, Ph.D.

Dr. George M. Hornberger was appointed to the U.S. Nuclear Waste Technical Review Board on September 10, 2004, by President George W. Bush.

Dr. Hornberger is Ernest H. Ern Professor of Environmental Sciences in the Department of Environmental Sciences at the University of Virginia.

Dr. Hornberger's work in catchment hydrology and hydrochemistry has centered on the coupling of field observations with mathematical modeling. The focus has been to understand how water is routed physically through soil and rock to streams and how hydrological processes and geochemical processes combine to produce observed stream dynamics. The modeling work allows the extension of work on individual catchments to regional scales. Dr. Hornberger's work in transport of colloids in geological media involves the processes affecting the transport of inorganic colloids and biocolloids (e.g., bacteria) through porous media.

Dr. Hornberger's honors and awards include Virginia Chapter of Sigma Xi President's and Visitor's Prize (1986); Robert E. Horton Award, Hydrology Section, American Geophysical Union (1993); Fellow, American Geophysical Union (1994); Biennial Medal for Natural Systems, Modeling, and Simulation, Society of Australia (1995); John Wesley Powell Award for Citizens' Achievement, U.S. Geological Survey (1995); Fellow, Association for Women in Science (1996); member of the National Academy of Engineering (February 1996); Excellence in Geophysical Education Award, American Geophysical Union (1999); and Langbein Lecturer, American Geophysical Union (2002).

He has chaired the Board on Earth Sciences and Resources of the National Research Council (2003 to present); the Publications Committee of the American Geophysical Union (2000 to 2004); the National Research Council Commission on Geosciences, Environment, and Resources (1996 to 2000); the Advisory Committee on Nuclear Waste, Nuclear Regulatory Commission (2001 to 2003); the Board of Journal Editors, American Geophysical Union (1998 to 2000); the Committee to Prepare a Science Plan for a Water-Cycle Initiative (1999 to 2000); and the National Research Council Committee on the Review of EarthScope Science Objectives and Implementation Planning (2001).

Dr. Hornberger was associate editor of *Water Resources Research* from 1982 to 1984, North American editor of the *Journal of Hydrological Processes* from 1985 to 1992, and editor of *Water Resources Research* from 1993 to 1997.

He received a bachelor's degree in civil engineering from Drexel University in 1965, a master's degree in civil engineering (hydrology) from Drexel in 1967, and a Ph.D. in hydrology from Stanford University in 1970.

Dr. Hornberger resides in Charlottesville, Virginia.

Andrew C. Kadak, Ph.D.

Dr. Andrew C. Kadak was appointed to the U.S. Nuclear Waste Technical Review Board on September 10, 2004, by President George W. Bush.

Dr. Kadak is Professor of the Practice in the Nuclear Engineering Department at the Massachusetts Institute of Technology (MIT). His research interests include the development of advanced reactors, in particular the high-temperature pebble-bed gas reactor, space nuclear power systems, improved technology-neutral licensing standards for advanced reactors, and operation and management issues of existing nuclear power plants. Dr. Kadak also serves as chairman of the MIT undergraduate committee working on curriculum development and recruitment. He is president of Kadak Associates, a consulting firm specializing in management, organizational, and communication strategies for the nuclear industry.

Before joining the faculty of MIT, Dr. Kadak worked for Yankee Atomic Electric Company. He held various positions there from 1979 to 1987, including president and chief executive officer. From 1975 to 1979, Dr. Kadak was manager of nuclear information at New England Power Company. He was principal physicist for pressurized-water reactor physics at Combustion Engineering Corporation from 1972 to 1975.

Dr. Kadak was president of the American Nuclear Society from 1999 to 2000. He has served as a board and executive committee member of the Nuclear Energy Institute and the industry's Advisory Committee on High-Level Waste. He also has served as a member of the National Association of Regulatory Utility Commissioners special panel on high-level nuclear waste and the Aspen Institute's Dialogue on Nuclear Waste Disposal.

In 1995, he was a member of the Advisory Committee on External Regulation of DOE Nuclear Safety. He also has conducted several audits of nuclear companies to assess their management practices and has served as chairman of a panel related to the DOE's Nevada Test Site. Dr. Kadak has presented more than 50 lectures and speeches on topics related to the technical and business aspects of nuclear power.

Dr. Kadak earned a bachelor's degree in mechanical engineering from Union College in 1967, a master's degree in nuclear engineering from the Massachusetts Institute of Technology in 1970, a Ph.D. in nuclear engineering from MIT in 1972, and an MBA from Northeastern University in 1983.

Dr. Kadak resides in Barrington, Rhode Island.

Ronald M. Latanision, Ph.D.

Dr. Ronald M. Latanision was appointed to the U.S. Nuclear Waste Technical Review Board on June 26, 2002, by President George W. Bush.

Dr. Latanision is professor emeritus of materials science and engineering and nuclear engineering at the Massachusetts Institute of Technology (MIT) and a principal and Director, Mechanics and Materials in Exponent Corporation. He brings to the Board expertise in materials processing and in corrosion of metals and other materials in aqueous (ambient as well as high-temperature and high-pressure) environments.

Dr. Latanision is the author or co-author of more than 200 scientific publications. Among the awards that Dr. Latanision has received are the David Ford McFarland Award for Achievement in Metallurgy from The Pennsylvania State University Chapter of the American Society for Metals, in 1986, and the Willis Rodney Whitney Award from the National Association of Corrosion Engineers in 1994. He was elected Distinguished Alumnus of The Ohio State University College of Engineering in 1991, and Honorary Alumnus of MIT in 1992.

Dr. Latanision is a Fellow of the American Society of Metals International and the National Association of Corrosion Engineers. He is founder and co-chairman of the New England Science Teachers and is a member of the National Academy of Engineering and the American Academy of Arts and Sciences. He has been a consultant to industry and government and has been active in organizing international conferences.

In 1964, Dr. Latanision received a bachelor of science degree in metallurgy from The Pennsylvania State University. In 1968, he was awarded a Ph.D. in metallurgical engineering by The Ohio State University. In 1968 and 1969, he was a Postdoctoral Fellow at the National Bureau of Standards. From 1969 to 1974, he worked for Martin Marietta Laboratories, first as a research scientist and then as acting head of materials science. He joined MIT in 1975 as director of the H. H. Uhlig Corrosion Laboratory. During a sabbatical in 1982–83, he served as a science advisor to the U.S. House of Representatives Committee on Science and Technology. He also served as a member of the National Materials Advisory Board of the National Research Council.

Dr. Latanision lives in Winchester, Massachusetts.

Ali Mosleh, Ph.D.

Dr. Ali Mosleh was appointed to the U.S. Nuclear Waste Technical Review Board on September 10, 2004, by President George W. Bush.

Dr. Mosleh is a professor and director of the Reliability Engineering Program and director of the Center for Risk and Reliability at the University of Maryland. He conducts research on methods for probabilistic risk analysis (PRA) and reliability of complex systems, and he has made many contributions to diverse fields of theory and application. They include Bayesian methods for inference with uncertain evidence; analysis of data and expert judgment; treatment of model uncertainty; risk and reliability of hybrid systems of hardware, human, and software programs; methods and tools for dynamic PRA; cognitive models for human reliability analysis; and models of the influence of organizational factors on system safety.

Dr. Mosleh is the developer of the Accident Precursor Analysis methodology and many of the methods currently used for the treatment of common-cause failures in highly reliable systems. On these topics, he holds several patents and has edited, authored, or co-authored more than 250 publications, including books, guidebooks, and papers in technical journals and for conferences. Dr. Mosleh has led numerous projects on risk, safety, and security assessments for the aerospace, nuclear, chemical, and information systems and telecommunication industries. He also led the design and development of more than 10 major risk and reliability analysis software currently used by various government agencies and the private sector.

Dr. Mosleh is a Fellow of the Society for Risk Analysis (SRA), Chair of the Engineering Division of SRA, and engineering editor of the SRA journal. He is the recipient of several scientific achievement awards, and a consultant and technical advisor to national and international organizations on risk assessment and management. He has chaired or organized numerous international technical conferences on risk and reliability.

Dr. Mosleh received his Ph.D. in nuclear science and engineering from the University of California, Los Angeles, in 1981.

He resides in Columbia, Maryland.

Priscilla P. Nelson, Ph.D.

Dr. Priscilla P. Nelson was appointed to the U.S. Nuclear Waste Technical Review Board on January 17, 1997, by President William Clinton.

Dr. Nelson is Director, Division of Civil and Mechanical Systems, for the Directorate for Engineering at the National Science Foundation. Dr. Nelson brings to the Board special expertise in rock engineering and underground construction.

In 1970, Dr. Nelson earned a bachelor of science degree in geological sciences from the University of Rochester. She earned master of science degrees in geology from Indiana University in 1976 and in structural engineering from the University of Oklahoma in 1979. She was awarded a Ph.D. in geotechnical engineering by Cornell University in 1983. Dr. Nelson's career has included service as a Peace Corps volunteer and employment as a field engineer for the Alaskan Resource Sciences Corporation from 1975 to 1977. She joined the faculty of The University of Texas at Austin in 1983 and became full professor and holder of the John Focht Teaching Fellowship before joining the National Science Foundation in 1996. She has served as a consultant for major underground construction projects, including for the Superconducting Super Collider project from 1985 through 1992.

Dr. Nelson has more than 13 years of teaching experience and more than 100 technical and scientific publications to her credit. She has served as a member of the U.S. National Committee for Rock Mechanics, the U.S. National Committee for Tunneling Technology, and the Board on Radioactive Waste Management, all activities of the National Research Council. She is a member of the American Rock Mechanics Association (ARMA), the American Society of Civil Engineers (ASCE), the International Tunnelling Association, the American Underground Construction Association, the Association of Engineering Geologists, the American Society for Engineering Education, and other professional organizations. She is past president of the Geo-Institute of ASCE and of ARMA. Her honors and awards include Exxon Teaching Fellowships at The University of Texas at Austin (1985–1987), the Case Studies Award from the U.S. National Committee for Rock Mechanics (1988), the Haliburton Education Foundation Award of Excellence (1991), the Basic Research Award from the U.S. National Committee for Rock Mechanics (1993), and election to The Moles, an association of the heavy construction industry (1995). At the National Science Foundation, she has received the Director's Award for Integrative Collaboration three times, and she received the Director's Award for Meritorious Service in 1997. In 1999, she was appointed to the Senior Executive Service. Also in 1999, she received the Director's Award for Superior Accomplishment from the NSF.

Dr. Nelson lives in Arlington, Virginia.

Richard R. Parizek, Ph.D.

Dr. Richard R. Parizek was appointed to the U.S. Nuclear Waste Technical Review Board on February 11, 1997, by President William Clinton.

Dr. Parizek is a professor of geology and geoenvironmental engineering at the Pennsylvania State University; president of Richard R. Parizek and Associates, consulting hydrogeologists and environmental geologists; and a registered Professional Geologist. Dr. Parizek brings to the Board special expertise in hydrogeology and environmental geology. His research interests include the hydrogeology of karst, fractured rock, and glaciated terranes; factors controlling groundwater occurrence and movement; and the relationship between land use and groundwater pollution resulting from disposal of nuclear waste and other hazardous substances.

Dr. Parizek has more than 42 years of teaching experience and numerous journal publications to his credit. His awards include a cooperative fellowship from the National Science Foundation (1960), Kurl Mason Award, Pennsylvania Department of Environmental Resources, superior achievement award from the U.S. Environmental Protection Agency (1976), the Clearwater Conservancy Award (1985), the Matthew J. and Anne C. Wilson Teaching Award (1986), the medal for distinguished service to environmental science and engineering of the Institute of Meteorology and Water Management, Warsaw, Poland (1991), M. King Hubbard Award, National Ground Water Association (1998), Award for Distinguished Service in Hydrogeology, Geological Society of America (1999), and C.V. Theis Award, American Institute of Hydrology (2001). Dr. Parizek was appointed an administrative law judge of the Atomic Safety and Licensing Board Panel of the U.S. Nuclear Regulatory Commission in 1990, a position he left upon appointment to the Nuclear Waste Technical Review Board.

Dr. Parizek is a member of the American Association for the Advancement of Science, the American Institute of Hydrology, the Geological Society of America, the National Groundwater Association, the International Association of Scientific Hydrology, and Sigma Xi.

In 1956, Dr. Parizek earned a bachelor of science degree in geology from the University of Connecticut. He earned a master of science degree in geology in 1960 and a Ph.D. in geology in 1961, both from the University of Illinois. Dr. Parizek began his career as research assistant with the Illinois State Geological Survey in 1956 and began teaching in 1961 as assistant professor of geology and geophysics at The Pennsylvania State University. He became a full professor in 1971 and continues to teach in the Department of Geosciences. Dr. Parizek also has been a visiting scientist with the U.S. Geological Survey and a visiting scholar at Stanford University, the Desert Research Institute, Changchun College of Geology and the Institute of Karst Geology in the Peoples' Republic of China, and National Cheng Kuug University in Taiwan.

Dr. Parizek lives in State College, Pennsylvania.

Henry R. Petroski, Ph.D., P.E.

Dr. Henry Petroski was appointed to the U.S. Nuclear Waste Technical Review Board on September 10, 2004, by President George W. Bush.

Dr. Petroski is Aleksandar S. Vesic Professor of Civil Engineering and a professor of history at Duke University. His current research focuses on failure analysis and design theory. Ongoing projects include using case histories to understand the role of human error and failure in engineering design as well as developing conceptual models for invention and evolution in the engineering design process. Before joining the faculty of Duke University in 1980, he taught at the University of Illinois and the University of Texas at Austin and was a group leader at Argonne National Laboratory, where he was responsible for research and development in fracture mechanics.

Among the honors that Dr. Petroski has received are a Guggenheim Fellowship (1990–1991); honorary degrees from Clarkson University (1990), Trinity College (1997), Valparaiso University (1999), and Manhattan College (2003); the Ralph Coates Roe Medal from the American Society of Mechanical Engineers (1991); and the Civil Engineering History and Heritage Award from the American Society of Civil Engineers (1993). He has received the Centennial Award as an Outstanding Engineering Graduate of Manhattan College (1992) and the Alumni Award for Distinguished Service from the College of Engineering of the University of Illinois at Urbana-Champaign (1994). Dr. Petroski is an honorary member of The Moles, a Fellow of the American Society of Civil Engineers and the Institution of Engineers of Ireland, and a member of the American Academy of Arts and Sciences and the National Academy of Engineering.

Dr. Petroski is the author of the book *To Engineer Is Human: the Role of Failure in Successful Design* (1985) and is the writer and presenter of the 1987 BBC television documentary "To Engineer Is Human," which has been broadcast on PBS. Among his other books are: *The Pencil: A History of Design and Circumstance* (1990); *The Evolution of Useful Things* (1992); *Design Paradigms: Case Histories of Error and Judgment in Engineering* (1994); *Engineers of Dreams: Great Bridge Builders and The Spanning of America* (1995), *Invention by Design: How Engineers Get from Thought to Thing* (1996); *Remaking the World: Adventures in Engineering* (1997); *Small Things Considered: Why There Is No Perfect Design* (2003); and *Pushing the Limits: New Adventures in Engineering* (2004). Dr. Petroski also writes the engineering column for *American Scientist*, which is published by Sigma Xi, the scientific research society, and a column on the profession for *Prism*, the American Society for Engineering Education's journal. He has published more than 75 refereed journal articles in such publications as *International Journal of Fracture*, *Engineering Fracture Mechanics*, *Journal of Applied Mechanics*, *Structural Safety*, and *Research in Engineering Design*.

Dr. Petroski received a bachelor's degree in mechanical engineering from Manhattan College in 1963 and a Ph.D. in theoretical and applied mechanics from the University of Illinois at Urbana-Champaign in 1968. He is a professional engineer registered in Texas and a chartered engineer registered in Ireland.

Dr. Petroski resides in Durham, North Carolina.

Appendix B
2004 Meeting List

January 20

Panel on the Engineered System
Las Vegas, Nevada
Topics:
- Project update
- Repository design update

Transcript available

January 21

Panel on the Waste Management System
Las Vegas, Nevada
Topic:
- Transportation strategic planning considerations

Transcript available

January 20–22

Board Business Meeting
Las Vegas, Nevada
Minutes available

March 9–10

Panel on the Natural System Meeting
Las Vegas, Nevada
Topics:
- Unsaturated zone fluid flow and radionuclide transport
- Saturated zone fluid flow and radionuclide transport

Transcript available

May 18–19

Spring Board Meeting
Washington, D.C.
Topics:
- Program update
- Corrosion during the thermal pulse

Transcript available

May 17–20

Board Business Meeting
Washington, D.C.
Minutes available

September 20 **Fall Board Meeting**
Las Vegas, Nevada
Topic:
- Total system performance assessment

Transcript available

September 19–21 **Board Business Meeting**
Las Vegas, Nevada
Minutes available

October 13–14 **Panel on the Waste Management System Meeting**
Salt Lake City, Utah
Topic:
- Transportation issues

Transcript available

Appendix C
Panel Organization

Panel on the Natural System

Chair:	George M. Hornberger	Staff:	David Diodato*
Members:	Daryle H. Busch		John H. Pye
	Thure E. Cerling		Leon Reiter

Panel on the Engineered System

Chair:	Ronald M. Latanision	Staff:	Carlos A. W. Di Bella*
Members:	Wm. Howard Arnold		John H. Pye
	Daryle H. Busch		Karyn D. Severson
	David J. Duquette		
	Henry Petroski		

Panel on Repository System Performance and Integration

Chair:	Ali Mosleh	Staff:	Leon Reiter*
Members:	Mark D. Abkowitz		David M. Diodato
	Ronald M. Latanision		Daniel S. Metlay
	Thure E. Cerling		John H. Pye
	Henry Petroski		

Panel on the Waste Management System

Chair:	Mark D. Abkowitz	Staff:	Daniel J. Fehringer*
Members:	Wm. Howard Arnold		Carlos A. W. Di Bella
	David J. Duquette		Daniel S. Metlay
	Andrew C. Kadak		Karyn D. Severson

*Staff Coordinator

Appendix D
U.S. Nuclear Waste Technical Review Board Publications

The following publications are available by mail from the Nuclear Waste Technical Review Board or electronically from the Board's Web site at **www.nwtrb.gov**.

Letter Report to the U.S. Congress and the Secretary of Energy. December 2004.

This letter and enclosure comprise the Board's second report to Congress and the Secretary of Energy for calendar year 2004. The letter briefly summarizes areas where the Board believes the DOE has made progress, areas requiring attention, and the Board's priorities for the coming year. The enclosure contains a more detailed discussion of these topics.

Report to the U.S. Congress and the Secretary of Energy. May 2004.

In this report, the Board summarizes its major activities from January 1, 2003, through December 31, 2003. During that period, the Board continued its evaluation and held meetings on a range of technical and scientific issues, including seismicity, DOE plans for transporting spent nuclear fuel and high-level radioactive waste, the design and operation of facilities at the proposed repository site, performance-confirmation activities, and the potential for localized corrosion. Correspondence and related materials are included in the appendices to the report along with the Board's strategic plan for fiscal years 2004–2009, its performance plans for 2004 and 2005, and its performance evaluation for 2003.

Report to the U.S. Congress and the Secretary of Energy. December 19, 2003.

This letter and attachments constitute the Board's second report to Congress and the Secretary of Energy for calendar year 2003. This report is composed of letters on localized corrosion sent to the director of the Office of Civilian Radioactive Waste Management (OCRWM) on October 21, 2003, and November 25, 2003. It also contains the Board Technical Report on Localized Corrosion.

Board Technical Report on Localized Corrosion. November 25, 2003.

This report contains information supporting the conclusions that the Board presented in its October 21, 2003, letter to the DOE concerning the potential for localized corrosion of waste packages during the thermal pulse.

Report to the U.S. Congress and the Secretary of Energy. April 2003.

This report summarizes the Board's major activities between January 1, 2002, and December 31, 2002. During this period, the Board focused on evaluating the technical basis of the DOE's work related to analyzing a planned repository site at Yucca Mountain in Nevada. Included in an appendix to the report are letters to the DOE related to technical issues identified by the Board as part of its ongoing review in 2002. Also included in the appendices are the Board's strategic plan for fiscal years 2003–2008, its performance plans for FY 2003 and FY 2004, and its performance evaluation for FY 2002.

Report to the U.S. Congress and the Secretary of Energy. April 2002.

This report summarizes the Board's major activities between February 1, 2001, and January 31, 2002. During this period, the Board focused on evaluating the technical basis of the DOE's work related to a site recommendation, including the DOE's characterization of the Yucca Mountain site, the DOE's design of the repository and waste package, and the DOE's estimates of how a repository system developed at the site might perform. The report includes a description of activities undertaken by the Board in developing its assessment of the technical basis for the DOE's current performance estimates.

Letter Report to Congress and the Secretary of Energy. January 24, 2002.

This letter report constitutes the Board's second report to Congress and the Secretary of Energy for calendar year 2001. The report summarizes the Board's evaluation of the DOE's technical and scientific investigation of the Yucca Mountain site during the year.

Proceedings from an International Workshop on Long-Term Extrapolation of Passive Behavior, July 19–20, 2001, Arlington, Virginia. December 2001.

The Board conducted a workshop on issues related to predicting corrosion behavior for periods of unprecedented duration. The workshop was held on July 19 and 20, 2001, in Arlington, Virginia. The workshop consisted of a panel of 3 Board members and 14 internationally recognized corrosion scientists, 8 of whom were from outside the United States. Following the workshop, most panelists submitted brief papers giving their views on issues related to predicting very long term corrosion. This publication is a compilation of those submissions.

Report to the U.S. Congress and the Secretary of Energy. April 2001.

In this report, the Board summarizes its major activities in calendar year 2000. During 2000, the Board identified four priority areas for evaluating the potential repository at Yucca Mountain. The areas are the following:

- meaningful quantification of conservatisms and uncertainties in the DOE's performance assessments
- progress in understanding the underlying fundamental processes involved in predicting the rate of waste package corrosion
- an evaluation and a comparison of the base-case repository design with a low-temperature design
- development of multiple lines of evidence to support the safety case of the proposed repository, the lines of evidence being derived independently of performance assessment and thus not being subject to the limitations of performance assessment.

The report summarizes the Board's views on each priority area. A more detailed discussion of the priorities can be found in letters to the DOE included among the appendices to the report.

Report by letter to the Secretary of Energy and Congress. December 2000.

This report, in the form of a letter, presents a brief update of the Board's views on the status of the DOE program.

Report to the U.S. Congress and the Secretary of Energy. April 2000.

In this report, the Board summarizes its major activities in calendar year 1999. Among the activities discussed in the report is the Board's 1999 review of the DOE's viability assessment (VA) of the Yucca Mountain site. The Board's evaluation of the VA concludes that Yucca Mountain continues to warrant study as the candidate site for a permanent geologic repository and that work should proceed to support a decision on whether to recommend the site for repository development. The Board suggests that the 2001 date for a decision is very ambitious, and focused study should continue on natural and engineered barriers. The Board states that a credible technical basis does not currently exist for the above-boiling repository design included in the VA. The Board recommends evaluation of alternative

repository designs, including lower-temperature designs, as a potential way to help reduce the significance of uncertainties related to predictions of repository performance.

Report to the U.S. Congress and the Secretary of Energy. April 1999.

In this report, the Board summarizes its major activities during calendar year 1998. The report discusses the research needs identified in the DOE's recently issued *Viability Assessment* of the Yucca Mountain site, including plans to gather information on the amount of water that will eventually seep into repository drifts, whether formations under the repository will retard the migration of radionuclides, the flow-and-transport properties of the groundwater that lies approximately 200 meters beneath the repository horizon, and long-term corrosion rates of materials that may be used for the waste packages. The report describes other activities undertaken by the Board in 1998, including a review of the hypothesis that there were hydrothermal upwellings at Yucca Mountain, a workshop held to increase understanding of the range of expert opinion on waste package materials, and a review of the DOE's draft environmental impact statement for the Yucca Mountain site.

Report to the U.S. Congress and the Secretary of Energy: Moving Beyond the Viability Assessment. April 1999.

In its report, the Board offers its views on the DOE's December 1998 *Viability Assessment* of the Yucca Mountain site in Nevada. The Yucca Mountain site is being characterized to determine its suitability as the location of a permanent repository for disposing of spent nuclear fuel and high-level radioactive waste. The Board discusses the need to address key uncertainties that remain about the site, including the performance of the engineered and natural barriers. The Board addresses the DOE's plans for reducing those uncertainties and suggests that consideration be given to alternative repository designs, including ventilated low-temperature designs that have the potential to reduce uncertainties and simplify the analytical bases for determining site suitability and for licensing. The Board also comments on the DOE's total system performance assessment, the analytical tool that pulls together information on the performance of the repository system.

Report to the U.S. Congress and the Secretary of Energy. November 1998.

In its report, the Board offers its views on the direction of future scientific and technical research under way and planned by the DOE as part of its program for characterizing a site at Yucca Mountain, Nevada, as a potential repository for spent fuel and high-level radioactive waste. The Board discusses some of the remaining key scientific and technical uncertainties related to performance of a potential repository. The Board's report addresses some of these uncertainties by examining information about the proposed repository system presented to it in meetings and other technical exchanges. The Board considers and comments on some of the important connections between the site's natural properties and the current designs for the waste package and other engineered features of the repository.

Review of Material on Hydrothermal Activity. July 24, 1998.

This series of documents concerns the Board's review of material related to Mr. Jerry Szymanski's hypothesis of ongoing, intermittent hydrothermal activity at Yucca Mountain and large earthquake-induced changes in the water table there. The series includes a cover letter, the Board's review, and the reports of the four consultants the Board contracted with to assist in the review.

Report to the U.S. Congress and the Secretary of Energy: 1997 Findings and Recommendations. April 1998.

This report details the Board's activities in 1997 and covers, among other things, the DOE's viability assessment, due later this year; underground exploration of the candidate repository site at Yucca Mountain, Nevada; thermal testing under way at the site; what happens when radioactive waste reaches the water table beneath Yucca Mountain; transportation of spent

fuel; and the use of expert judgment. The Board makes four recommendations in the report concerning (1) the need for the DOE to begin now to develop alternative design concepts for a repository, (2) the need for the DOE to include estimates of the likely variation in doses for alternative candidate critical groups in its interim performance measure for Yucca Mountain, (3) the need for the DOE to evaluate whether site-specific biosphere data is needed for license application, and (4) the need for the DOE to make full and effective use of formally elicited expert judgment.

Report by letter to the Secretary of Energy and the Congress. December 23, 1997.

This report, in the form of a letter, addresses several key issues, including the DOE's viability assessment of the Yucca Mountain site, design of the potential repository and waste package, the total system performance assessment, and the enhanced characterization of the repository block (east-west crossing).

Report to the U.S. Congress and the Secretary of Energy. March 1997.

This report summarizes Board activities during 1996. Chapter 1 provides an overview of the Department of Energy's high-level nuclear waste management program from the Board's perspective, including the viability assessment, program status, and progress in exploration and testing. The chapter ends with conclusions and recommendations. Chapter 2 examines the three technical issues—hydrology, radionuclide transport, and performance assessment—and provides conclusions and recommendations. Chapter 3 deals with design, including the concept for underground operations, repository layout and design alternatives, construction planning, thermal loading, and engineered barriers. The Board also makes conclusions and recommendations. Chapter 4 provides an overview of recent Board activities, including the international exchange of information, the Board's visit to the River Mountains tunnel, and a presentation to the NRC. Appendices include information on Board members, the organization of the Board's panels, meetings held in 1996 and scheduled for 1997, the DOE's responses to previous Board recommendations, a list of Board publications, references for the report, and a glossary of technical terms.

Nuclear Waste Management in the United States—The Board's Perspective. June 1996.

This publication was developed from remarks made by Dr. John Cantlon, Chairman of the Nuclear Waste Technical Review Board, at Topseal '96, an international conference on nuclear waste management and disposal. The meeting was sponsored by the Swedish Nuclear Fuel and Waste Management Company and the European Nuclear Society. The publication highlights the Board's views on the status of the U.S. program for management and disposal of commercial spent nuclear fuel and provides a brief overview of the program's organization. It summarizes the DOE's efforts to characterize the Yucca Mountain site and to develop a waste isolation strategy for the site. The publication also outlines legislative and regulatory changes under consideration at that time and the Board's views on the technical implications of those possible changes.

Report to the U.S. Congress and the Secretary of Energy: 1995 Findings and Recommendations. April 1996.

This report summarizes Board activities during 1995. Chapter 1 provides an overview of the DOE's high-level waste management program, including highlights, current status, legislative issues, milestones, and recommendations. Chapter 2 reports on Board Panel activities and Chapter 3 provides information on new Board members, meetings attended, interactions with Congress and congressional staff, Board presentations to other organizations, interactions with foreign programs, and a review of the Board's report on interim storage of spent nuclear fuel. Appendices include Board testimony and statements before Congress, Board correspondence of note, and the Department of Energy's responses to recommendations in previous Board reports.

Disposal and Storage of Spent Nuclear Fuel—Finding the Right Balance. March 1996.

This special report caps more than two years of study and analysis by the Board into the issues surrounding the need for interim storage of commercial spent nuclear fuel and the advisability and timing of the development of a federal centralized storage facility. The Board concludes in the report that the DOE's efforts should remain focused on permanent geologic disposal and the site investigations at Yucca Mountain, Nevada; that planning for a federal centralized spent fuel storage facility and the required transportation infrastructure be begun now, but actual construction delayed until after a site-suitability decision is made about the Yucca Mountain site; that storage should be developed incrementally; that limited, emergency backup storage capacity be authorized at an existing nuclear facility; and that, if the Yucca Mountain site proves unacceptable for repository development, other potential sites for both centralized storage and disposal be considered.

Report by letter to the Secretary of Energy and the Congress. December 13, 1995.

This report, in the form of a letter, addresses the DOE's progress in underground exploration with the tunnel boring machine, advances in the development of a waste isolation strategy, new work on engineered barriers, and progress being made in performance assessment.

Report to the U.S. Congress and the Secretary of Energy: 1994 Findings and Recommendations. March 1995.

This report summarizes Board activities during 1994. It covers aspects of the DOE's Program Approach, their emerging waste isolation strategy, and their transportation program. It also explores the Board's views on minimum exploratory requirements and thermal-loading issues. The report focuses a chapter on the lessons that have been learned in site assessment from projects around the world. Another chapter deals with volcanism and resolution of difficult issues. The Board also details its observations from its visit to Japan and the Japanese nuclear waste disposal program. Findings and recommendations in the report centered around structural geology and geoengineering, hydrogeology and geochemistry, the engineered barrier system, and risk and performance analysis.

Report to the U.S. Congress and the Secretary of Energy. May 1994.

This report summarizes Board activities primarily during 1993. It reviews the nuclear waste disposal programs of Belgium, France, and the United Kingdom; elaborates on the Board's understanding of the radiation protection standards being reviewed by the National Academy of Sciences; and, using "future climates" as an example, examines the DOE's approach to "resolving difficult issues." Recommendations center on the use of a systems approach in all of The Office of Civilian Radioactive Waste Management's (OCRWM) programs, prioritization of site-suitability activities, appropriate use of total system performance assessment and expert judgment, and the dynamics of the Yucca Mountain ecosystem.

Letter Report to Congress and the Secretary of Energy. February 1994.

This report is issued in letter format due to impending legislative hearings on the DOE's fiscal year 1995 budget and new funding mechanisms sought by the Secretary of Energy. The 8-page report restates a recommendation made in the Board's Special Report, that an independent review of the OCRWM's management and organizational structure be initiated as soon as possible. Also, it adds two additional recommendations: ensure sufficient and reliable funding for site characterization and performance assessment, whether the program budget remains level or is increased, and build on the Secretary of Energy's new public involvement initiative by expanding current efforts to integrate the views of the various stakeholders during the decision-making process—not afterward.

Underground Exploration and Testing at Yucca Mountain: A Report to Congress and the Secretary of Energy. October 1993.

This report focuses on the exploratory studies facility (ESF) at Yucca Mountain, Nevada: the conceptual design, planned exploration and testing, and excavation plans and schedules. In addition to a number of detailed recommendations, the Board makes three general recommendations. First, the DOE should develop a comprehensive strategy that integrates exploration and testing priorities with the design and excavation approach for the exploratory facility. Second, underground thermal testing should be resumed as soon as possible. Third, the DOE should establish a geoengineering board with expertise in the engineering, construction, and management of large underground projects.

Special Report to Congress and the Secretary of Energy. March 1993.

The Board's report provides a nontechnical approach for those not familiar with the details of the DOE's high-level nuclear waste management program. It highlights three important policy issues: the program is driven by unrealistic deadlines, there is no integrated waste management plan, and program management needs improvement. The Board makes three specific recommendations: amend the current schedule to include realistic intermediate milestones; develop a comprehensive, well-integrated plan for the overall management of all spent nuclear fuel and high-level defense waste from generation to disposal; and implement an independent evaluation of the OCRWM organization and management. These recommendations should be implemented without slowing the progress of site-characterization activities at Yucca Mountain.

Sixth Report to the U.S. Congress and the U.S. Secretary of Energy. December 1992.

The Board's report begins by summarizing recent Board activities, congressional testimony, changes in Board makeup, and the Little Skull Mountain earthquake. Chapter 2 details panel activities and offers seven technical recommendations on the dangers of a schedule-driven program; the need for top-level systems studies; the impact of defense high-level waste; the use of high capacity, self-shielded waste package designs; and the need for prioritization among the numerous studies included in the site-characterization plans. In Chapter 3, the Board offers candid insights to the high-level waste management program in five countries, specifically those areas that might be applicable to the U.S. program, including program size and cost, utility responsibilities, repository construction schedules, and alternative approaches to licensing. Appendix F provides background on the Finnish and Swiss programs.

Fifth Report to the U.S. Congress and the U.S. Secretary of Energy. June 1992.

The Board's report focuses on the cross-cutting issue of thermal loading. It explores thermal-loading strategies (U.S. and others) and the technical issues and uncertainties related to thermal loading. It also details the Board's position on the implications of thermal loading for the U.S. radioactive waste management system. Also included are updates on Board and panel activities during the reporting period. The report offers 15 recommendations to the DOE on the following subjects: ESF and repository design enhancements, repository sealing, seismic vulnerabilities (vibratory ground motion and fault displacement), the DOE approach to the engineered barrier system, and transportation and systems program status.

Fourth Report to the U.S. Congress and the U.S. Secretary of Energy. December 1991.

The Board's report provides update on the Board's activities and explores in depth the following areas: ESF construction; test prioritization; rock mechanics; tectonic features and processes; volcanism; hydrogeology and geochemistry in the unsaturated zone; the engineered barrier system; regulations promulgated by the EPA, the NRC, and the DOE; the DOE performance assessment program; and quality assurance in the Yucca Mountain project. Ten recommendations are made across these diverse subject areas. Chapter 3 offers insights from the Board's visit with officials from the Canadian nuclear power and spent fuel disposal programs. Background on the Canadian program is in Appendix D.

Third Report to the U.S. Congress and the U.S. Secretary of Energy. May 1991.

The Board's report briefly describes recent Board activities and congressional testimony. Substantive chapters cover exploratory shaft facility alternatives, repository design, risk-benefit analysis, waste package plans and funding, spent fuel corrosion performance, transportation and systems, environmental program concerns, more on the DOE task force studies on risk and performance assessment, federal quality assurance requirements for the repository program, and the measurement, modeling, and application of radionuclide sorption data. Fifteen specific recommendations are made to the DOE. Background information on the German and Swedish nuclear waste disposal programs is included in Appendix D.

Second Report to the U.S. Congress and the U.S. Secretary of Energy. November 1990.

The Board's report begins with the background and framework for repository development and then opens areas of inquiry, making 20 specific recommendations concerning tectonic features and processes, geoengineering considerations, the engineered barrier system, transportation and systems, environmental and public health issues, and risk and performance analysis. The report also offers concluding perspectives on DOE progress, the state of Nevada's role, the project's regulatory framework, the nuclear waste negotiator, other oversight agencies, and the Board's future plans.

First Report to the U.S. Congress and the U.S. Secretary of Energy. March 1990.

The Board's report sets the stage for the Board's evaluation of the DOE program to manage the disposal of the nation's spent fuel and high-level waste. The report outlines briefly the legislative history of the nation's spent fuel and high-level waste management program including its legal and regulatory requirements. The Board's evolution is described, along with its protocol, panel breakdown, and reporting requirements. The report identifies major issues based on the Board's panel breakdown, and highlights five cross-cutting issues.

Appendix E
U.S. Nuclear Waste Technical Review Board Correspondence with U.S. Department of Energy

In addition to published reports, the Board periodically writes letters to the Director of the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM). The letters typically provide the OCRWM with the Board's views on specific technical areas earlier than do Board reports. The letters are posted on the Board's Web site after they have been sent to the OCRWM. For archival purposes, the six Board letters written during the period covered by this report are reproduced here.

The OCRWM typically responds to the Board's reports and letters, indicating its plans to respond to the Board's recommendations. Included here are the OCRWM's responses received by the Board during calendar year 2004 and early 2005. Inclusion of these responses does not imply the Board's concurrence.

- Letter from Mark Abkowitz, Chair, Panel on the Waste Management System, to Margaret S. Y. Chu, Director, OCRWM; March 29, 2004.
  Subject: DOE's participation at the Panel on the Waste Management System meeting held January 21, 2004

- Letter from Ronald M. Latanision, Chair, Panel on the Engineered System, to Margaret S. Y. Chu, Director, OCRWM; April 5, 2004.
  Subject: DOE's participation at Panel on the Engineered System meeting held March 9–10, 2004

- Letter from Richard N. Parizek, Chair, Panel on the Natural System, to Margaret S. Y. Chu, Director, OCRWM; May 3, 2004.
  Subject: DOE's participation at Panel on the Natural System meeting held January 20, 2004

- Letter from Margaret S. Y. Chu, Director, OCRWM, to David J. Duquette, Chair, Executive Committee; May 17, 2004.
  Subject: DOE's responses to recommendations in the December 16, 2003 letter

- Letter from Margaret S. Y. Chu, Director, OCRWM, to Mark Abkowitz, Chair, Panel on the Waste Management System; May 28, 2004.
  Subject: DOE's responses to recommendations in the March 29, 2004 letter

- Letter from Margaret S. Y. Chu, Director, OCRWM, to Ronald M. Latanision, Chair, Panel on the Engineered System; July 21, 2004.
  Subject: DOE's responses to recommendations in the April 5, 2004 letter

- Letter from David J. Duquette, Chair, Executive Committee, to Margaret S. Y. Chu, Director, OCRWM; July 28, 2004.
  Subject: DOE's participation at the May Board meeting

- Letter from Margaret S. Y. Chu, Director, OCRWM, to Richard N. Parizek, Chair, Panel on the Natural System; September 10, 2004.
  Subject: DOE's responses to recommendations in the May 3, 2004 letter

- Letter from B. John Garrick to Margaret S. Y. Chu, Director, OCRWM; November 30, 2004.
  Subject: DOE's participation at the September Board meeting

- Letter from B. John Garrick to Margaret S. Y. Chu, Director, OCRWM; December 1, 2004.
  Subject: DOE's participation at the Panel on the Waste Management System meeting held October 13–14, 2004

- Letter from Margaret S. Y. Chu, Director, OCRWM, to B. John Garrick; January 26, 2005.
  Subject: DOE's responses to recommendations in the July 28, 2004 letter

- Letter from Margaret S. Y. Chu, Director, OCRWM, to B. John Garrick; February 1, 2005.
  Subject: DOE's responses to recommendations in the December 1, 2004 letter

- Letter from Theodore J. Garrish, Deputy Director, OCRWM, to B. John Garrick; March 31, 2005.
  Subject: DOE's responses to recommendations in the November 30, 2004 letter

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

March 29, 2004

Dr. Margaret S. Y. Chu
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Chu:

Thank you for the Department of Energy's (DOE) support of our January 21 panel meeting on transportation strategic planning. Now that the DOE has received significant funding to develop a transportation system for Yucca Mountain, we anticipate that updates on progress in this area may become a regular feature of our future Board meetings. We also anticipate holding additional panel meetings devoted solely to transportation on a regular basis.

At the January 21 meeting, we heard that there has been significant experience in transporting spent fuel and similar materials safely, both in the United States and abroad, and that the planning and operational issues related to the movement of those materials can readily be identified. Because a Yucca Mountain transportation system would be substantially larger than those used for many previous shipping campaigns in the United States, the challenges in developing such a transportation system and operating it safely and efficiently become magnified. From that perspective, we offer the following comments on information presented at the January 21 meeting.

- The Board believes that proper transportation planning for meeting a 2010 operational start-up is a large and ambitious task. This observation is based on both the current status of Yucca Mountain project transportation planning and a retrospective view of the Waste Isolation Pilot Plant (WIPP) transportation planning and implementation. Consequently, proper strategic planning is vital at this time. Although the release of the DOE's initial strategic plan in November 2003 is commendable, the Board feels that the plan lacks the necessary detail for truly understanding the DOE's intentions and awareness of the complexity and scale of transportation planning. The Board recommends that the DOE develop and produce a Gantt chart (or its equivalent) showing the schedule for transportation planning activities according to each activity's scope, duration, resources required, and relationship to other activities. This will enable the DOE to demonstrate that a systematic approach to transportation planning is being undertaken, identify the activities that are anticipated to occur in sequence or in parallel, and acknowledge what constitute critical-path activities.

- The Board cannot stress enough the importance of collaboration and communication with a diverse set of transportation stakeholders—early and often. This set includes stakeholders at all levels of government. Although the Board believes that the DOE's resumption of transportation planning discussions with regional government organizations represents a positive step, that is not a substitute for the need to engage in constructive dialogue with individual states and affected units of local government. Marginalizing these relationships will not only make the DOE appear disingenuous but will also become problematic when the DOE requests the future cooperation of these entities (e.g., permitting).

- The Board sees waste acceptance emerging as a key strategic planning consideration. There is a compelling need for the DOE and the utility industry to clarify the interpretation of current contract provisions regarding the type of spent fuel that can be shipped and the timetable for doing so, as well as to negotiate any changes to these provisions to satisfy both DOE and utility shipping concerns. Absent these clarifications and negotiations, cask requirements and transport logistics that are compatible with the waste to be shipped will be a formidable, if not impossible, task to define. Although the Board understands that the DOE and the utility industry have been reluctant to discuss these issues because of pending litigation, the Board encourages the DOE to seek a method for facilitating such an exchange, perhaps through the use of an objective, unbiased third party.

- A complete and accurate inventory of rail, truck, and barge access/egress infrastructure for each nuclear power plant and corresponding site interfaces is a critical-path element in the transportation planning process that the DOE needs to address. The feasibility of certain modes for servicing specific facilities and the resources required to upgrade the infrastructure to meet safety and security standards will be important determinants in mode and route decisions as well as in scoping the financial requirements for operating such a system.

- Cask procurement can be a lengthy and expensive activity, especially given the design, testing, certification, and fabrication requirements associated with the production of new cask types. Before the launching of a full-scale development program, the Board advises the DOE to conduct a thorough review of waste inventory and acceptance assumptions; anticipated shipment schedules; the ability to utilize existing cask designs and the flexibility inherent in new designs to handle anticipated waste types, modes, and volumes; interface with the Yucca Mountain surface facility; and effects on ancillary transportation equipment design.

- The DOE should not underestimate its use of truck transport of spent nuclear fuel and high-level radioactive waste, irrespective of whether rail is designated as the primary transport mode. With heavy-haul and super-heavy-haul shipments under consideration, obtaining permits, upgrading or expanding lanes on roadways, and providing enhanced security are just a few of the issues that will need to be addressed. These challenges will be exacerbated by the total reliance on trucking for the final portion of any shipment if

the Yucca Mountain project decides to receive waste shipments before a rail spur into the facility is available.

- For satisfying post-9/11 public expectations, security planning needs to be explicitly considered as part of a comprehensive transportation risk management process. The DOE should give serious consideration to adopting U.S. Nuclear Regulatory Commission security requirements, which a concerned public may view as more effective than similar DOE requirements.

- Emergency response capability is seen by states and local communities as a vital component of shipment safety and security because it ensures that they can participate in protecting the public if a transportation incident occurs. Given that the WIPP transportation program worked with states for seven years to develop community relationships and provide emergency response training before the first shipment, and on the basis of estimates from various counties of the emergency response planning and training resources required, the DOE will need to demonstrate that adequate preparatory time and financial resources will be available.

- The Board observes that the DOE can draw on considerable operational experience on how to transport nuclear waste safely. This is evidenced by previous and ongoing campaigns involving WIPP, foreign research reactor fuel, naval spent fuel, and West Valley spent fuel. However, no formal integration of transportation activities within the agency appears to be taking place. The Board encourages the DOE to establish such a mechanism, perhaps by reestablishing its Senior Executive Transportation Forum.

Thank you again for the DOE's support of our meeting.

Sincerely,

{Signed By}

Mark Abkowitz, Chair
Panel on the Waste Management System

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

April 5, 2004

Dr. Margaret S. Y. Chu
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Chu:

The Board's Panel on the Engineered System held a meeting January 20, 2004, in Las Vegas. The theme of the meeting was "Repository Design Update." There were nine presentations at the meeting: five by the staff of your Office of Repository Development, one by a representative of your Office of Strategy and Program Development, two by a representative of Nye County, and one by a representative of the Nuclear Energy Institute. In addition, representatives of OCRWM's Management and Operating Contractor, BSC, were present at the meeting to answer questions. The purpose of this letter is to thank you again for the participation in the meeting by you, your staff, and your contractor and to provide the following Board feedback from the meeting.

- As described at the meeting, the design of the repository surface facilities includes temporary storage for up to 40,000 metric tons of spent fuel. We understand that the current plan is to construct only 1,000 metric tons of storage capacity and that additional storage would be constructed only as needed and only to the extent needed. We also understand that the DOE intends that the entire 40,000 metric tons of storage capacity will be included in the license application. The technical justification for a 40,000 metric ton storage facility is unclear. As pointed out in BSC's February 2002 "Thermal Operating Modes" white paper, a larger surface facilities area with a pad for extended surface aging could affect the analysis of aircraft-crash hazard. The Board recommends that the technical justification for such a large storage facility be explained.

- The Board understands that BSC recently awarded a fixed-price contract to build the first full-scale waste-package prototype. We believe that the technical information obtained during the course of performance of this contract will be very important, and we agree that more waste-package prototypes are needed. We understand that the reasons for building prototypes include reasons other than obtaining technical information. However, we would like more explanation about the technical information that will be obtained by the current plan to build 14 more prototypes.

- While not unprecedented, the stainless-steel perforated plate and stainless-steel bolt system proposed as the ground-support system for emplacement drifts is highly unusual and expensive. We would like to learn more about the technical basis for the selection of stainless steel as the material of construction, particularly for the perforated plate. We also would like to know which other materials were considered for ground support and the technical bases for their rejection. We understand that the emplacement-drift ground-support system is designed for a preclosure service life of 100 years and "not to preclude" a preclosure period of up to 300 years. We would like a description of the planned inspection and maintenance activities — including a description of how those activities would be conducted — for both the first 100 years and the subsequent 200 years.

- The Board notes that changes have been made in the subsurface repository design to increase the radius of each emplacement drift turnout and to move the ventilation control door to the outer end of each turnout. These changes will affect postclosure waste-package temperatures, particularly the temperatures of packages close to the turnouts. In addition, these changes are likely to exacerbate "cold trap" effects near and in the turnouts. We strongly recommend that temperature and relative humidity calculations be revised to reflect the design changes, if that has not been done already.

- The Nye County work on the evolution of chemistry in the engineered barrier system and on the topic of natural ventilation is very interesting. These topics are important because they influence both waste-package corrosion and transport from the engineered barrier system. It is clear that the environment in drifts is not a quasi-static or slowly changing one but a dynamic one driven in part by temperature differences among waste packages and along the drifts. Such differences will always exist but will be greater during the thermal pulse period. A repository at Yucca Mountain will have some degree of natural ventilation or natural circulation regardless of whether it is deliberately engineered into the repository design or not. Models for temperature and relative humidity predictions must take these natural processes into account fully.

We would like to thank you again for your participation in the meeting and for the assistance of your staff in preparing for the meeting. We particularly appreciate the technical coordination assistance provided by Claudia Newbury and the excellent presentations on repository design by Paul Harrington.

Sincerely,

{Signed By}

Ronald M. Latanision
Chair, Panel on the
Engineered System

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

May 3, 2004

Dr. Margaret S. Y. Chu
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Chu:

On behalf of the Nuclear Waste Technical Review Board's Panel on the Natural System, I would like to express our appreciation to you and to the rest of the Yucca Mountain Project team for participating in our March 9-10, 2004, meeting in Las Vegas and for the subsequent Board field trip to Yucca Mountain on March 11. The purpose of the meeting and field trip was to investigate the fundamental scientific and technical basis for estimates of the potential performance of the natural barriers to radionuclide transport under conditions not disturbed by repository heating. The presentations at the meeting were clear, substantive, and helpful. The Board's observations and recommendations from the meeting are presented below.

Increasing Fundamental Understanding

Field and laboratory observations and analyses presented by the Department of Energy (DOE) and others suggest that the natural system provides an effective barrier to migration of some radionuclides over time periods that may be comparable to the regulatory period. However, several key hydrogeologic features or processes that may significantly affect fluid flow and radionuclide transport are presently not well understood, are constrained by limited or poor data, or both.

The DOE often deals with uncertain features and processes by making conservative estimates of their effects on radionuclide transport. Such conservativisms regarding the performance of the natural system tend to emphasize more-rapid advective transport processes. More realistic estimates that might arise from further evaluation of some features and processes could lead to slower transport predictions for some radionuclides. However, there is a possibility that some other poorly understood features or processes may lead to faster radionuclide transport. Therefore, it is important that the DOE develop a better fundamental understanding of the overall behavior of the natural system.

In the following paragraphs, the Board identifies some areas where additional work might increase basic understanding, narrow the wide range of predicted radionuclide transport times, and increase confidence in predictions of the performance of the natural barriers. An enhanced

technical basis for the performance of the natural barriers is an important part of an overall repository strategy that uses multiple barriers to provide defense-in-depth.

Technical and Scientific Recommendations

Increases in fundamental understanding of the behavior of the natural system could result from scientific investigations conducted in the following three areas. First, although the hydraulic properties of major block-bounding faults, such as the Solitario Canyon fault, never have been field-tested, it seems clear that these faults can influence fluid flow and radionuclide transport substantially. Large-scale hydraulic tests of those major faults are therefore needed. Second, improvements in the characterization of the spatial distribution and sedimentary architecture of the saturated alluvium could substantially enhance fundamental understanding of groundwater flow and radionuclide transport along Fortymile Wash south of Yucca Mountain. For example, the recent sonic log drilled by Nye County is an excellent source of data for supporting studies of sorption of radionuclides in alluvial sediment; additional logs from locations where uncertainties are high have the potential to yield similar benefits. Deeply weathered cobbles from that geologic log suggest the potential for delays in radionuclide transport due to diffusion that could be demonstrated if the DOE conducts field-scale long-term tracer studies (for example, at the Alluvial Testing Complex). These studies should be done. Third, depending on rock properties such as fracture frequency and thin coatings on the fracture faces, matrix diffusion could either increase or decrease current estimates of radionuclide transport time by thousands of years. For this reason, a better empirical basis for predicting matrix diffusion is needed.

Three other areas — colloid-facilitated transport, the active fracture modeling approach, and boundary fluxes on the site-scale saturated zone model — are significant elements of DOE analyses that have substantial unresolved uncertainty. First, evidence from a nuclear weapons test site suggests that some water-borne colloids can lead to rapid radionuclide transport in the saturated zone. Laboratory and computer studies conducted by the DOE show that other colloids might substantially slow radionuclide migration. Consequently, understanding of this phenomenon should be improved by field, laboratory, and modeling studies. Second, for unsaturated zone fluid flow and radionuclide transport, predictions are influenced significantly by assumptions inherent in the formulation of the active fracture model (AFM). The AFM needs to be tested and evaluated to establish a technical basis for using this approach. Third, in the saturated zone, the technical basis for the DOE's site-scale flow model would be stronger if the model were more consistent with the most recent regional model calculations of flow across the site-scale model boundaries. Updating the DOE's model on the basis of these calculations could affect predictions of radionuclide transport times.

Multiple Lines of Evidence

The Board continues to believe that an integrated explanation is needed of how elements of the repository act as a system to isolate waste. Such an explanation should rest on a fundamental understanding of the system as discussed in previous paragraphs and on multiple lines of evidence. 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 Peña Blanca analogue site in Chihuahua, Mexico, having many similarities to Yucca Mountain, provides a good opportunity to evaluate, for example, whether consideration of secondary mineralization

processes may reduce overall system dose estimates substantially and what effect alpha decay of radionuclides in minerals may have on mobility. The Board commends the Science and Technology program for its plans to test Yucca Mountain modeling approaches at the Peña Blanca analogue site. Naturally occurring radioisotopes at Yucca Mountain provide another valuable line of evidence for flow and transport. Additional isotopic data, such as carbon-14 measurements, collected from discrete zones in the flow path from Yucca Mountain, could be used to test and evaluate DOE models and predictions and to constrain recharge rates in the model domain. In summary, the validity of model forecasts can be evaluated better in the presence of a list of independent physical and chemical lines of evidence that support or challenge the forecasts.

Concluding Comments

At a May 2002 meeting of the Board, you stated your intention to devote attention to aspects of the natural system, and we are encouraged by your interest in this important work. Observations during our field trip to Yucca Mountain demonstrated two things in particular: (1) better understanding 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. The Board believes strongly that the important work you have done in this area should be continued.

Again, we thank you, your staff, and your scientists very much for an excellent meeting and field trip.

Sincerely,

Richard R. Parizek
Chair, Panel on the Natural System

Department of Energy
Washington, DC 20585

May 17, 2004

David J. Duquette, Ph.D.
Acting Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, VA 22201-3367

Dear Dr. Duquette:

We have received the December 16, 2003, letter from the Nuclear Waste Technical Review Board (Board) providing the Board's initial reactions to the information presented by the U.S. Department of Energy (DOE) at the Board's September 2003 meeting in Amargosa Valley, Nevada. The DOE's responses to the views expressed by the Board are provided in the enclosure to this letter.

The DOE appreciates the Board's continuing review of our activities as we work to complete the analyses and documentation to support the license application for a repository at Yucca Mountain, Nevada, scheduled to be completed in December.

Sincerely,

Margaret S.Y. Chu, Ph.D.
Director
Office of Civilian Radioactive
Waste Management

Enclosure

U.S. Department of Energy Responses to Observations from the Nuclear Waste Technical Review Board on the September 2003 Full Board Meeting

Issues Relating to Natural Characteristics of Yucca Mountain

1. Igneous scenarios.

According to the DOE's estimates, igneous scenarios may dominate the risk to humans from a Yucca Mountain repository. To date, it appears that the DOE intends to pursue only one of the three recommendations made by the Board in its June 30, 2003, letter—study of aeromagnetic anomalies near the Yucca Mountain site. The Board repeats its recommendation that the DOE also conduct modeling studies of compressible fluids and studies of waste package-magma interaction and waste entrainment.

Response:

Further to our letter of October 10, 2003, the Department of Energy (DOE) has evaluated the Board's recommendations to conduct modeling of compressible fluids and studies of waste package-magma interaction and waste entrainment. A model is being developed to bound the behavior of magma flow within a fissure and within a drift. This modeling would also address the likelihood of a "dog-leg" occurring under these bounding flow conditions, and the sustainability of a "dog-leg."

The DOE acknowledges that additional analyses and laboratory and field experiments could lead to a better understanding of the effects of waste package-magma interaction and waste entrainment in magma. It may be possible to gain some insights from experiments and analyses that could be performed over the next couple of years. These analyses and experiments, if conducted, would be used to build confidence in our conclusions and would not be included in our Total System Performance Assessment for the License Application. These analyses and experiments could lead to a reduction in uncertainties associated with waste package-magma interaction.

2. Enhanced borehole studies.

As plans are developed for drilling aeromagnetic anomalies near Yucca Mountain, the Board encourages the DOE to consider additional development of those boreholes as monitoring wells to obtain hydraulic head, water chemistry, and related hydrogeologic data at relatively small additional cost. Additional hydrogeologic data from these areas may resolve differing hypotheses regarding the direction of water flow in the saturated zone and may provide additional information about the ability of the saturated zone to function as a barrier to migration of radioactive materials.

Response:

The DOE agrees that collection of additional hydrologic data is worthy of consideration in those cases where the boreholes are within or adjacent to flow paths from the Yucca Mountain repository to the compliance boundary. The DOE will evaluate the possibility of completing those boreholes as monitoring wells in order to collect hydrologic information if the water table is encountered. The additional cost to construct wells may not be small because the DOE would have to increase the diameter of the holes and install surface and/or intermediate casing in addition to the completion string. Well development via pumping would also be required to prepare the wells for water level measurement and water sample collection. In addition, obtaining permits from the State of Nevada to pump from such wells has not been successful.

Based on the information currently available, additional hydrologic data from drilling the anomalies in the Crater Flat area would not appear to be relevant to assessing radionuclide migration from the Yucca Mountain repository to the compliance boundary. The DOE does not intend to complete any of these holes as monitoring wells, but will record the approximate depth to water if the water table is encountered. We will continue to share our plans with the Board as those plans are developed.

3. Chlorine-36.

The Board encourages the DOE to resolve discrepancies in chlorine-36 studies and agrees with the decision to commission a third-party review that includes integrated chlorine-36 and other bomb-pulse data to help address inconsistencies. Such an integrated methodology should include the measurement of tritium. If an accepted integrated methodology could be developed, it could enhance understanding of hydrogeologic controls on fast-path flows into the repository and yield a conceptual model consistent with both chlorine-36 and other bomb-pulse data. The Board believes that resolving chlorine-36 discrepancies will require a "root cause" analysis that lays out each step in the procedure, how the discrepancies were addressed by each of the two analytical groups, and what each set of measurements has in common as well as what differences exist and the potential reasons for these differences and actions for resolving them.

Response:

The DOE appreciates the Board's support of our third party approach, utilizing researchers from the University and Community College System of Nevada (UCCSN), to continue the Cl-36 work and the general approach of using a suite of bomb-pulse isotopes (Cl-36, I-129/127, and Tc-99).

The DOE notes the Board's recommendation that tritium measurements be included as part of the integrated approach. Additional tritium measurements are not part of the UCCSN Cl-36 study; however, the U.S. Geological Survey – Los Alamos National Laboratory (USGS-LANL) Cl-36 validation team and the UCCSN team will evaluate the tritium data in concert with the other isotopic data with the goal of developing a conceptual model consistent with all of the data. The DOE also notes the Board's recommendation that resolving the discrepancies will require

a "root cause" analysis. The summary report being developed by the USGS-LANL Cl-36 validation team will contain a discussion that lays out potential "root causes" for the Cl-36 discrepancies. In addition, the methodology and approach outlined by the UCCSN researchers has a reasonable chance of satisfactorily resolving the discrepancies and getting at the root cause. Interested members of the Board and staff are invited to the quarterly meetings on Cl-36 at University of Nevada in Las Vegas to participate in the discussions and offer their opinions and insights. The DOE will keep the Board informed of the schedule for quarterly meetings and of significant developments resulting from the Cl-36 study.

Issues Relating to Potential Waste Package Corrosion

1. Microbial activity.

Decreasing nitrate concentrations with depth, as shown in one of Bo Bodvarsson's slides, suggest microbial activity. A waste package design that relies on nitrate to reduce the likelihood of localized corrosion must take into account the effects of microbial activity on nitrate concentrations both before and during the thermal pulse.

Response:

The DOE agrees that a waste package design that relies on nitrate to reduce the likelihood of localized corrosion must take into account the potential effects of microbial activity on nitrate concentrations. Decreasing nitrate concentrations with depth in one borehole, SD-9 (Slide 22, Bodvarsson and Tsang 2003[1]), have alternative explanations, such as complex hydrologic structure, spatial variability within single hydrologic units, pore water chemistry record of temporal changes, or microbial denitrification. For example, the profile of water compositions sampled with depth, such as that from borehole SD-9, is likely influenced by pre-Holocene hydrologic conditions. The concentration of chloride decreases significantly below the non-welded PTn unit, which has been interpreted, using chloride mass balance relationships, to show that more recent infiltration is more concentrated. The deposition and production of nitrate near the ground surface were likely limited during pre-Holocene conditions, similar to the deposition of chloride. The DOE will update the Board on the evaluation of nitrate inventory in the unsaturated zone at future Board meetings.

2. Gas pressure.

The maximum temperature at which brines can exist on waste package surfaces is a strong function of gas pressure. Elevated pressures allow brines to exist at higher temperatures, increasing the likelihood that corrosion will be initiated. Even transient elevated pressures could be important. The DOE should provide a careful and complete explanation of gas pressures during the thermal pulse within the drift environment.

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[1] Bodvarsson, Gudmundur and Tsang, Yvonne 2003. *Flow and Transport in the Unsaturated Zone*. Presentation to the Nuclear Waste Technical Review Board, September 16, 2003.

Response:

Gas pressure within the emplacement drifts is expected to increase only a few tens of pascals during the thermal period, an increase that will have only negligible effect on the temperature range of aqueous solution stability. Athough the 2-D coupled process models generally show a pressure increase of one- or two-hundred pascals, this artifact almost disappears when the "near-infinite" equivalent permeability of the drifts is considered within 3-dimensional models. In the more realistic 3-D models, the pressure rise is generally only a few tens of pascals.

This very small pressure increase (tens of pascals) is negligible for all practical purposes. The pressure rise is due to boiling in the rock matrix blocks close to the drifts and the very small limitations on the overall capacity of the system to move the increased mass of gas away from the source (i.e., similar to the pressure increase that forces the generated steam to flow from the rock matrix into adjacent fractures). The gas pressure is also slightly elevated in the fractures, and this slight pressure increase propagates into the emplacement drifts as an imposed condition of the geosphere within the boiling zone. Some of the steam flows from the fractures into the drifts, and this causes a significant reduction in the mass fraction of air in the gas phase within the drifts. The slight pressure increase within the emplacement drifts goes away near the end of the thermal period, after about 1,000 years.

The pressure increases given above are miniscule compared to the ambient pressure at the site and have negligible effect on the boiling point of water. Such temperature adjustments are minor compared to the effect on boiling temperature due to the elevation of the repository. A pressure increase of 10 pascals is one-ten thousandth of a bar. The site elevation is such that it is at an ambient pressure of roughly 0.9 bar. This represents a decrease of one-tenth bar, and it produces a drop of about 4°C in the boiling point of water[2]. Given that the pressure changes we are discussing are about 1/1000 of this elevation related pressure difference, the temperature effect on the boiling point is roughly 0.004°C, which is clearly much smaller than the uncertainty on temperatures in post closure. Similarly, such a slight pressure increase is negligible relative to its ability to raise the boiling temperature of aqueous solutions (or conversely the deliquescence temperature of brines).

Issues Relating to Management and Communication

1. Quality/schedule tradeoffs.

The Board appreciates John Arthur's assurance that the license application schedule is not constraining the quality of work within the Yucca Mountain project. The Board strongly agrees with the DOE that a license application should be filed only when appropriate quality standards have been met. A schedule-driven approach to quality management can potentially compromise

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[2] BSC (Bechtel SAIC Company) 2002. *Thermal Testing Measurements Report.* ANL-NBS-HS-000041 REV 00. Las Vegas, Nevada: Bechtel SAIC Company.

the safety culture surrounding the preparation of the license application, thereby making the project vulnerable to poor decision-making. The Board emphasizes the importance and inherent long-term efficiency in "taking the time to do it right."

Response:

The DOE agrees that a license application should only be filed when the appropriate quality standards have been met. The DOE will not submit a license application to the U.S. Nuclear Regulatory Commission (NRC) until we are satisfied that we have met the necessary quality and regulatory requirements.

2. Repository performance confirmation.

With an operational period that may extend beyond repository closure, it appears that performance confirmation may be a component of the DOE's proposed radioactive waste disposal system that will span licensing, construction, and possibly operation. Thus, performance confirmation holds the possibility of enhancing confidence in repository prediction not only by "confirming" DOE models but also by testing the underlying conceptual, physical, and mathematical bases of those models. The Board encourages the DOE to have a clear understanding of what it means by performance confirmation and integrate it thoroughly with performance assessment and repository design. This includes the need to establish formal management practices that ensure that appropriate interactions occur between these system components. Moreover, the Board believes that the performance confirmation program can benefit significantly from the input of the interested public and affected parties.

Response:

The Board is correct in noting that the performance confirmation program will continue through initial licensing, repository construction, and repository operation until permanent closure. The program must satisfy NRC licensing requirements in 10 CFR Part 63[3], including the requirement to continue performance confirmation testing until permanent closure.

The DOE's license application will provide sufficient information to enable NRC to reach a finding that there is reasonable expectation that waste can be disposed at the repository without unreasonable risk to the health and safety of the public. If the NRC authorizes construction of a repository at Yucca Mountain, the performance confirmation program will continue, focusing on testing the adequacy of assumptions, data, and analyses presented in the license application to support the NRC reasonable expectation finding.

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[3] 10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available.

10 CFR Part 63 specifies the types of testing required for performance confirmation, including tests to evaluate:

- Subsurface conditions, including geotechnical and design parameters
- Functions of the natural and engineered barriers
- Waste package condition
- Effectiveness of any design features added after construction authorization, such as borehole seals

Additional testing may be undertaken to enhance confidence in repository performance by testing the underlying conceptual, physical, and mathematical bases of models.

The DOE's formal management procedures will ensure appropriate integration of the performance confirmation program with performance assessment and repository design.

3. Program integration and communication.

The Board believes that the technical basis documents being developed for the Yucca Mountain Project have significant potential for improving program integration and enhancing program communication with the wider technical community as well as the general public. For gaining the maximum benefit from these documents, integrating their most important conclusions into a concise description of the safety case for a Yucca Mountain repository will be important. However, if the documents are not well integrated or if they contain technical errors, then communication of the safety case to the broad scientific and public audiences will be weakened. Where appropriate, the discussion of relevant analogs can be used as a line of evidence and enhance the DOE's communication.

Response:

The DOE appreciates that the Board recognizes the potential of the technical basis documents both in enhancing technical integration, and in informing the wider scientific community as well as the general public. The DOE also agrees that the most important conclusions need to be integrated into a concise description of the performance of the repository system in the postclosure timeframe. Chapter 2 of the Safety Analysis Report in the license application will include a comprehensive discussion of the technical basis for the evaluation of postclosure performance. The technical basis will be supported by relevant analogs when appropriate. The DOE will draw on the technical basis documents along with other technical references in developing this chapter of the Safety Analysis Report. This chapter will include a concise overview of repository safety after permanent closure, including a description of the multiple barriers that contribute to postclosure performance of the repository.

The DOE has scheduled in-depth reviews of the technical conclusions that will be provided in the license application. These reviews will focus on quality and integration of the technical basis for the conclusions on the postclosure performance of the repository system.

The DOE recognizes that a broad-audience document that presents a clear description of the safety case would be desirable. Its function would be to explain to non-specialists why we

believe that there is a basis for confidence in the safety of the proposed system. Such a document is being considered, but its production must await the content of the license application, to assure that the two documents are consistent and to avoid any confusion as to the DOE's position.

Department of Energy
Washington, DC 20585
MAY 2 8 2004

Dr. Mark Abkowitz
Chairman
Panel on the Waste Management System
United States Nuclear Waste Technical
Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

Dear Dr. Abkowitz:

Thank you for your March 29, 2004, letter in which you provided comments on information presented by the Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM). That information was presented during the January 21, 2004, Waste Management System Panel Meeting on transportation strategic planning.

We appreciate your interest in OCRWM's approach to transportation planning. Your questions regarding interaction with stakeholders, waste acceptance, transportation infrastructure and interfaces, cask procurement, security planning, emergency preparedness, and operational lessons learned from previous and ongoing DOE shipment campaigns are all important. We are incorporating many of your comments and concerns as we continue to develop the transportation system.

Some of the issues you've raised are being addressed in a comprehensive fashion currently. Others will be addressed comprehensively after critical milestones are achieved that support subsequent detailed planning. We believe our discussions during the Board's Spring Meeting in Washington, D.C., on May 18-19, 2004 were useful for us, and hope you found them helpful as well. We believe that our presentation at that meeting described the areas where we are able to do detailed planning, as well as the areas where we are managing to milestones prior to having detailed project scope, schedules and resources identified. We believe those discussions addressed most of the comments made in your letter. As we proceed with our planning for transportation, we will be interested in the Technical Review Board's views on the technical issues we will be addressing.

OCRWM places a great emphasis on working with our stakeholders, including the Technical Review Board, collaboratively throughout the planning process. We are looking forward to more productive discussions at the fall Transportation Panel Meeting in Salt Lake City. In the meantime, please contact Gary Lanthrum, my transportation Office Director, to discuss that meeting, or other technical aspects of transportation system development.

Sincerely,

Margaret S.Y. Chu, Ph.D.
Director
Office of Civilian Radioactive
Waste Management

Department of Energy
Washington, DC 20585

QA: N/A

July 21, 2004

Ronald M. Latanison, Ph.D.
Chair, Panel on the Engineered System
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, VA 22201-3367

Dear Dr. Latanison:

Thank you for your letter of April 5, 2004, providing the Nuclear Waste Technical Review Board's (Board) response to the information presented by the U.S. Department of Energy (Department) on repository design at the January 20, 2004, meeting of the Board's panel on the engineered system. The Department appreciates the Board's continuing review of our activities as we work to develop and document the technical basis for the License Application for a repository at Yucca Mountain, Nevada. Our responses to the Board's views and recommendations are summarized in the enclosure to this letter.

The Department continues to benefit from the constructive views of the Board, and we look forward to further dialog on our repository design and related issues.

Sincerely,

Margaret S.Y. Chu, Ph.D.
Director
Office of Civilian Radioactive
Waste Management

Enclosure:
U.S. Department of Energy (Department) Responses to the April 5, 2004, Letter from the Nuclear Waste Technical Review Board (Board)

Ronald M. Latanison, Ph.D. -2-

bcc w/encl:
L. J. Desell, DOE/HQ (RW-1), FORS
T. E. Kiess, DOE/HQ (RW-40E), FORS
Richard Goffi, BAH, Washington, DC
J. T. Mitchell, Jr., BSC, Las Vegas, NV
J. N. Bailey, BSC, Las Vegas, NV
CMS Coordinator, BSC, Las Vegas, NV
M. W. Pendleton, BSC, Las Vegas, NV
N. H. Williams, BSC, Las Vegas, NV
W. J. Arthur, III, DOE/ORD (RW-2W), Las Vegas, NV
W. J. Boyle, DOE/ORD (RW-40W), Las Vegas, NV
J. R. Dyer, DOE/ORD (RW-2W), Las Vegas, NV
A. V. Gil, DOE/ORD (RW-40W), Las Vegas, NV
C. M. Newbury, DOE/ORD (RW-40W), Las Vegas, NV
K. W. Powers, DOE/ORD (RW-2W), Las Vegas, NV
P. F. Sanchez-Bartz, DOE/ORD (RW-2W), Las Vegas, NV
J. D. Ziegler, DOE/ORD (RW-40W), Las Vegas, NV
Records Processing Center = "16"

MFR: OLA&S:CMN-1273

RW04-10-00176

ENCLOSURE

U.S. DEPARTMENT OF ENERGY (DOE) RESPONSES TO THE APRIL 5, 2004, LETTER FROM THE NUCLEAR WASTE TECHNICAL REVIEW BOARD (BOARD)

1. SPENT FUEL AGING FACILITY AT THE REPOSITORY

1.1 RECOMMENDATION

As described at the meeting, the design of the repository surface facilities includes temporary storage for up to 40,000 tons of spent fuel. We understand that the current plan is to construct only 1,000 metric tons of storage capacity and that additional storage would be constructed only as needed. We also understand that the DOE intends that the entire 40,000 metric tons of storage capacity will be included in the license application. The technical justification for a 40,000 metric ton storage facility is unclear. As pointed out in BSC's February 2002 "Thermal Operating Modes" white paper, a larger surface facilities area with a pad for extended surface aging could affect the analysis of aircraft–crash hazard. The Board recommends that the technical justification for such a large storage facility be explained.

1.2 RESPONSE

The Final Environmental Impact Statement (DOE 2002) for the repository considered up to 40,000 MTHM of aging capacity to address the potential need to age commercial spent nuclear fuel and to stage DOE spent nuclear fuel and high-level radioactive waste. In the license application (LA), the Aging Facility being designed as part of the repository surface facilities has the capacity for 21,000 metric tons of heavy metal (MTHM) and contingency to expand to 40,000 MTHM. This facility provides sufficient capacity to allow efficient loading of emplacement drifts with the required combination of DOE waste and commercial spent nuclear fuel to meet thermal management goals. It will also allow DOE to stage spent nuclear fuel and high-level radioactive waste so that the rates for waste receipt and emplacement can be decoupled, if necessary.

The Aging Facility would be constructed on an as-needed basis. Our preliminary throughput analyses support an operational need for an Aging Facility capacity from 15,000 to 17,000 MTHM. That capacity was increased to the 21,000 MTHM value to allow some margin for the early throughput estimate. The DOE intends to construct a small pad for aging up to 1,000 MTHM as part of the surface facilities needed for initial repository operations. The rest of the planned Aging Facility is designed as a series of four modules, each with a capacity of 5,000 MTHM. Our current estimates show that the 21,000 MTHM capacity of the Aging Facility will be sufficient to address all the necessary aging and staging requirements for the repository. As we approach the point where we will be receiving fuel, formal material receipt assessments will be performed to assure compliance with Nuclear Regulatory Commission (NRC) licensing specifications for both subsurface emplacement and surface aging. Locations for three additional 5,000 MTHM modules and one 4,000 MTHM module have been identified as a contingency to bring the total capacity to 40,000 MTHM should it be required. This

approach will provide the regulatory basis and the flexibility to construct additional aging capacity, should it be required to support future operational needs.

The preclosure safety analysis conducted for the LA will also evaluate the consequences of various potential external hazards, including aircraft crashes, and the relevant event sequences associated with the maximum anticipated surface-aging facility size. This analysis is intended to provide the basis for the NRC to determine, with reasonable assurance, that a repository with surface-aging capacity of at least 21,000 MTHM, with potential expansion to 40,000 MTHM, will not represent an unreasonable risk to the health and safety of the public during the preclosure operating period.

2. WASTE PACKAGE PROTOTYPES

2.1 RECOMMENDATION

The Board understands that BSC recently awarded a fixed-price contract to build the first full-scale waste-package prototype. We believe that the technical information obtained during the course of performance of this contract will be very important, and we agree that more waste-package prototypes are needed. We understand that the reasons for building prototypes include reasons other than obtaining technical information. However, we would like more explanation about the technical information that will be obtained by the current plan to build 14 more prototypes.

2.2 RESPONSE

The waste-package prototype testing-program is designed to provide information regarding:

- Manufacturing process variability (fabricator to fabricator)
- Impact of transportation effects on waste packages
- Waste package weld-preparation performance
- Nondestructive examination (NDE) process confirmation and process improvement
- Confirmation of residual stress states (interaction effects, transport effects, etc.)
- Metallurgical analyses (phase-transformation data), confirmation of mechanical properties (as necessary)
- Mechanical testing related to postulated accident scenarios or credible event sequences.

2.2.1 Testing to Confirm As-Built Conditions

This testing program, described below, will aid in establishing a baseline for acceptance of production waste packages during the operation of the repository.

2.2.1.1 Nondestructive Testing

Manufacturing Process Variability - It is anticipated that multiple vendors will be required to fabricate the approximately 11,000 waste packages needed for the Yucca Mountain Project (YMP). The various fabrication processes used by the fabricators (especially solution heat-treatment and quenching), although guided by procurement requirements, industry codes and standards, and technical and quality requirements, may not be completely uniform from one fabricator to the next. Process differences between fabricators may impact the ultimate performance of the waste package. A prudent way to identify and evaluate these potential differences is to evaluate waste package prototypes from various fabricators before actual manufacture of production waste packages begins. The variability between fabricators and processes can then be identified and potentially significant differences, if any, can be addressed as early as possible in order to develop appropriate mitigation measures.

Transportation Effects on Waste Packages - The waste packages will likely be transported several thousands of miles from the fabricators' facilities to YMP facilities. Transportation over these distances could impact waste package geometry, surface condition, and, potentially, other conditions. The geometry (ovality) of the waste packages will be measured after transport. The as-built information from the fabricator before transport will be compared to the condition of the waste packages upon arrival at the YMP facilities. In addition, the waste packages will be inspected to determine if any alteration to the surface condition has occurred during transport. This information will be used to establish and refine specifications for shipping the waste packages and to address any related waste package closure issues at the repository.

Waste Package Weld Preparation Performance - When a waste package is filled with fuel, it will begin to heat up rapidly. As the waste package heats up, it may distort physically. Although the amount of distortion is expected to be small, the potential impact on weld preparation and the "fit up" to the closure lids must be confirmed as distortion; and small variations in waste package ovality may be critical to successful completion of the final closure welds. The evaluation of this potential problem will involve simulated heating of a waste package prototype and measurement of the distortion. In addition, information regarding the sufficiency of the gap between the inner vessel and the outer corrosion barrier, as well as confirmation of the interpass welding temperature, will be obtained by conducting this test.

NDE of the Outer Lid Closure Weld - The postclosure performance of the waste package will, in part, be determined by the condition of the outer corrosion-barrier closure weld. Accordingly, this weld will be nondestructively examined. Current plans include visual inspection, ultrasonic examination, and eddy-current testing. Visual inspection will provide information on the surface character of the weld, ultrasonic examination will provide volumetric data regarding the quality of the weld, and eddy-current testing will provide data regarding the surface condition (e.g., surface-breaking flaws). NDE of the waste package prototypes will be used to establish parameters for NDE during repository operations.

2.2.1.2 Destructive Testing

The following destructive tests will be performed using waste package prototypes. Depending on the extent of destructive testing, the prototypes used for these tests may be available for certain operational testing, such as demonstration of mechanical handling operations, but current planning reserves these prototypes for destructive testing only.

Confirmation of Residual Stresses of the Outer Corrosion Barrier - The current manufacturing process to control residual stresses in the outer corrosion barrier of the waste package is solution heat-treatment and subsequent quenching following completion of the fabrication process. Although this stress-mitigation process is included in the manufacture of the waste packages, subsequent destructive testing is required to verify that the solution heat-treatment and quench accomplish what was intended and to determine if any tensile stresses develop on the surface of the outer corrosion barrier during transportation.

Although nondestructive X-ray diffraction can give a general idea of what the stress state is on the surface, it cannot be used to determine the through-wall stress state of the plate material, nor can it be effectively used on welds because of the large grain sizes within the welds themselves. Only destructive testing can realistically provide the required information regarding the magnitude and depth of stress in the plate material and in the weld areas.

One destructive testing process involves the use of strain gauges affixed to the surface being examined and the use of sensitive measuring equipment. The material is either machined or chemically etched away, and the stress relaxation is measured by the strain gauge instrumentation. A set of residual stress values as a function of depth is then developed.

Destructive X-ray diffraction will be used to determine the depth and magnitude of residual stresses. This test involves measuring the surface of the material and then removing a small layer of material and repeating the X-ray measurement. This process is repeated until the stresses have been measured to the depth of interest.

Metallographic Analyses – Metallography is an analytical testing method used to evaluate the structure of metals. This destructive testing method will enable the evaluation of phase precipitation and grain size changes as a result of heating, provide assurance that the general appearance of the metallography meets the specification #SB-575 of the American Society of Mechanical Engineers (constituents based on chemical composition), and confirm other characteristics that are dependent upon material composition. Metallography will also be used to confirm that the outer corrosion barrier of the waste package has been successfully stress mitigated. In addition, weld-flaw data collected during this testing program will be combined and compared with data from a 2003 weld-flaw analysis study, and a data resource will be compiled for statistical analysis.

2.2.2 Demonstration of Fabricability

The waste package prototype strategy provides for the demonstration of fabrication processes well before manufacture of the production waste packages. This strategy is necessary to ensure

that the waste packages can be manufactured as designed in an efficient, effective, and quality manner. Experience has shown that it is likely that fabrication of the prototypes will identify problems. If problems are encountered during the prototype manufacturing process, design changes can be implemented as necessary before committing funds for the actual production waste packages. Manufacturing process reviews and feedback to subcontractors will serve to improve the fabrication processes and, hence, the quality of the final product. Demonstration of fabricability will be the primary focus of at least the first two waste package prototypes. In addition, the demonstration of fabricability will be a secondary function of all other waste package prototypes.

2.2.3 Operational Testing (Verification of Process Operations)

Operational testing includes such activities as verification of mechanical handling equipment operability, fuel loading activities, subsurface handling and emplacement activities, and waste package closure activities. In addition, it will be necessary to complete an operational readiness review prior to actual operations. All of these operational testing activities will require the use of waste package prototypes.

2.2.4 Number of Waste Package Prototypes

A total of 15 waste package prototypes are planned to support the program outlined here. Table 1 provides a summary of the potential uses of the prototypes, along with the estimated number of prototypes necessary to support design, testing, start-up, and pre-operations. In Table 1, *P* indicates a primary function of a prototype, and *S* indicates a secondary function. Each waste package prototype has only one primary function but may have several secondary functions.

Table 1. Estimated Number of Waste Package Prototypes

Prototype Number (not necessarily order of fabrication)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Configuration → / Activity ↓	21 PWR AP	21 PWR AP	21 PWR AP	21 PWR AP	5 DHLWDOE Co. long	Naval Long	44 BWR	5 DHLWDOE Co. short	5 DHLWDOE Co. long	5 DHLWDOE Co. short	Not Yet Determined	Not Yet Determined	Not Yet Determined	Not Yet Determined	Not Yet Determined
Demonstrate Fabricability/Variability	P	P	P	P	S	S	S	S	S	S	S	S	S	S	S
Develop Cadre of Qualified Vendors	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Verification of Process Operations															
Mechanical Handling Verification								P	P			P			
Fuel Loading Verification				S	P	P	P	S				S			
Closure Cell Process Verification	S	S	S					S	S	S	S	S	P	P	S
Operator Training				S	S	S	S	S				S			
Nondestructive Testing	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Destructive Testing	S	S	S						S	S	P				
Mechanical Properties Testing	S	S	S							P	S				
Drop Testing (if required)															P
# Potential Uses per Prototype	6	6	6	5	5	5	5	7	6	6	6	7	4	4	5

P Primary Function of Prototype
S Secondary Function of Prototype
Configuration not yet determined

3. EMPLACEMENT DRIFT GROUND SUPPORT

3.1 RECOMMENDATION

While not unprecedented, the stainless-steel perforated plate and stainless-steel bolt system proposed as the ground-support system for emplacement drifts is highly unusual and expensive. We would like to learn more about the technical basis for the selection of stainless steel as the material of construction, particularly for the perforated plate. We also would like to know which other materials were considered for ground support and the technical bases for their rejection. We understand that the emplacement-drift ground-support system is designed for a preclosure service life of 100 years and "not to preclude" a preclosure period of up to 300 years. We would like a description of the planned inspection and maintenance activities – including a description of how those activities would be conducted – for both the first 100 years and the subsequent 200 years.

3.2 RESPONSE

Although the use of stainless steel ground support components is not typical in mining and tunneling applications, it is not unprecedented as numerous mines operating in high-sulfide ore bodies with low pH seepage waters have used stainless-steel rock bolts for ground support for their superior corrosion resistance. Both Atlas Copco and Ingersol Rand (now International Rollforms, Inc.) supply stainless-steel rock bolts as standard items.

3.2.1 Rock Mass Description

The rock types comprising the repository host horizon include nonlithophysal rock (a typical, fractured volcanic) and lithophysal rock (same matrix as nonlithophysal rock but with lithophysal void porosity as high as approximately 25 percent). The matrix of the lower lithophysal unit (about 85 percent of the repository emplacement area) is also heavily fractured, with average fracture spacings of less than 10 cm. Extensive fracture mapping studies have been conducted in both of these rock units, and detailed panel mapping of lithophysae has been conducted in the Enhanced Characterization of the Repository Block cross drift. Modeling analyses, reported in *Drift Degradation Analysis* (BSC 2004a), show that the median block sizes created in the nonlithophysal rock are around 0.15 MT (0.06 m^3). Observation of fracture spacing as well as particle sizes from coring in the lower lithophysal unit indicates that the rock fragments expected during failure are small, being on the order of the fracture and lithophysae spacing.

During the preclosure period, the combined in situ, thermal, and seismic loading to the rock mass is relatively small. Although failure is not expected, the value engineering team assembled to evaluate this issue agreed that the most likely potential failure mechanism to occur within the lithophysal rock mass would be a "raveling" mode, characterized by loosening of the rock surface and gravity-driven fall of small rock fragments. In the nonlithophysal rock mass, the potential failure mode would be formation of relatively small "key-block" or wedge-type

failures, a small number of which occurred during excavation and scaling of the existing tunnels[1]. Based on the potential failure modes, particularly the raveling of small rock fragments, the preferred support method is use of a continuous-type of surface covering that "knits" the rock surface together and provides sufficient confinement to prevent loosening and raveling.

3.2.2 Value Engineering Process

The specification of the ground support was developed using the value engineering process.

A group of engineers, geologists, and performance assessment specialists, both internal and external to the YMP, were assembled to perform the initial design evaluation. External consultants included Dr. Nick Barton, Barton and Associates; George Yoggy, Master Builders; and Patrick Andrieux, Itasca Canada (formerly Noranda Mining).

A number of criteria for the ground support were established for the evaluation, based on repository performance requirements and operational and safety considerations. The criteria of greatest importance included:

1. The ground support methods must not have a significant negative impact on the capabilities of natural or engineered barriers.

2. The ground support must support the regulatory waste retrieval requirement.

3. The design of the ground support should result in the need for little or no maintenance over the entire preclosure period (taken to be approximately 100 years, with the potential to maintain the repository in an open condition for up to 300 years)[2].

4. The ground support should not impede the rock mass drying effect from forced ventilation air.

5. Personnel safety during all aspects of ground support installation and maintenance is of highest priority.

Ground support alternatives developed and evaluated by the team included standard support methods such as concrete and shotcrete linings, grouted rock bolts, wire mesh or steel plates, thin organic or cement-based spray-on linings, steel sets, and full-tube conduit-type linings. In all deliberations, the attempt was made to develop support methods with standard materials and components and to use off-the-shelf hardware, where possible.

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[1] No significant ground instabilities or ground falls have occurred since the excavations were completed.

[2] The ground support has been classified as not important to safety. Studies for unsupported tunnels, conducted as part of the preclosure safety assessment, examined rockfall potential when subjected to preclosure in situ, thermal, and seismic loading. The rockfall was found to have insufficient mass to result in a credible nuclear safety scenario.

From a purely geotechnical and mining perspective, the preferred ground support method for all excavations was the use of standard fiber-reinforced shotcrete and grouted rock bolts. However, uncertainties exist regarding the potential impact of cementitious and organic surface coatings on the chemistry of seepage waters. This uncertainty leads to greater uncertainties regarding drip shield and waste package corrosion, and near-field environment radionuclide transport mechanisms. It was determined that this uncertainty currently rules out the use of either cementitious or organic materials from ground support in emplacement drifts.

Consequently, it was determined that only steel components would be used for ground support. This determination results in the use of friction-type rock bolts (either Swellex or Split Set were considered) for general ground-reinforcement. To provide the surface confinement desired to eliminate raveling of small rock fragments, Bernold-style perforated steel sheeting was chosen for use. This type of surface support consists of thin steel sheets that are rolled to the tunnel radius and punched to create slots that allow air circulation behind the sheet. The punching process also corrugates the sheet, which results in significant structural stiffness. These sheets are overlapped for connection and predrilled for rock bolt installation. The bolts are installed through the sheets and pulled tight to the rock surface, preventing loosening and raveling. The slot dimensions can be custom designed to prevent loss of small rock fragments. A 240° coverage of the tunnel periphery is used to minimize rockfall onto the invert rail system. It is envisioned that a highly mechanized rail-based system will be developed for installation of this support system. A single piece of equipment for lifting and holding the steel sheets to the rock surface, followed by drilling of radial boltholes and installation of friction bolts, could be developed relatively easily.

3.2.3 Ground Support Materials Selection

The most effective corrosion control practice is selection of a suitable metal or alloy for the service time in a particular environment. The total service life for the ground support system is currently established at 100 years, which encompasses the NRC requirement that the waste be retrievable starting at any time up to 50 years after the start of waste emplacement operations.

Candidate steel ground-support materials, including carbon steel, high-strength low-alloy steel, and stainless steel were considered in the corrosion evaluation for the longevity of ground support materials for the LA. The potential corrosion mechanisms that may be expected in the repository environment include dry oxidation; humid-air corrosion; aqueous, pitting, or crevice corrosion; stress corrosion cracking; hydrogen embrittlement; and microbiologically influenced corrosion.

The following conclusions were reached based on the corrosion evaluation for the candidate ground-support materials in Section 7.3 of the report *Longevity of Emplacement Drift Ground Support Materials for LA* (BSC 2003a):

- The impact of dry oxidation on the performance of carbon steel and stainless steel is insignificant or negligible.

- For humid-air corrosion, ground-support components made of carbon steel will fail after a service life of 30 years, whereas a rock bolt made of high-strength, low-alloy steel will not fail for a service life of 100 years. Ground-support components made of stainless steel 316 will not fail for a service life of 100 years.

- Carbon steel and high-strength, low-alloy steel will fail because of aqueous corrosion within 10 years, whereas stainless steel 316 will not fail for 100 years of service life.

- Stainless steel 316 indicates superior performance against pitting and crevice corrosion. The potential effect of higher temperatures on general and localized corrosion for stainless steel 316 is insignificant.

- Based on the stress level, temperature, and ground water conditions, it is expected that stress corrosion cracking of friction-type rock bolts will probably not occur during preclosure. The potential impact of hydrogen embrittlement on friction-type rock bolts is minimal or insignificant.

- The effect of microbiologically influenced corrosion is significant on carbon steel, whereas it is insignificant on stainless steel 316.

The following paragraph is cited from Section 7.4 of the report *Longevity of Emplacement Drift Ground Support Materials for LA* (BSC 2003)

> . . . for a service life of 100 years during the preclosure, both the friction-type rock bolts (Split Sets and/or Swellex bolts) and the perforated steel sheets need to be made of stainless steel, such as 316 (equivalent or better), from the viewpoint of corrosion control. This result confirms the current design on materials for rock bolts and perforated sheets in emplacement drifts. Rock bolts and perforated steel sheets made of stainless steel with thickness of 3 mm will not fail due to corrosion for a service life of 100 years. Furthermore, Swellex bolts may perform better than Split Sets in terms of corrosion attack due to its tubing configuration. Among all friction-type rock bolts, Super Swellex bolts have the highest holding capacity, which is desirable from the viewpoint of structural stability. Moreover, the Super Swellex bolt has a larger tube thickness compared with others, which is also desirable from the viewpoint of minimizing the effects of corrosion.

3.2.4 Maintenance and Cost

The ground support has been classified as not important to safety. Examination of potential preclosure rockfall size shows that waste package breach is not credible. To facilitate waste package retrieval, should it be required, emplacement drift stability will be monitored during the 100-year design-basis preclosure period from the initiation of waste emplacement. A preliminary observation and ground-support maintenance plan has been developed, however, the details of this plan can only be developed as the subsurface design proceeds. The specific observation equipment and intervals have not been determined, but the current thinking is that observation of the ground support will be performed using remote-controlled video cameras. Observations will center on examination of areas of deformation that would indicate extensive

yield behind the ground-support system. A determination of the need to maintain the support in that area will be made on a case-by-case basis based on an evaluation of the significance of the changes in the affected ground support. Although the repository design will include provisions that support deferral of closure for up to 200 years beyond the end of the design-basis preclosure period, the monitoring and maintenance program for this contingency is not needed at this time.

A primary objective for the use of full tunnel-support coverage and stainless steel components with an expected service life in excess of 100 years was to eliminate or minimize the need for maintenance. Although the initial cost of the planned stainless-steel ground support system is higher than for 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 for reentry into emplacement drifts to maintain ground support.

4. "COLD TRAP" EFFECTS IN THE EMPLACEMENT DRIFT TURNOUTS

4.1 RECOMMENDATION

The Board notes that changes have been made in the subsurface repository design to increase the radius of each emplacement drift turnout and to move the ventilation control door to the outer end of each turnout. These changes will affect the postclosure waste package temperatures, particularly the temperature of packages close to the turnouts. In addition, these changes are likely to exacerbate "cold trap" effects near and in the turnouts. We strongly recommend that temperature and relative humidity calculations be revised to reflect the design changes, if that has not been done already.

4.2 RESPONSE

The DOE agrees that changes in the subsurface repository design, specifically the increase in the radius of the emplacement-drift turnout and relocation of the ventilation control door, need to be evaluated as to the effect on predictions of temperature and relative humidity inside the drift, especially in the postclosure time frame. The YMP has recently modeled the natural convection and condensation of in-drift moisture during the postclosure period and the associated redistribution of energy, documenting the results in the forthcoming analysis and model report on in-drift natural convection and condensation. This model reflects the recent design changes and provides predictions of temperature, moisture content, and condensation patterns. This analysis and model report will be completed in the near future.

In general, a longer turnout and relocated ventilation door provide additional, cooler rock surfaces outside of the emplacement section of the drifts and on which condensation of moisture may occur (cold trap effect). The warm, moist air that moves from the emplacement drifts into the turnouts as a result of natural convection processes will be depleted of most of its vapor content by condensation on the cooler rock-surfaces. At the same time, relatively dry air circulates back toward the emplacement sections of the drifts, thereby reducing the vapor mass and the relative humidity in these areas. The energy transport associated with the movement of in-drift air also affects the waste package temperatures, particularly those close to the turnouts. However, compared to the reduction in relative humidity, the changes in temperature are rather small.

5. NATURAL VENTILATION AND DRIFT ENVIRONMENT

5.1 RECOMMENDATION

The Nye County work on the evolution of chemistry in the engineered barrier system and on the topic of natural ventilation is very interesting. These topics are important because they influence both waste package corrosion and transport from the engineered barrier system. It is clear that the environment in drifts is not a quasistatic or slowly changing one but a dynamic one driven in part by temperature differences among waste packages and along the drifts. Such differences will always exist but will be greater during the thermal pulse period. A repository at Yucca Mountain will have some degree of natural ventilation or natural circulation regardless of whether it is deliberately engineered into the repository design or not. Models for temperature and relative humidity predictions must take these natural processes into account fully.

5.2 RESPONSE

Nye County's work on the in-drift chemical environment and natural ventilation are undoubtedly important alternative concepts enriching the knowledge base that supports DOE's analyses of the performance of the repository system.

During the preclosure period, a large volume of air will move through the drifts at high velocity due to active ventilation. During the postclosure period, the volume and velocity of air moving through the drifts will drop substantially because only intrinsic natural circulation augmented by temperature differences along the drifts will sustain air movement. YMP models take air and moisture exchange between the fracture system and the in-drift environment into account. The only way that temperature differences along the length of the drift and between waste packages could increase or become more uneven following closure is if there was an impediment to the flow of heat, such as backfill cover. There could also be some advection of moisture (inevitably carrying some heat) from the rock into the drift caused by fluctuations in barometric pressure. However such moisture movement would be limited and would decrease with time, because of the continued increase in the size of the dry-out zone surrounding each emplacement drift during the thermal pulse.

6. REFERENCES

6.1 DOCUMENTS CITED

BSC 2003a. *Longevity of Emplacement Drift Ground Support Materials for LA.* 800-K0C-TEG0-01200-000 REV00A. Las Vegas, Nevada. Bechtel SAIC Company.

BSC 2003b. *Technical Basis Document No. 5: In-drift Chemical Environment.* Las Vegas, Nevada. Bechtel SAIC Company.

BSC 2004a. *Drift Degradation Analysis.* ANL-EBS-MD-000027 REV 03A. Las Vegas, Nevada. Bechtel SAIC Company.

DOE 2002. *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada.*

DOE/EIS-0250. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

6.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

July 28, 2004

Dr. Margaret S. Y. Chu, Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Chu:

On behalf of the Nuclear Waste Technical Review Board, I thank you, your staff from the Department of Energy (DOE), and your contractor team for participating in the Board's spring meeting on May 18-19, 2004, in Washington, D.C. The Board appreciates your responsiveness to our recent letters and report on the potential for corrosion of the Alloy 22 waste packages during the thermal pulse.* The hard work that went into preparing the meeting presentations was evident and worthwhile; the presentations provided important new information and analyses. We want to note in particular the excellent technical coordination and assistance provided by Bob Andrews, Claudia Newbury, and Mark Peters.

Corrosion Issues

In its October 21, 2003, letter and in its November 25, 2003, letter and report, the Board concluded that, given the information presented by the DOE and others at the Board's January 2003 and May 2003 meetings, deliquescence-induced crevice corrosion would be likely to initiate during the higher-temperature period of the thermal pulse. That conclusion was based particularly on corrosion tests conducted in an aqueous environment rich in calcium chloride. Test results showed clearly that corrosion would take place in that environment when temperatures ranged roughly between 140°C and 160°C. The results also suggested that the expected mitigating effect of the presence of nitrate ions might not be sufficient to inhibit the corrosion process fully.

Based primarily on information presented at the Board's May 2004 meeting, it appears unlikely that dusts that accumulate on waste package surfaces during the preclosure period would contain significant amounts of calcium chloride or that significant amounts of calcium chloride would evolve on waste package surfaces during the thermal pulse. Consequently, the calcium chloride-rich environment selected for corrosion tests does not appear representative of the conditions that can be expected on waste package surfaces in a Yucca Mountain repository. If calcium chloride is not present, calcium chloride-rich brines will not form by deliquescence, and crevice corrosion due to the presence of such brines in the temperature range of roughly 140°C to 160°C will not occur. Thus, the Board concludes that deliquescence-induced localized corrosion during the higher-temperature period of the thermal pulse is unlikely.

*The thermal pulse is the period of approximately 1,000 years after repository closure when temperatures in repository tunnels would be above the boiling point of water.

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Ideally, corrosion tests should be carried out both in environments that closely approximate the various conditions to which the waste package alloy will be exposed and in environments that reasonably bound those conditions. The extent to which the DOE has characterized accurately the likely waste package environments (i.e., temperature, relative humidity, and chemical species present) is unclear at this point. Accurate characterization of probable waste package environments and the corrosion response of the waste package alloy to those environments will continue to be a major focus of the Board's technical and scientific review.

Several corrosion issues that require additional analysis were discussed at the May 2004 Board meeting. First, the DOE raised the possibility that when temperatures in repository tunnels fall below boiling, localized corrosion could occur in concentrated sodium chloride solutions with low concentrations of inhibitors. The Board believes that further investigation of the possibilities for localized corrosion at below-boiling temperatures is warranted and that such an investigation should focus on (1) possible mechanisms that might create environments that would facilitate localized corrosion and (2) the likelihood that such environments could exist. Second, the presence of ammonium ion and the implications of its presence for corrosion or other performance aspects need to be explained. Third, the State of Nevada suggested that nitrates could be aggressive corrodents in some circumstances. The Board believes that it would be worthwhile to review existing corrosion data to determine whether they bound nitrate-containing environments that reasonably could be anticipated at Yucca Mountain.

Integration

DOE contractors have been performing corrosion tests at high-temperatures in high-chloride brines for several years, presumably because it was thought that the test conditions might occur at Yucca Mountain or might reasonably bound actual conditions. However, as became clear as a result of presentations at the May 2004 meeting, geochemical considerations preclude high-temperature, high-chloride brine conditions at Yucca Mountain, rendering the corrosion tests of limited relevance. This situation underscores the need for thorough integration and close cooperation among diverse technical disciplines, particularly when "coupled" processes are involved. For example, excellent integration among geochemists and corrosion scientists/engineers was evident at the meeting and helped bring clarity to an extremely important corrosion issue. Continuing integration will be necessary for resolving other issues associated with the DOE's current repository design.

Hydrology and Thermohydrology Issues

In its November 2003 report, the Board indicated that it agreed with the DOE that boiling during the thermal pulse and capillarity during and following the thermal pulse would significantly reduce the seepage of water into repository drifts but that the pervasiveness of these barriers throughout repository tunnels is not assured. At the May 2004 meeting, the DOE presented detailed descriptions of numerous field and computer investigations—many of which are at the leading edge of science—that form the basis for the DOE's high level of confidence in the effectiveness of vaporization and capillary barriers in its current repository design. In particular, the DOE maintains that there would be no seepage during the period when repository rocks are above boiling and that seepage would be limited at lower temperatures.

After reviewing the information presented at the May 2004 meeting, the Board continues to question the pervasiveness of vaporization and capillary barriers because of persistent uncertainties related to the expected repository tunnel environments. Examples of uncertainties include (1) the conceptual basis for the drift-scale thermohydrologic seepage analysis, including the axial convective transport of water vapor, air, and thermal energy in drifts; (2) the source of liquid water observed in the bulkheaded part of the cross drift; (3) the effects of drift degradation on the waste package environment; and (4) potentially unrealistic combinations of parameters used in the performance-assessment calculations of seepage.

The Board understands that significant scientific challenges are associated with analyzing the complex hydrology at Yucca Mountain, especially when the repository is subject to a large thermal perturbation. However, the Board believes that addressing uncertainties such as those noted above could create a more solid technical basis for determining whether the DOE's high confidence in the effectiveness of capillary and vaporization barriers is warranted.

Seismic Update

We were very pleased to learn from the update at the May 2004 meeting that the DOE has initiated a program aimed at deriving more realistic estimates of seismic hazard at the Yucca Mountain site. In its June 27, 2003, letter to you, the Board indicated its concern about what may be physically unrealizable estimates of very low-probability (annual probabilities of exceedance of 10^{-6} or less) seismic ground motion being calculated for Yucca Mountain by the DOE and its contractors. The new program appears to be a thoughtful first step. It is based on using the extent of fracturing observed in the tunnels at Yucca Mountain to limit the ground motions that could have taken place at the site during the last 10 million years. We look forward to reading the written report on these initial efforts when it becomes available and to learning more about subsequent analyses. As discussed in our June 2003 letter, deriving limits to low-probability ground motions will be challenging. We therefore urge the DOE to implement an external peer review of these efforts.

Transportation Planning

Information presented at the May 2004 meeting indicates that real progress is being made in planning a transportation system for a Yucca Mountain repository. The timelines that the DOE presented at the meeting identify several important milestones that your Office of National Transportation plans to develop further into detailed project plans with cost, schedule, and technical baselines. The Board's Panel on the Waste Management System has tentatively scheduled a meeting for October 13-14, 2004, in Salt Lake City, Utah. We look forward to a more detailed review of progress in transportation planning at that time. We also would like to discuss aircraft hazard and public perceptions of transportation risk at the panel meeting.

Concluding Comments

Once again, thank you for participating in our spring meeting and for the contributions of your staff and contractors. From the Board's perspective, the meeting met its objective: to provide a forum for the free and open exchange of views and information on the potential for corrosion during the thermal pulse. Success in achieving this objective was due in large part to the leadership you provided and to the effort that you and your staff and contractors put into conducting new studies, integrating information, and developing presentations. We also were pleased that the Nuclear Regulatory Commission, the Electric Power Research Institute, and the State of Nevada contributed their insights at the meeting. The Board looks forward to future exchanges of this kind.

Sincerely,

David J. Duquette
Chair, Executive Committee

djd006vh

Department of Energy
Washington, DC 20585

QA: N/A

September 10, 2004

Richard R. Parizek, Ph.D.
Chair, Panel on the Natural System
U.S. Nuclear Waste Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

Dear Dr. Parizek:

Thank you for your letter of May 3, 2004, providing the Nuclear Waste Technical Review Board's (Board) response to the information presented by the U.S. Department of Energy (Department) at the March 9-10, 2004, meeting of the Board's Panel on the Natural System (Panel). The Department appreciates the Board's continuing review of our activities as we work to develop and document the technical basis for the license application for a repository at Yucca Mountain. Our responses to the Panel's views and recommendations are summarized in the enclosure to this letter.

The Department looks forward to further dialog on the Natural System and related issues.

Sincerely,

Margaret S.Y. Chu, Ph.D.
Director
Office of Civilian Radioactive
Waste Management

Enclosure

ENCLOSURE

U.S. DEPARTMENT OF ENERGY (DOE) RESPONSES TO THE MAY 3, 2004, LETTER FROM THE NUCLEAR WASTE TECHNICAL REVIEW BOARD (BOARD) PANEL ON THE NATURAL SYSTEM

1.0 INCREASING FUNDAMENTAL UNDERSTANDING

1.1 RECOMMENDATION

Field and laboratory observations and analyses presented by the Department of Energy (DOE) and others suggest that the natural system provides an effective barrier to migration of some radionuclides over time periods that may be comparable to the regulatory period. However, several key hydrogeologic features or processes that may significantly affect fluid flow and radionuclide transport are presently not well understood, are constrained by limited or poor data, or both.

The DOE often deals with uncertain features and processes by making conservative estimates of their effects on radionuclide transport. Such conservativisms regarding the performance of the natural system tend to emphasize more-rapid advective transport processes. More realistic estimates that might arise from further evaluation of some features and processes could lead to slower transport predictions for some radionuclides. However, there is a possibility that some other poorly understood features or processes may lead to faster radionuclide transport. Therefore, it is important that the DOE develop a better fundamental understanding of the overall behavior of the natural system.

1.1.1 RESPONSE

We concur that some aspects of fluid flow and radionuclide transport are uncertain. The most significant uncertainties that affect performance of these natural barriers in affecting radionuclide transport have been included in the performance assessment. Although in some cases, conservative approximations have been utilized, this can be acceptable in a licensing analysis.

In Fiscal Year (FY) 2002, the DOE defined a technical work plan that focused on improving confidence in the models for the repository system, including specific testing and analyses aimed at increasing the fundamental understanding of the natural system. This plan was presented to the Board in May 2002[1]. We are in the process of documenting the results of these activities as part of the comprehensive technical basis in a license application that will be submitted to the

[1] Swift, P. 2002. Project Plans for Fiscal Year 2002-2003: Performance Assessment. Presentation to the Nuclear Waste Technical Review Board, May 8, 2002.

Nuclear Regulatory Commission later this year. The DOE believes that the fundamental understanding of key hydrogeologic processes that may significantly affect fluid flow and radionuclide transport is adequate to support the licensing basis for the Yucca Mountain site.

The DOE will continue to evaluate fluid flow and radionuclide transport to the extent that these processes are important to overall system performance through our Performance Confirmation Program. Activities in the Performance Confirmation Program will evaluate the adequacy of assumptions, data, and analyses that may lead to the findings that permit construction of the repository and subsequent emplacement of wastes. Key parameters that evaluate barrier capability will be monitored and/or tested to evaluate conditions assumed in the license application that may affect compliance with the performance objectives of 10 CFR Part 63[2], as discussed in the following responses to comments on specific testing needs.

The DOE is also initiating work to further investigate some of the key conservatisms in the natural system models and to enhance our understanding of repository performance[3]. This work includes efforts to more completely understand processes involving fracture-matrix interaction, drift shadow, saturated zone groundwater movement, retardation, site-scale hydrologic parameters, and scaling effects in hydrologic parameter estimation. Results could lead to potential modifications of the technical basis at future stages of the licensing process.

2.0 TECHNICAL AND SCIENTIFIC RECOMMENDATIONS

2.1 RECOMMENDATION: HYDRAULIC PROPERTIES OF MAJOR BLOCK-BOUNDING FAULTS

First, although the hydraulic properties of major block-bounding faults, such as the Solitario Canyon fault, never have been field-tested, it seems clear that these faults can influence fluid flow and radionuclide transport substantially. Large-scale hydraulic tests of those major faults are therefore needed.

2.1.1 RESPONSE

In the past two decades, significant amounts of data (geologic, hydrologic, and geochemical) have been collected from the Yucca Mountain site. In the unsaturated zone, the DOE has completed air injection testing in the Bow Ridge fault and the southern Ghost Dance fault and hydrologic testing to determine air permeability, porosity, and gaseous tracer transport characteristics (transport porosity and longitudinal dispersivity) in the northern Ghost Dance fault. Although data on water flow in faults are relatively limited in the unsaturated zone, faults are explicitly incorporated in models using the dual-permeability conceptual model. Hydraulic properties for the fractures in fault zones were separately calibrated to account for differences in

[2] 10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available.

[3] Budnitz, R. 2004. Update on OCRWM's Science and Technology Program. Presentation to the Nuclear Waste Technical Review Board, January 20, 2004.

fracture properties as compared to fractures outside of fault zones. Flow and transport parameters for the matrix of fault zones were assumed to be identical to the matrix outside of fault zones. Various model simulations have been completed to capture the uncertainties that result from data limitations and the complexity of unsaturated zone flow. Additional testing of faults in the unsaturated zone is not planned at this time.

Although faults were not directly tested in the saturated zone, the results of testing at the C-wells complex provided insight into the role of faults in the saturated zone. Numerous fault traces (e.g., Midway Valley Fault, Paintbrush Canyon Fault, Bow Ridge Fault, and Fran Ridge Fault) traverse between the pumping well and the distant monitoring wells. The measured drawdown during testing at the C-wells complex indicated the existence of connected fault anisotropy. Test results also indicate that the flow system behaved like an equivalent continuum or as a dual porosity system over large scales.

Major faults in the saturated zone are conceptualized as zones of enhanced permeability that simulate preferential flow in faults with gridblocks that are nominally 500-by-500 m in a horizontal direction. Representing faults by 500-by-500 m gridblocks accounts for uncertainties in their geographic location. While the precise flow regime within a fault may not be representative when using volume-averaged representations of faults, the overall flow through the system, particularly at the model boundaries, is not significantly affected by the volume averaging approach. The impact of grid cell averaging is expected to be minimal at the scale of the site-scale flow model and is implicitly included in the specific discharge uncertainty, as applied to the saturated zone transport abstraction model. Hydraulic and tracer testing of fault zone hydrologic characteristics, including anisotropy, is planned to evaluate and test these modeling results in the Performance Confirmation Program. This testing will evaluate fault zone hydraulic conductivity (permeability), porosity, dispersivity, and anisotropy in fractured rock along the flow path from the repository. Quantified results from these tests will be compared to values used in the saturated zone flow and transport models.

Therefore, the relevant effects of faults on groundwater flow paths and rates of radionuclide transport have been included in the performance assessment, as has the uncertainty associated with these faults.

2.2 RECOMMENDATION: SPATIAL DISTRIBUTION AND SEDIMENTARY ARCHITECTURE OF ALLUVIUM

Second, improvements in the characterization of the spatial distribution and sedimentary architecture of the saturated alluvium could substantially enhance fundamental understanding of groundwater flow and radionuclide transport along Fortymile Wash south of Yucca Mountain. For example, the recent sonic log drilled by Nye County is an excellent source of data for supporting studies of sorption of radionuclides in alluvial sediment; additional logs from locations where uncertainties are high have the potential to yield similar benefits. Deeply weathered cobbles from that geologic log suggest the potential for delays in radionuclide transport due to diffusion that could be demonstrated if the DOE conducts field-scale long-term tracer studies (for example, at the Alluvial Testing Complex). These studies should be done.

2.2.1 RESPONSE

As you know, the testing at the Alluvial Testing Complex (ATC) was suspended during site characterization when a permit to withdraw and inject water was denied by the State of Nevada. Before the testing was terminated, single-hole hydraulic and tracer testing and multiple well hydraulic tests were conducted at the ATC. The results of these tests were used to develop estimates of groundwater specific discharge in the alluvium. The DOE plans to restart testing at the ATC, pending resolution of permitting issues with the State of Nevada, using multiple borehole tracer testing as part of the Performance Confirmation Program. Cross-hole pump and tracer transport tests are planned to evaluate conceptual and numerical models for flow and transport in the alluvium south of Yucca Mountain. In addition, Nye County is planning a multi-well test in the alluvium as part of the Early Warning Drilling Program and has plans to investigate the geometry of the alluvium-tuff interface geophysically.

2.3 RECOMMENDATION: MATRIX DIFFUSION

Third, depending on rock properties such as fracture frequency and thin coatings on the fracture faces, matrix diffusion could either increase or decrease current estimates of radionuclide transport time by thousands of years. For this reason, a better empirical basis for predicting matrix diffusion is needed.

2.3.1 RESPONSE

The drift-to drift liquid release and tracer tests (Alcove 8-Niche 3) provide information on seepage, matrix diffusion, and transport over spatial scales in the range of 20 meters in the vicinity of a near-vertical fault[4]. Alcove 8 is located in the upper lithophysal tuff of the Topopah Spring directly above Niche 3, located in the middle nonlithophysal tuff of the Topopah Spring. The role of matrix diffusion is examined by comparing the experimental observations collected from Alcove 8-Niche 3 and results of tracer tests in Alcove 1 with model predictions. The results 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[5].

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[4] BSC (Bechtel SAIC Company) 2003. In Situ Field Testing of Processes. ANL-NBS-HS-000005 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031208.00001.

[5] BSC (Bechtel SAIC Company) 2004. UZ Flow Models and Submodels. MDL-NBS-HS-000006 REV 02. Las Vegas, Nevada: Bechtel SAIC Company.

Similar tracer behavior with different diffusion coefficients was observed by Reimus et al. in tracer experiments in fractured volcanic tuff at the C-wells site[6]. This consistency suggests that similar transport processes (advection and matrix diffusion) are at work in the unsaturated and saturated zone barriers in the fractured tuffs of low matrix permeability.

Laboratory and field tests have demonstrated that matrix diffusion occurs in fractured volcanic tuffs near Yucca Mountain and provide a basis for quantifying the effect of matrix diffusion on radionuclide migration through the fractured tuff of the saturated zone. An empirical relationship relating matrix diffusion coefficients to matrix porosity and permeability has been developed from laboratory experiments of diffusion coefficients in intact volcanic tuff matrices and from corresponding matrix porosity and permeability measurements. In the field, the observed tracer breakthrough curves in multiple tracer tests at the C-wells can be explained and interpreted only using transport models incorporating matrix diffusion.

Three additional projects are underway on the subject of matrix diffusion, including a laboratory study to determine the effect of pore connectivity and episodic flow on matrix diffusion, a field study of isotopic disequilibrium as an indicator of in-situ matrix diffusion, and a study to verify the scale-dependence of matrix diffusion parameters. Further, the 2-km natural gradient tracer test, in the saturated zone, will provide a better empirical basis for predicting matrix diffusion.

2.4 RECOMMENDATION: COLLOID-FACILITATED TRANSPORT

. . . evidence from a nuclear weapons test site suggests that some water-borne colloids can lead to rapid radionuclide transport in the saturated zone. Laboratory and computer studies conducted by the DOE show that other colloids might substantially slow radionuclide migration. Consequently, understanding of this phenomenon should be improved by field, laboratory, and modeling studies.

2.4.1 RESPONSE

Colloid filtration rate constants and retardation factors for colloidal transport in fractured volcanic rocks and alluvium have been estimated from a number of laboratory and field experiments. These experiments suggest that the longer the colloids have to travel through saturated medium, the higher the probability that they will be reversibly or irreversibly filtered by the rock phase.

Field and laboratory experiments using both natural and surrogate colloids indicate that most colloids will be filtered by the volcanic rock and the alluvium, and that only a small percentage will remain unretarded (mobile) during migration in the saturated zone. Attachment rate constants and detachment rate constants of colloids to the rock matrix have been measured, and

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[6] Reimus, P.W.; Haga, M.J.; Adams, A.I.; Callahan, T.J.; Turin, H.J.; and Counce, D.A. 2003. "Testing and Parameterizing a Conceptual Solute Transport Model in Saturated Fractured Tuff Using Sorbing and Nonsorbing Tracers in Cross-Hole Tracer Tests." Journal of Contaminant Hydrology, 62-63, 613-636. New York, New York: Elsevier. TIC: 254205.

separate uncertainty distributions of colloid retardation factors have been developed for the fractured volcanic rocks and alluvium.

There are uncertainties associated with the colloid retardation factors obtained for the volcanic rocks and alluvium. These uncertainties are accounted for in the DOE's technical basis for the license application.

The DOE requested that the University of Nevada, Las Vegas, propose an integrated, multi-disciplinary, multi-organizational effort to provide more understanding of the role of colloids in radionuclide movement. Initiative of that work is on hold pending resolution of budget issues.

2.5 RECOMMENDATION: ACTIVE FRACTURE MODEL

. . . for unsaturated zone fluid flow and radionuclide transport, predictions are influenced significantly by assumptions inherent in the formulation of the active fracture model (AFM). The AFM needs to be tested and evaluated to establish a technical basis for using this approach.

2.5.1 RESPONSE

The active fracture model is important for unsaturated zone flow and transport calculations. This model is supported by comparisons of transport simulations with field data, such as carbon-14 measurements and mineral fracture coating data. Because field data are relatively sparse and only indirectly support the active fracture model, total system performance assessment (TSPA) analyses use a range of active fracture model parameters from three infiltration scenarios. The implementation of the active fracture model in the abstraction model (finite element heat and mass particle tracker) was shown to reproduce the qualitative features of the breakthrough curves documented in the unsaturated zone transport process model reports on which the abstraction was based[7]. Thus, the abstraction has been compared with the full complexity of the unsaturated zone model and was found to represent the system robustly for the entire range of parameters and conceptual models required.

Further, testing in a cubic meter block from the lower lithophysal unit, planned for FY 2005, is specifically designed to verify the van-Genuchten parameters of the characteristic curves for the fractured tuff, and to validate the active fracture model.

2.6 RECOMMENDATION: SITE-SCALE MODEL BOUNDARIES

Third, in the saturated zone, the technical basis for the DOE's site-scale flow model would be stronger if the model were more consistent with the most recent regional model calculations of flow across the site-scale model boundaries. Updating the DOE's model on the basis of these calculations could affect predictions of radionuclide transport times.

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[7] BSC. 2004. Particle Tracking Model and Abstraction of Transport Processes. MDL-NBS-HS-000020 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040120.0001.

2.6.1 RESPONSE

The DOE is in the process of revising the *Site-Scale Saturated Zone Flow Model [Analysis Model Report] AMR* to document an alternative conceptual model, using the updated hydrologic framework model and boundary fluxes derived from the 2002 regional flow model. This analysis will consider:

1) Additional water-level data from Phase 2 of the Nye County Drilling Program,
2) A reinterpreted Hydrologic Framework Model,
3) Revised recharge distribution from the 2002 Regional Model and the 2003 Unsaturated Zone Model,
4) Updated boundary fluxes from the 2002 Regional Model,
5) Additional permeability data, and
6) Fifteen new Nye County head targets for calibrations.

The analysis will evaluate the potential impacts of the resulting flow fields (flow paths and specific discharge) on transport calculations and breakthrough curves. The analysis will also include additional evaluation of alternative conceptual models, such as an alternative representation of the Solitario Canyon fault and the large hydraulic gradient. Work initiated recently seeks to optimize the interface between site and regional groundwater models and will incorporate up-to-date versions of each.

3.0 MULTIPLE LINES OF EVIDENCE

3.1 RECOMMENDATION

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 Peña Blanca analogue site in Chihuahua, Mexico, having many similarities to Yucca Mountain, provides a good opportunity to evaluate, for example, whether consideration of secondary mineralization processes may reduce overall system dose estimates substantially and what effect alpha decay of radionuclides in minerals may have on mobility. The Board commends the Science and Technology program for its plans to test Yucca Mountain modeling approaches at the Peña Blanca analogue site. Naturally occurring radioisotopes at Yucca Mountain provide another valuable line of evidence for flow and transport. Additional isotopic data, such as carbon-14 measurements, collected from discrete zones in the flow path from Yucca Mountain, could be used to test and evaluate DOE models and predictions and to constrain recharge rates in the model domain. In summary, the validity of model forecasts can be evaluated better in the presence of a list of independent physical and chemical lines of evidence that support or challenge the forecasts.

3.1.1 RESPONSE

The DOE agrees with the Board that multiple lines of evidence can be used to supplement and evaluate the conceptual understanding of the natural system at Yucca Mountain. The

Peña Blanca analogue site provides an opportunity to evaluate models of the Yucca Mountain site by testing against field observations and process modeling of these observations at the Peña Blanca site. The ongoing work at Peña Blanca is evaluating fracture-matrix interactions, transport behavior, and colloidal transport.

One of the few methods to investigate transport processes over the spatial and temporal scale of interest to repository performance is the use of naturally occurring radioisotopes, such as carbon-14. The DOE has used observations of carbon and other isotopes to test and evaluate transport properties developed at smaller scales in the saturated zone. Although uncertainty and variability exists in these observations, they generally indicate advective transport times of unretarded species that range from a few hundred to a few thousand years along likely flow paths in the tuff and alluvial aquifers. These advective travel times are similar to those that result from the saturated zone flow and transport model. The DOE has also used isotopic data, along with hydrochemical data, to provide bounds on the magnitude and timing of recharge in the saturated zone at the regional scale. New methods of interpreting carbon-14 and carbon-13 analyses together provide an independent line of evidence related to saturated zone processes, for example, advective transport of natural tracers.

4.0 CONCLUDING COMMENTS

4.1 RECOMMENDATION

At a May 2002 meeting of the Board, you stated your intention to devote attention to aspects of the natural system, and we are encouraged by your interest in this important work. Observations during our field trip to Yucca Mountain demonstrated two things in particular: (1) better understanding 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. The Board believes strongly the important work you have done in this area should be continued.

4.1.1 RESPONSE

At the May 2002 Board meeting, I introduced my vision of the Science and Technology Program, noting that one focus of this program would be activities that enhance understanding through continuous improvement in scientific understanding of the Yucca Mountain repository system. This program is managed as a separate activity from the license application. Science and technology projects are not needed to support the license application, but may provide useful information after the initial license application. One of the key focus areas of the Science and Technology Program is the natural system. Results of testing and analyses completed in the Science and Technology Program will be available after license application and can be incorporated at a later stage in the program, as appropriate.

At this same meeting in May 2002, the DOE summarized its plans for additional technical work to support the license application based on a risk-informed prioritization and emphasizing a defensible and sound technical basis for the license application, as noted above. The extensive

testing and modeling program undertaken to understand and characterize flow and transport in the unsaturated and the saturated zones at Yucca Mountain provides a sufficient basis for predicting radionuclide releases at the compliance boundary. While it is clear that enhanced understanding of the natural system is attainable, the DOE believes that the technical basis for a license application is adequate. As noted previously[1], scientific studies of the natural system will be completed in the Performance Confirmation Program to evaluate the adequacy of the technical basis that led to findings that may permit construction of a repository at Yucca Mountain.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

November 30, 2004

Dr. Margaret S. Y. Chu
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Chu:

On behalf of the Nuclear Waste Technical Review Board, I thank you and your team of DOE staff and contractors for participating in the Board's meeting on September 20, 2004, in Las Vegas, Nevada. We appreciated both your program overview and your welcome to the new Board members. The information presented at the meeting was very useful, and the field trip to Yucca Mountain on September 22 was a worthwhile and valuable experience for the new members.

In this letter, the Board provides follow-up comments on the information presented at the meeting.

Waste Management System

The Board believes strongly that waste handling and surface storage at Yucca Mountain should be viewed and analyzed as parts of an integrated waste management system that begins when waste is selected for shipment at reactor and other sites and that ends after placement of the waste in a repository. Because the many elements of a waste management system are interdependent, integrated analyses are needed to understand the viability of the system, identify possible safety and operational concerns, and optimize the system.

Issues raised in the presentation on the design of surface and underground facilities at Yucca Mountain illustrate the vital importance of integrating waste management activities as a part of facility design. For example, under current plans, fuel assemblies could be handled up to four times at Yucca Mountain before being emplaced in the repository. The Board believes that the DOE should analyze ways to minimize the number of times that fuel assemblies are handled. The Board also encourages the DOE to analyze how the aging of spent fuel in surface storage at Yucca Mountain would be used to achieve thermal goals as part of a clearly articulated thermal management strategy. Evaluating the implications of various aging scenarios should be included in this analysis.

bjg004vf

Science and Engineering

Need for Integration. The value of integrating program activities also extends to scientific and engineering activities. In particular, changes in engineering design or operations should be analyzed using Total System Performance Assessment (TSPA) to determine the potential level of significance of the effects of the changes on the overall repository system. For example, as the Board pointed out in its June 30, 2003, letter, if the repository design is modified to mitigate the effects of igneous activity, such modifications should be evaluated for their effects on repository operation and performance.

Increasing Fundamental Understanding. In the past, the DOE has increased its fundamental understanding of Yucca Mountain through a large number of scientific and engineering investigations that were part of the site characterization program. Appropriately, much of this work continues in one form or another to address existing and future scientific and technical issues. In addition, you have established the Science and Technology (S&T) program to increase fundamental understanding and to explore concepts that could improve the waste management system. Because the objectives of the S&T program are so important, the Board believes that sustaining the S&T program at or above its current level is very important.

Because several significant scientific issues remain unresolved, maintaining access to the Exploratory Studies Facility and the Enhanced Characterization of the Repository Block (ECRB) for ongoing scientific and engineering investigations is important. For example, the Drift-Scale Test, which is planned to run for 8 years, is presently in its 4-year cool-down phase. Observations of hydrogeologic changes in response to heat fluxes in this test will be needed to evaluate models that predict repository performance. Similarly, water collected in the ECRB and the possible presence of bomb-pulse chlorine-36 at the repository horizon continue to raise questions about water flow inside Yucca Mountain.

Corrosion Issues. The Electric Power Research Institute (EPRI) reported at the meeting that preliminary short-term tests with synthetic magma indicate that Alloy 22 may have significant corrosion resistance to some magmas. However, the chemical compositions of possible magmas at Yucca Mountain vary widely. Therefore, the Board believes that EPRI's results, although very important as an early indicator, do not provide a sufficient technical basis for determining the corrosion resistance of Alloy 22 in magma.

The possibility of stress corrosion cracking of the titanium drip shield also was mentioned at the meeting. The Board looks forward to receiving more information on the technical basis for the DOE's conclusions that stress corrosion cracks that completely penetrate the drip shield would be rare and that, if they did occur, would be narrow and plugged by mineral precipitates or overcome by capillary forces. We also recommend that the DOE determine the likelihood that conditions necessary for stress corrosion cracking of the drip shield would occur at Yucca Mountain.

These two issues need to be addressed within the context of other corrosion tests that should be carried out in environments that closely approximate the various conditions to which Alloy 22 and titanium will be exposed and in environments that reasonably bound those conditions. For example, the Board's July 28, 2004, letter mentions the need for further investigation of the possibilities of localized corrosion. The extent to which the DOE has characterized likely waste package environments accurately is unclear at this point.

Progress on Ground-Motion Estimates. The seismic update made clear that the program has taken significant steps toward developing realistic estimates of ground motions. The Board encourages the DOE to continue these efforts using sound physical principles to limit the proposed, very low-probability earthquake ground motions. We understand that the DOE's S&T program also is addressing this issue over a longer time frame. Of importance is that all currently planned work is continued and that short- and long-term seismic efforts are well integrated. Because of the challenging nature of the task, the analyses should be submitted to external peer review.

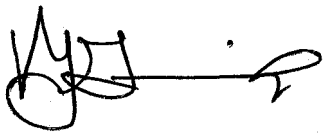
Total System Performance Assessment

The afternoon session of the meeting was devoted primarily to a presentation on TSPA, which provided an overview of significant issues and the TSPA process for the new Board members. The importance of TSPA as a part of the repository safety assessment highlights the critical need to complete the testing and validation of the process computer models and methods that support TSPA.

Within the context of TSPA, the Board has three specific interests for future Board meetings. First, we would like to review the results of the TSPA that will be submitted as part of the license application, i.e., TSPA-LA. Second, we would like to understand better the technical and integration problems associated with TSPA and model validation activities (as indicated by the red zones in the August 2004 Annunicator Panel) and how they are being resolved. Finally, the Board would like to know how TSPA and other technical activities will be affected by the court's decision to vacate the 10,000-year time period associated with the EPA standard.

Once again, I thank you and the DOE's staff and contractors for participating in the Board's September meeting. We look forward with interest to further interactions with the DOE on the topics discussed in this letter.

Sincerely,



B. John Garrick
Chairman

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

December 1, 2004

Dr. Margaret S. Y. Chu
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Chu:

On behalf of the Nuclear Waste Technical Review Board and its Waste Management System panel, chaired by Board member Mark Abkowitz, I thank your staff for participating in the panel's meeting on October 13 and 14, 2004, in Salt Lake City, Utah. The Board members found the U.S. Department of Energy (DOE) presentations informative and thought-provoking.

Transportation Planning. The Board commends the DOE on its effort in developing a systematic approach to transportation planning. Attempts to adopt such an approach were evident at the national transportation program level and within specific components of the planning effort (e.g., transportation security risk assessment). The Board believes that developing a successful transportation plan will require significant interactions, both operationally and institutionally. The following are examples of potentially fruitful areas for such interactions.

- Exchange of technical information between the DOE and the railroad industry on equipment design and system operations.
- Dialogue about technical issues between the DOE and the utilities in developing a reliable and credible schedule for the amount and types of spent fuel to be shipped.
- Exchange of technical information with other DOE and private spent-fuel transportation shippers to learn from their planning experiences.

The Board observes that presently there is not an overarching implementation organization that can develop a safe, secure, and efficient transportation system. To ensure successful technical integration, it is important for the DOE to develop specific logistical plans that identify the entity that is responsible for each system component and the key interactions required of each involved entity. A detailed strategic plan for transportation could be used to guide this effort. For example, the DOE needs to focus its attention on the transportation options within Nevada for both rail and truck. In particular, contingency plans need to be developed for higher levels of truck use in case a rail spur is not built or is delayed beyond the initiation of the shipping campaign.

bjg005vf

The Board is concerned that non-technical constraints, such as those related to schedule or budget, may compromise transportation planning. The Board urges the DOE to provide adequate resources for supporting transportation planning issues and to exercise great care in how decisions are made so that the integrity of the planning process is preserved and key technical issues that warrant serious consideration are not overlooked.

The public comment periods at the meeting provided evidence that communication between the DOE and stakeholders could be improved to ensure that the public understands the technical aspects of the program and the DOE's plans. This is particularly important in the context of the presentation on risk perception.

Security and emergency-response planning. The DOE's approach to transportation security risk assessment appears to be organized appropriately. The Board notes, however, that determining the probabilities of potentially disruptive events is very difficult. Development and use of realistic scenarios can enhance the technical basis of the overall analysis and could lead to establishment of an effective response infrastructure. Emphasis on defensive and mitigative actions should be commensurate with the likelihood and consequences of the scenarios. Risk assessment results, as they become available, should be merged into an integrated, all-hazards risk management approach that fully considers both safety and security threats.

The DOE's approach to emergency-response planning through the 180(c) program appears to be based too much on funding formulas and not enough on the underlying objective of ensuring that adequate emergency-response capability exists along all selected routes. The DOE needs to define what constitutes a minimum acceptable level of emergency response along each segment of each transport route and needs to develop a method for verifying that such capability exists. Also important is understanding the general expectations of security provisions—for example, the role of safe havens, notifications, escorts, and emergency personnel, including first responders. Shipments of foreign research-reactor fuel can provide useful information in this regard.

Transportation risk assessment. The DOE's approach to transportation risk assessment has been largely one of applying deterministic models (i.e., RADTRAN). As described at the meeting, RADTRAN appears to include several conservative assumptions. The Board was pleased to learn that version 5 of RADTRAN has the capability (using Latin Hypercube Sampling) to perform uncertainty analysis, thus providing a modeling capability more closely aligned with the Board's desire to see transportation analyses that are more risk-based and realistic. After code testing and validation, we look forward to seeing transportation risk results based on RADTRAN 5.

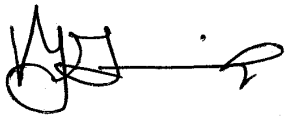
Related to assessing transportation risks is the Package Performance Study being planned by the U.S. Nuclear Regulatory Commission (NRC). The Board would like to be kept informed on the status of the NRC study. We are particularly interested in the technical adequacy of the test program in which the rail cask will be tested and how the tests will be used to validate the models used in other cask designs, such as those used for truck shipments.

Route selection. Evaluation and designation of shipment routes by the DOE is important. This topic is of great interest to stakeholders along selected transportation corridors. Closely related is the decision on using dedicated trains, because a decision not to use dedicated trains could limit the routes available for consideration. The Board believes that it is appropriate to involve state regional groups in establishing routing criteria and recommending preferred routes, although the variation in views of these groups on this issue is evident. Moreover, tribal groups may not be adequately represented in these deliberations. To ensure that the state regional groups are successful in their efforts, this process must be managed carefully and diligently. Of particular importance, the DOE needs to ensure that the technical issues involved in route selection are identified and that sound methods for addressing the issues are developed and applied.

Program integration. The DOE presentations did not demonstrate the degree of program integration needed to ensure that the transportation system will operate successfully. The DOE needs to plan for and be able to demonstrate harmonization of cask design, fleet acquisition, waste acceptance, operational practice, and other activities that must be carried out at reactor sites, during shipping, and at the repository. The Board looks forward to further discussion of program integration in future meetings.

Thank you again for the DOE's support of this meeting.

Sincerely,



B. John Garrick
Chairman

Department of Energy
Washington, DC 20585

QA: NA

January 26, 2005

B. John Garrick, Ph.D., P.E.
Chair, Executive Committee
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, VA 22201-3367

Dear Dr. Garrick:

Thank you for the Nuclear Waste Technical Review Board's (Board) letter of July 28, 2004, providing the response to the information presented by the U.S. Department of Energy (Department) at the May 18-19, 2004, meeting of the Board. The Department appreciates the Board's continuing review of our activities as we work to develop and document the technical basis for the License Application for a repository at Yucca Mountain. Our responses to the Board's views and recommendations are summarized in the enclosure to this letter.

The Department continues to benefit from the constructive views of the Board, and we look forward to further dialog on our repository design and related issues.

Sincerely,

Margaret S.Y. Chu, Ph.D.
Director
Office of Civilian Radioactive
Waste Management

Enclosure

U.S. DEPARTMENT OF ENERGY (DOE) RESPONSES TO THE JULY 28, 2004, LETTER FROM THE NUCLEAR WASTE TECHNICAL REVIEW BOARD (BOARD)

Corrosion Issues

Calcium chloride-rich environment

Based primarily on information presented at the Board's May 2004 meeting, it appears unlikely that dusts that accumulate on waste package surfaces during the preclosure period would contain significant amounts of calcium chloride or that significant amounts of calcium chloride would evolve on waste package surfaces during the thermal pulse. Consequently, the calcium chloride-rich environment selected for corrosion tests does not appear representative of the conditions that can be expected on waste package surfaces in a Yucca Mountain repository. If calcium chloride is not present, calcium chloride-rich brines will not form by deliquescence, and crevice corrosion due to the presence of such brines in the temperature range of roughly 140°C to 160°C will not occur. Thus, the Board concludes that deliquescence-induced localized corrosion during the higher-temperature period of the thermal pulse is unlikely.

Response

We agree with the Board that calcium chloride type deliquescent brines are very unlikely to exist or be stable at Yucca Mountain. In addition, the soluble constituents in the potential dust deposits that could be present on the drip shield and waste package surfaces are rich in beneficial inhibiting ions including nitrate and to a lesser extent sulfate ions. In the presence of these anions, even in the unlikely case where calcium chloride type brines were to form and to remain stable, they would not support localized corrosion. The effect of nitrate on inhibiting localized corrosion in these type brines is quantified and documented in the updated Analysis Model Report on general and localized corrosion of waste package outer barrier. Expected benign response of Alloy 22 exposed to these types of calcium chloride rich deliquescent brines is corroborated by the technical bases discussed in the Electric Power Research Institute's presentation to the Board at the May 2004 meeting (Kessler, J. et al. 2004).

Although we agree that calcium chloride type brines are very unlikely to exist or be stable at Yucca Mountain, other chloride brines with varying amounts of corrosion inhibitors, such as nitrate and sulfate, may be present at elevated temperatures. Understanding the localized corrosion behavior of Alloy 22 given such conditions is important. Thus, the Project is continuing to evaluate the localized corrosion response of Alloy 22 over a broad range of potential salt brine compositions and over the full range of relevant temperature, relative humidity, pH values, etc. For example, the corrosion response in sodium-potassium mixed salts is being evaluated. Current measurements indicate there is a potential for some of these saturated $NaCl$-$NaNO_3$-KNO_3-H_2O type deliquescent brines to boil at maximum temperatures on the order of 200°C. To date, DOE has not found that significant corrosion damage will occur under these deliquescent salt conditions. However, the likelihood of formation and

consequences of these high-temperature brines are being analyzed further to assess the potential for localized corrosion to occur under high temperature conditions.

Characterization of waste package environment

Ideally, corrosion tests should be carried out both in environments that closely approximate the various conditions to which the waste package alloy will be exposed and in environments that reasonably bound those conditions. The extent to which the DOE has characterized accurately the likely waste package environments (i.e., temperature, relative humidity, and chemical species present) is unclear at this point. Accurate characterization of probable waste package environments and the corrosion response of the waste package alloy to those environments will continue to be a major focus of the Board's technical and scientific review.

Response

The projected range of environments that could potentially be present on the waste package surface represents a heterogeneous matrix that will vary with time as the in-drift temperature and relative humidity change. Consequently, the Project has chosen to evaluate the Alloy 22 general and localized corrosion response over a broad range of potentially relevant as well as bounding test environments.

The types of environments expected on the waste package surface over 10,000 years were summarized for the Board at the May 2004 meeting. In addition, the likely concentrated brine environments and their expected frequencies and uncertainties have been calculated based on modeled repository-relevant seepage waters and the modeled behavior of soluble species in dust deposits. Although the frequency of different types of brines was not addressed at the May 2004 meeting, the results were recently documented. Because ranges of geochemical and thermal-hydrologic conditions are possible, there is a range of brine environments that could potentially form on the waste package surface depending on temperature, relative humidity, and the presence of intact drip shields. For the expected case, with the drip shield function intact, expected brines are of the sodium nitrate, potassium nitrate, sodium chloride, or calcium nitrate types. Dust samples collected in the tunnels at Yucca Mountain have been analyzed and grouped to summarize the types of deliquescent brines that could form. Only a few of the dust samples analyzed indicate that a calcium nitrate type brine could form. Deliquescent brines cover a pH range from approximately 6 to 12, depending on brine type and the CO_2 partial pressure. The associated chloride concentration varies from to 1 to 8 molal and decreases with increasing relative humidity. Dissolved fluoride concentrations vary from approximately 10^{-6} molal to 0.3 molal, depending on the individual brines. The nitrate concentrations are greater at lower relative humidity (higher temperature) and decrease at lower temperature (increasing relative humidity). As a result, the nitrate to chloride molal ratio will vary from approximately 0.4 to 26, i.e., well into the beneficial range where nitrate acts as a localized corrosion inhibitor.

Currently work is underway to evaluate the following conditions:

- The amount and composition of dust on waste packages as well as the volume of brine and quantities of dissolved salts, and assess the significance of any acid-gas volatilization.
- Assess the deliquescence-related properties of ammonium salts.
- Study the effects of any chloride-containing silicate minerals or minerals containing hydroxide, which can be replaced by chloride.
- Document the argument(s) for exclusion of localized corrosion of the waste package outer barrier due to the deliquescence of dust constituents.

As mentioned earlier, past and currently ongoing corrosion tests encompass the range of these predicted environments.

Localized corrosion at below boiling temperature

First, the DOE raised the possibility that when temperatures in repository tunnels fall below boiling, localized corrosion could occur in concentrated sodium chloride solutions with low concentrations of inhibitors. The Board believes that further investigation of the possibilities for localized corrosion at below-boiling temperatures is warranted and that such an investigation should focus on (1) possible mechanisms that might create environments that would facilitate localized corrosion and (2) the likelihood that such environments could exist.

Second, the presence of ammonium ion and the implications of its presence for corrosion or other performance aspects need to be explained

Response:

Extensive Alloy 22 localized corrosion test results have been used to develop a localized corrosion predictive model that covers the below boiling temperature range as well as higher temperatures (BSC 2004a). The model quantifies the beneficial effect of soluble nitrate (calculated to be present in all concentrated seepage and deliquescent brines that might form on the waste package surface) and conservatively incorporates a threshold nitrate/chloride molal ratio of 0.5 or greater to rule out localized corrosion at temperatures up to 160°C. Although the model does not take credit for other beneficial anions such as sulfate, carbonate, and bicarbonate, experimental results indicate the presence of these anions (as well as nitrate) contributes to inhibition of localized corrosion (Dunn et al. 2004 and BSC 2004b).

At temperatures near the boiling point (about 96°C at the repository elevation), the projected waste package relative humidity will range from about 35-100 percent and will increase with decreasing temperature (BSC 2004c). With the drip shields intact, any seepage brines will be diverted; and, thus, waste package surface brine environments will result only from deliquescence of soluble salts present in surface deposits. Because the deliquescent dust constituents form brines that have nitrate to chloride molal ratios of at least 0.4 for any exposure condition, localized corrosion will likely be inhibited.

The drip shield is expected to perform its design function of seepage diversion for the next 10,000 years. Even if the drip shields were to fail, it is estimated that only a small fraction (1

percent) of the seepage brines could evaporatively concentrate into concentrated chloride brines (BSC 2004c). In general, the nitrate to chloride ion ratio in seepage brines tends to be lower than for the dust deliquescent brines. The localized corrosion model implemented in the total system performance assessment-license application initiates localized corrosion if the nitrate to chloride ion ratio is less than 0.5. The value of 0.5 was conservatively selected, and no localized corrosion has been observed in expected lower temperature Na, K, Cl, NO_3 brines and sulfate brines under open circuit potential conditions for nitrate to chloride ratios between 0.05 and 0.5 (Payer 2004). Under accelerated cyclic potentiostatic polarization conditions, inhibition of localized corrosion, i.e., $E_{corr} < E_{crit}$. was observed at chloride to nitrate ratios above 0.15 at 80°C (Payer 2004).

It is evident that a minimum nitrate concentration is needed to counteract the aggressive nature of the chloride ion at the surface of the passive film. The mechanisms for nitrate inhibition of localized corrosion are likely to involve:

1. Electro-reduction of the nitrate ion to the ammonium ion leading to a beneficial increase in local pH in the creviced regions.

2. Electro-reduction of the nitrate ion to atomic nitrogen, followed by adsorption of nitrogen on the depassivated metal in the crevice or at the base of an incipient pit. In this case, nitrogen may act as an anodic site blocker. Once adsorbed, nitrogen might then undergo further reduction to the ammonium ion.

The ongoing ammonium studies are addressing the importance of ammonium salts as they may affect the volatilization of nitrate, and solution conditions that result from the behavior of ammonia. Our current understanding based on handbook data and published literature is that ammonium nitrate and ammonium chloride, two common constitutents of atmospheric dust, will volatilize completely on the waste package surface either during preclosure ventilation or within a few years afterward. Ammonium sulfate and bisulfate salts are less deliquescent and relatively nonvolatile.

The currently available data on the ammonium content in dust comes from reanalysis of tunnel dust samples, and from the National Airfall Deposition Program monitoring data (collection station at Red Rock). These data indicate that ammonium and nitrate have generally comparable molalities, so there is the potential for volatilization of nitrate (e.g., as HNO3 or N2O). Understanding the extent to which nitrate in the dust analyses is incorporated in nonvolatile compounds (NaNO3 and KNO3) depends on the partitioning of ammonium among the various common atmospheric compounds. We are investigating the literature for atmospheric chemistry to establish this partitioning and its uncertainty.

Volatilization of ammonia from deliquescent brine could lower brine pH, but there is ample buffering capacity associated with the silicate mineral constituents of the dust, to maintain brine pH in the neutral range.

Third, the State of Nevada suggested that nitrates could be aggressive corrodents in some circumstances. The Board believes that it would be worthwhile to review existing corrosion data

to determine whether they bound nitrate-containing environments that reasonably could be anticipated at Yucca Mountain.

Response:

The State of Nevada studies used an unrealistic experimental design involving the collection and condensation of acidic gas volatiles (e.g., HNO_3 and HCl) from evaporation of groundwaters (Pulvirenti, et al. 2004). It is more likely that in the open repository system these volatiles will disperse to the drift wall and become neutralized by reaction with the surrounding rock. In this way, acid-gas volatility will limit, rather than increase, the development of low pH (acidic conditions) on the waste package surface. Exposure environments such as the one created *in vitro* by Pulvirenti et al. (2004) are not realistic or expected repository environments.

As mentioned earlier, DOE has focused on evaluating corrosion behavior over a broad range of potentially relevant and accelerated test environments. Based on the results of the Physical and Chemical Environment model (BSC 2004c), the calculated maximum chloride concentration in the range of relevant seepage and deliquescent concentrated brines is about 13 molal, and the calculated maximum nitrate concentration is about 28 molal. In comparison, existing cyclic polarization data for creviced specimens include a broad range of chloride and nitrate concentrations up to 36 molal chloride plus 18 molal nitrate tested at 160°C. This essentially bounds the expected maximum nitrate levels for the full range of seepage and deliquescent dust brines. There appears to be no deleterious effect of nitrate concentration on the general corrosion rate. For example, test results for Alloy 22 covering a range of nitrate levels up to and above the calculated maximum nitrate level of 13 molal were reported at the May 2004 Board Meeting (Payer 2004). Also, specimens exposed in 2.7 molal NaCl + 15.1 molal KNO_3 for 158 days at temperatures up to 160°C exhibited very low corrosion rates of <0.2 μm/year. In addition, a limited amount of cyclic polarization data have been collected in concentrated nitrate solutions at high temperatures (e.g., 22.5 m $Ca(NO_3)_2$ + 0.225 m $MgCl_2$ at 145°C and 15 m $Ca(NO_3)_2$ + 1.5 m $CaCl_2$ at 125°C). No hysteresis was observed and no evidence of localized corrosion was found indicating that nitrate ions are beneficial to localized corrosion resistance even at high concentrations and at higher exposure temperatures.

Integration

DOE contractors have been performing corrosion tests at high-temperatures in high-chloride brines for several years, presumably because it was thought that the test conditions might occur at Yucca Mountain or might reasonably bound actual conditions. However, as became clear as a result of presentations at the May 2004 meeting, geochemical considerations preclude high-temperature, high-chloride brine conditions at Yucca Mountain, rendering the corrosion tests of limited relevance. This situation underscores the need for thorough integration and close cooperation among diverse technical disciplines, particularly when "coupled" processes are involved. For example, excellent integration among geochemists and corrosion scientists/engineers was evident at the meeting and helped bring clarity to an extremely important corrosion issue. Continuing integration will be necessary for resolving other issues associated with the DOE's current repository design.

Response

We agree that integration among diverse technical disciplines is an important element of assuring that there are no unintended gaps or inconsistencies between the models, data, and parameters developed and implemented by analysts in these different disciplines. The example cited by the Board of the calcium chloride, high-temperature corrosion test conditions not being representative of potential geochemical conditions at Yucca Mountain is a good example of the need for assuring such integration takes place. However, we disagree that these tests were of little relevance. Defining the corrosion potential and critical potential of Alloy 22 over a range of possible environmental conditions, including but not limited to high-chloride conditions and high-temperature conditions, was (and continues to be) an important element of the corrosion testing program. Although we agree that calcium chloride type brines are very unlikely to exist or be stable at Yucca Mountain, other chloride brines with varying amounts of corrosion inhibitors, such as nitrate and sulfate, may be present at elevated temperatures. Given such conditions, understanding the localized corrosion behavior of Alloy 22 is important. The tests cited by the Board give additional lines of evidence to support the confidence in the model when extrapolated to such conditions. Because a range of geochemical and thermal-hydrologic conditions are possible on the waste package surface, DOE intends to test Alloy 22 over this range and to extend the range to bound the possible behavior of the Alloy in extreme environments. This notwithstanding, the need for continued integration among diverse scientific and engineering disciplines remains an ongoing area of focus for the Department, particularly in the area of coupled processes.

Hydrology and Thermohydrology Issues

After reviewing the information presented at the May 2004 meeting, the Board continues to question the pervasiveness of vaporization and capillary barriers because of persistent uncertainties related to the expected repository tunnel environments. Examples of uncertainties include (1) the conceptual basis for the drift-scale thermohydrologic seepage analysis, including the axial convective transport of water vapor, air, and thermal energy in drifts; (2) the source of liquid water observed in the bulkheaded part of the cross drift; (3) the effects of drift degradation on the waste package environment; and (4) potentially unrealistic combinations of parameters used in the performance-assessment calculations of seepage.

The Board understands that significant scientific challenges are associated with analyzing the complex hydrology at Yucca Mountain, especially when the repository is subject to a large thermal perturbation. However, the Board believes that addressing uncertainties such as those noted above could create a more solid technical basis for determining whether the DOE's high confidence in the effectiveness of capillary and vaporization barriers is warranted.

Response

The pervasiveness of a capillary barrier has been tested and verified in both the middle nonlithophysal and lower lithophysal repository units. The testing ranges from several-meter scale in the niches to tens-of meters scale in Alcove 1 and Alcove 8-Niche 3. That a seepage threshold (orders of magnitude larger than predicted infiltration) exists has been shown by the

field tests and their analysis, although the performance calculation employs a more conservative approach in selecting the seepage relevant parameters. All of the field tests are incorporated into relevant seepage models.

As for the effectiveness of a vaporization barrier, modeling addressing explicitly model uncertainties and parameters uncertainties, including effects of drift degradation, has been performed. However, at the present time, field data that directly address the issue of seepage under thermal conditions and hence the pervasiveness of the vaporization barrier do not exist. If appropriate and consistent with the Department's safety case, experimental investigations along these lines may be considered in the future to add confidence in the effectiveness of a vaporization barrier.

Seismic Update

We were very pleased to learn from the update at the May 2004 meeting that the DOE has initiated a program aimed at deriving more realistic estimates of seismic hazard at the Yucca Mountain site. In its June 27, 2003, letter to you, the Board indicated its concern about what may be physically unrealizable estimates of very low-probability (annual probabilities of exceedance of 10^{-6} or less) seismic ground motion being calculated for Yucca Mountain by the DOE and its contractors. The new program appears to be a thoughtful first step. It is based on using the extent of fracturing observed in the tunnels at Yucca Mountain to limit the ground motions that could have taken place at the site during the last 10 million years. As discussed in our June 2003 letter, deriving limits to low-probability ground motions will be challenging. We therefore urge the DOE to implement an external peer review of these efforts.

Response

The Department is pursuing both mid- to long-term and short-term activities to establish limits on low-probability earthquake ground motions. An external peer review of these efforts would be premature as they have just begun. However, the Department is actively soliciting input from the cognizant technical community in formulating its plans.

The longer term activities are being conducted under the Science and Technology (S&T) program, which has as a goal the achievement of a fundamental advancement in the approach to probabilistic seismic hazard analysis. The timeframe for this effort is 5-10 years. This advancement is envisioned to involve numerical modeling of ground motion from specific faults and nonlinear propagation of seismic waves from the source to the locations of engineered facilities. Limits on low-probability ground motions will be incorporated through empirical and theoretical limits on seismic source parameters and nonlinear material properties along the propagation path. The S&T program has established a review panel with the charter of recommending research activities to further the program's objectives. The panel is focusing, first, on research to establish limits on extreme ground motions. The panel conducted a workshop on this subject on August 23-25, 2004, in Menlo Park, California, and is preparing its recommendations at this time.

The Office of Repository Development also is pursuing activities to develop a technical basis for limiting low-probability ground motions, but in a timeframe (12-18 months) that will allow the results to be used to support the licensing hearings and the final design of the repository. This shorter term effort likely will focus on (1) the observation that the rocks at Yucca Mountain, which are over 10 million years old, do not appear to have been fractured by extreme earthquake ground shaking and (2) numerical modeling of the propagation of seismic waves through the mountain, accounting for the finite strength of the rock. To obtain input from the cognizant technical community on the specific activities to be conducted, the Office of Repository Development conducted a workshop in Las Vegas, Nevada, on September 28-29, 2004.

Transportation Planning

Information presented at the May 2004 meeting indicates that real progress is being made in planning a transportation system for a Yucca Mountain repository. The timelines that the DOE presented at the meeting identify several important milestones that your Office of National Transportation plans to develop further into detailed project plans with cost, schedule, and technical baselines. The Board's Panel on the Waste Management System has tentatively scheduled a meeting for October 13-14, 2004, in Salt Lake City, Utah. We look forward to a more detailed review of progress in transportation planning at that time. We also would like to discuss aircraft hazard and public perceptions of transportation risk at the panel meeting.

Response:

DOE appreciates the Board's recognition of the progress being made in planning a transportation system for the Yucca Mountain repository. In the meeting of the Panel on Waste Management System held last month in Salt Lake City, DOE gave an update on more recent activities in the transportation area. DOE is committed to working with the States and local entities, and the Tribes in a cooperative manner to address transportation issues relative to the Yucca Mountain repository, such as routing and emergency response training similar to the Foreign Research Reactor and Waste Isolation Pilot Plant programs.

References

Dunn, D. S., L. Yang, C. Wu, and G. A. Cragnolino. 2004. "Effect of Inhibiting Oxyanions on the Localized Corrosion Susceptibility of Waste Package Container Materials." *Scientific Basis for Nuclear Waste Management XXVIII,* edited by John M. Hanchar, Simcha Stroes-Gascoyne, and Lauren Browning. Mater. Res. Soc. Symp. Proc. Vol. 824. Warrendale, PA. Pp.CC1.7.1-CC1.7.6.

BSC (Bechtel SAIC Company) 2004a. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier.* ANL-EBS-MD-000003 REV 02. Las Vegas, Nevada: Bechtel SAIC Company.

BSC 2004b. *Critical and Corrosion Potential For Alloy 22,* Appendix O, Technical Basis Document No.6: Waste Package and Drip Shield. Las Vegas, Nevada: Bechtel SAIC Company.

BSC 2004c. *Multiscale Thermohydrologic Model.* ANL-EBS-MD-000049 REV 02. Las Vegas, Nevada: Bechtel SAIC Company.

Kessler, J., D. Langmuir, F. King, and M. Apted. 2004. *Analysis of NWTRB's Scenarion Regarding Localized Corrosion by Formation of High-Temperature Deliquescent Brines.* Presentation at the Spring Nuclear Waste Technical Review Board Meeting, May 18-19, 2004. Washington, D.C.

Payer, J. H. *Corrosion Potential of Alloy 22*. Presentation at the Spring Nuclear Waste Technical Review Board Meeting, May 18-19, 2004. Washington, D.C.

Pulvirenti, A. L., K. M. Needham, M. A. Adel-Hadadi, and A. Barkatt, 2004. *Multi-Phase Corrosion of Engineered Barrier Materials.* CORROSION 2004, Paper No. 04694.

Department of Energy
Washington, DC 20585

QA: NA

February 1, 2005

Dr. B. John Garrick
Chairman
U.S. Nuclear Waste Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

Dear Dr. Garrick:

Thank your for your letter of December 1, 2004, providing the Nuclear Waste Technical Review Board's (Board) comments on the information presented by the U.S. Department of Energy's (Department) Office of Civilian Radioactive Waste Management (OCRWM) at the October 13 and 14, 2004, meeting of the Board's Waste Management System panel. We appreciated the opportunity to inform the Board about the progress in the transportation portion of the OCRWM Program as discussed by members of my staff from the Office of National Transportation. Our responses to the Board's views and comments are summarized in the enclosure to this letter.

The Department continues to benefit from the constructive views of the Board. We look forward to further dialogue on technical issues pertinent to transportation and the repository program at future Board meetings.

Sincerely,

Margaret S.Y. Chu, Ph.D.
Director
Office of Civilian Radioactive
Waste Management

Enclosure

ENCLOSURE

U.S. DEPARTMENT OF ENERGY (DOE) RESPONSES TO THE DECEMBER 1, 2004, LETTER FROM THE NUCLEAR WASTE TECHNICAL REVIEW BOARD (BOARD)

TRANSPORTATION PLANNING

COMMENT

There is no overarching implementation organization in the Office of Civilian Radioactive Waste Management (OCRWM) that can develop a safe, secure, and efficient transportation system.

RESPONSE

The Office of National Transportation (ONT) is responsible for developing, building, operating, and managing a national transportation system to ship spent nuclear fuel (SNF) and high-level radioactive waste (HLW) in a safe, secure, and efficient manner to a repository and, as such, is the overarching implementation organization within OCRWM. ONT manages two projects, National Transportation and Nevada Transportation. The Nevada Transportation Project is responsible for developing the transportation infrastructure in Nevada, primarily a railroad for connecting the repository to existing mainline track in the State. The National Transportation Project is organized into four subprojects: (1) Cask Acquisitions, (2) Rolling Stock Acquisitions, (3) Operations, and (4) Institutional. ONT has the responsibility for integrating these projects with the Office of Repository Development, with the Waste Acceptance Office, and with a broad range of stakeholders to ensure the transportation system is safe, secure, and efficient. In addition to ONT's integration responsibilities, OCRWM also has an Office of Systems Analysis and Strategy Development which is responsible for organizational integration as part of its strategic planning charter.

COMMENT

Specific logistical plans need to be developed that identify what entity is responsible for each system component and the key interactions required of each involved entity.

RESPONSE

We agree. ONT is building the foundation for transportation operations. Project plans are being developed that show responsibilities for the various transportation project elements and the interfaces required for each activity. A conduct of operations plan and specific campaign plans will be developed after key decisions are made regarding policy and technical issues such as the use of dedicated trains, and cask and rail car acquisition. While these plans are not complete at this point in the program, ONT is aggressively

putting the foundation in place to develop detailed plans for shipping, taking into account systems analyses and logistical modeling results. A logistics model is being developed at Sandia National Laboratories specifically for the OCRWM transportation program. Development of detailed shipment logistics are also tied to funding and to progress for the repository as a whole. The OCRWM Program Plan (an internal management document) spells out roles and responsibilities for each element of the organization.

COMMENT

DOE needs to focus its attention on the transportation options within Nevada for both rail and truck. In particular, contingency plans need to be developed for higher levels of truck use in case a rail spur is not built or delayed beyond the initiation of the shipping campaign.

RESPONSE

The Department notes the recommendation to develop contingency plans in the event of delays. We are investigating various contingencies at this time; however, our transportation planning already envisions a mix of transport modes as part of the system due to physical and operational constraints at reactor sites. Logistical planning will constantly be adjusted to reflect the status of the program, decisions by States to designate alternative highway routes, and the status of shipping sites. Operational decisions will not be finalized until several years before the first shipment.

COMMENT

Communication between DOE and the stakeholders could be improved to ensure the public understands technical aspects of the program, particularly in the context of risk perception.

RESPONSE

We do have a robust and proactive institutional program that is working with stakeholders to develop the transportation system, both for the Nevada rail corridor and for national transportation activities. We appreciate and agree about the need for the public to understand this program and have fully funded the institutional project to support the public information and public involvement aspects of the transportation program. Our approach has been first to work with various groups we believe are the correct ones to provide unbiased information to their constituents. An example of working with key stakeholders is the coordination in place with four State regional organizations: the Midwestern Regional and Northeastern Regional Offices of the Council of State Governments, the Southern States Energy Board and the Western Interstate Energy Board. These organizations and their State committee members are working with ONT to develop the plans for Section 180(c) policy implementation, public information and outreach plans, and coordination with local officials, routing determinations, and other similar transportation issues.

SECURITY AND EMERGENCY RESPONSE PLANNING

COMMENT

Risk assessment results should be merged into an integrated, all-hazards risk management approach that fully considers both safety and security threats.

RESPONSE

DOE appreciates the Board's concern that safety and security should be complimentary activities and will take into consideration the all-hazards risk management approach as it develops the transportation system. Traditional risk analysis techniques cannot be applied directly to terrorist acts since the probability of an attack cannot be ascertained; therefore, we are using a systematic approach that considers the consequences of a variety of threat scenarios and assesses threat mitigation options. In much the same way, we are taking actions to mitigate the consequences of accidents by using Nuclear Regulatory Commission (NRC) certified casks and the highest quality rail cars and by supporting emergency preparedness training. In addition, we are coordinating with the DOE's Office of Security and Safety Performance, the Departments of Homeland Security and Transportation, and industry to establish the appropriate transportation system to ensure both security and safety for OCRWM shipments.

COMMENT

DOE needs to define what constitutes a minimum acceptable level of emergency response along each segment of each transport route and needs to develop a method for verifying that such capability exists.

RESPONSE

Basic emergency preparedness is in place in States and local communities to respond to all hazardous materials transportation accidents, including those that have a much higher risk of immediate death or injury than do SNF or HLW. OCRWM will address the incremental level of preparedness associated with the risk of our shipments by providing the funding and technical support envisioned by Congress for State and Tribal governments. This support includes funding for planning and training activities under Section 180(c) of the Nuclear Waste Policy Act (NWPA) and technical assistance for training and exercises associated with emergency preparedness and transportation operational readiness.

DOE has articulated in prior 180(c) policy documents that the minimum level of response is that of awareness-level understanding for the shipments made under the NWPA. To achieve awareness-level capability, the State and Tribal governments along the routes will be provided funding and technical assistance such as train-the-trainer and exercise support with participation by DOE. Validation of preparedness capabilities would occur through planned readiness reviews and exercise programs, modeled after the Foreign

Research Reactor shipping program experience cited by the Board. In addition, we believe that it is important for the Board to recognize the role the local governments have in ascertaining whether a responder is prepared for the kinds of risks posed by hazardous shipments through their districts. The employer certifies the readiness of its employees. In addition, State and Tribal governments are responsible for maintaining emergency preparedness plans and coordinating training with local officials so that an integrated response system is in place.

COMMENT

Also important is understanding of the general expectations of security provisions, safe havens, notifications, escorts, and emergency personnel, including first responders.

RESPONSE

DOE has promulgated guidance for all shipping programs through the *Radioactive Materials Transportation Practices Manual*, DOE Order 460.2 M. OCRWM supported the development of the Manual, which outlines the Department's guidance on procedures to be followed by any DOE shipper. The Department's actions with regard to notifications, safe havens (which are for emergencies as much as for security), escorts, and emergency preparedness are articulated in the Manual. In addition, stakeholders reviewed the Manual during its development. OCRWM expects to update the practices applicable to its shipments starting in 2006 and will use a process similar to that used to develop the Manual to obtain input from our key stakeholders using the Transportation External Coordination (TEC) Working Group and the State regional groups for review of any additions or changes.

OCRWM will develop Transportation Campaign Plans to describe the roles and responsibilities for conducting specific shipments and will outline the steps and coordination needed for those shipments. The Transportation Plans will be developed prior to actual shipments and will involve State and Tribal officials, other appropriate Federal agencies, and the carriers in the planning process.

TRANSPORTATION RISK ASSESSMENT

COMMENT

DOE's approach to transportation risk assessment has been largely one of applying deterministic models (i.e., RADTRAN).

RESPONSE

RADTRAN 5, including the Latin Hypercube Sampling (LHS), was thoroughly tested and validated before 1999. RADTRAN is a probabilistic model rather than a deterministic one. The ability to distribute input as a complementary cumulative distribution function has been available to all RADTRAN users since 1998. Results

using this option have been published, notably in NUREG/CR-6672. The LHS option has not been available outside Sandia since January 2004; this is a temporary situation resulting from the shutdown of TRANSNET and the porting of RADTRAN, in 2003, from the Sandia server to a downloadable executable form. The LHS option is still available internally at Sandia, and we will continue to perform LHS analyses on request until LHS becomes available as a download (probably by early 2006). Even when RADTRAN uses single values of input parameters, probability is incorporated into the output, which reflects the risk triplet. This is particularly evident in the accident analysis: RADTRAN multiplies the conditional probability of each accident scenario by the appropriate dose, sums the products, and then multiplies by the estimated accident frequency. The result is reported as a "dose risk." Since the probability of incident-free transportation is negligibly different from unity, results are reported as doses rather than "dose risks."

COMMENT

The Board would like to be kept informed on the status of the NRC Package Performance Study.

RESPONSE

DOE will be pleased to share information it has relative to the Package Performance Study with the Board; however, conduct of the Package Performance Study is within the purview of the NRC. We have and will continue to support NRC's study activities. DOE cannot speak for the status of NRC activities and recommends that the Board contact the NRC directly relative to any issue pertinent to this request.

ROUTE SELECTION

COMMENT

DOE needs to ensure that the technical issues involved in route selection are identified and that sound methods for addressing issues are developed and applied.

RESPONSE

We agree with the Board that sound methods to address routing issues be developed and applied to the program. In this regard, DOE is using a decision model tool that Sandia National Laboratories has developed as part of the routing criteria development work underway with State regional groups and the TEC Working Group. In addition, ONT provided training on RADTRAN, TRAGIS, and the decision model for State officials in January. These analytical tools are being provided to State and Tribal decision makers and staff for their use as we work together to develop regional suites of routes for the OCRWM shipments. The next TEC meeting will have several smaller workshops to allow participants to become more familiar with the routing decision model.

COMMENT

Tribal groups may not be adequately represented in the deliberations establishing routing criteria and recommending preferred routes.

RESPONSE

DOE is sensitive to the needs of Tribal governments and it is our intention to work with Native American Tribal governments on a government-to-government basis to identify their preference for consultation and coordination. We expect to initiate visits to Tribes potentially impacted by future shipments to Yucca Mountain to discuss issues regarding emergency preparedness, information exchange, and coordination with their technical staff or leadership.

In addition, the TEC Working Group Tribal Issues Topic Group is an important resource for developing approaches to interacting with Tribes and discussing issues such as routing, emergency planning and funding, and security. Established in 1998, the Topic Group addresses government-to-government consultation between DOE and Tribes affected by its transportation activities, and has active tribal participation, which we expect to expand.

PROGRAM INTEGRATION

COMMENT

The DOE presentations did not demonstrate the degree of program integration needed to ensure the transportation system will operate successfully. DOE needs to plan for and be able to demonstrate harmonization of cask design, fleet acquisition, waste acceptance and operational practice, and other activities that must be carried out at reactor sites, during shipping, and at the repository. The Board looks forward to further discussion of program integration in future meetings.

RESPONSE

We will be happy to present the status of program integration activities at the next Board meeting. We look forward to further discussion. We believe that the systems are fully integrated because of ongoing work with the repository on cask acquisition, rail interface, and cask handling requirements for repository site operations. Cask integration meetings are held regularly to integrate the repository's operating needs with the design of transportation casks. Integration of aging cask designs with transportation cask designs is another area of integration between transportation and the repository design effort. ONT is also working with OCRWM's waste acceptance organization on transportation interfaces with the utilities. These interfaces address facility capabilities that affect cask and rolling stock specifications and operating plans.

Department of Energy
Washington, DC 20585

QA:NA

March 31, 2005

B. John Garrick, Ph.D.
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, VA 22201-3367

Dear Dr. Garrick:

I have appreciated the interactions we have had to date on the Yucca Mountain project. I want to be responsive to the Board's requests and continue to address your concerns. In that light, I have been "clearing the deck" of old correspondence. I realized we had still not replied to some of the issues contained in your November 30, 2004 letter. As you know, we previously responded to your transportation issues.

The enclosure addresses particular areas of your November 30, 2004, letter which I think are important for us to provide additional information.

Again, my apology for not responding sooner. I look forward to our future discussions.

Sincerely,

Theodore J. Garrish
Deputy Director
Office of Civilian Radioactive
Waste Management

Enclosure

Enclosure

Systems Integration and Stress Corrosion Cracking of the Titanium Drip Shield

The Department agrees with the Board's assessment of the importance of systematic integration and assessment of waste management activities to optimize the system as a whole and, in particular, the relationships between science and engineering. We were pleased to be able to discuss our two-tiered approach to systems integration and analysis at the Board's Winter Meeting. The upper-tier approach, known as the total system model (TSM), was initiated in early fiscal year (FY) 2004 while the lower-tier approach, known as throughput modeling, was started around the middle of FY 2004.

The TSM is a high-level model created to help estimate the logistic and cost impacts of various operational scenarios in acceptance, transportation, handling and emplacing of radioactive wastes. The TSM tracks waste shipments from the waste generating and storage sites through emplacement within the repository at Yucca Mountain, Nevada. Waste forms currently modeled in the TSM are commercial spent nuclear fuel (SNF), the Department's SNF, and defense high-level waste. The TSM also provides logistic information regarding the Civilian Radioactive Waste Management System, including information relative to the waste stream movement and the system resources (casks and their carriers) required to accomplish that movement. The lower-tier work is a suite of detailed models and studies, known generically as throughput models, and is focused on the throughput capability of each of the individual waste handling facilities at Yucca Mountain, Nevada.

The integration of the upper-tier TSM with the lower-tier throughput models helps represent the existing state of design. In the future, as these models are refined and enhanced, the TSM will support the waste management and related strategies; and the throughput models will support facility development and optimization.

Changes in engineering design or operations that have a potential to affect postclosure performance are and will be evaluated before they are formally incorporated in the baselined design. Postclosure impacts of potential changes in design and operations will be partially evaluated through preliminary sensitivity analyses by using the Total System Performance Assessment before moving forward with final design specifications. Such sensitivity analyses have been performed in the past and will be conducted using the LA design and models as appropriate. The Yucca Mountain Project (Project) activities, such as performance assessment and repository design, are carried out in accordance with a rigorous change control process to ensure integration.

At the Board's Winter Meeting, we briefly discussed Stress Corrosion Cracking (SCC) of titanium drip shields and consequences of the SCC. These topics are more fully addressed in the Project document, "Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material" (ANL-EBS-MD-000005, Revision 02). The model assumes that the drip shields will be subject to rockfall-induced residual stresses and will undergo SCC, independent of the environment, if the residual stresses exceed specified thresholds (50 percent of the yield stress). The report addresses the basis for the plugging of the cracks by mineral deposits and the role of capillary forces in

preventing liquid from penetrating the cracks. It concludes that the likelihood of conditions conducive to SCC of the drip shield occurring in the Yucca Mountain repository is thus extremely small.

As you noted, issues related to SCC need to be addressed within the context of other corrosion tests carried out in environments that closely approximate the conditions to which Alloy 22 and titanium will be exposed and in environments that reasonably bound those conditions. In its response to the Board's letter of July 28, 2004, OCRWM discussed corrosion testing environments and likely waste package environments in the repository. The projected range of environments that could be present on the waste package and drip shield surfaces represents a heterogeneous matrix that will vary with time as the in-drift temperature and relative humidity change.

The likely concentrated brine environments and their expected frequencies and uncertainties have been calculated based on modeled repository-relevant seepage waters and the modeled behavior of soluble species in dust deposits. Although the frequency of different types of brines was not addressed at the May 2004 meeting, the results were recently documented. Because ranges of geochemical and thermal-hydrologic conditions are possible, there is a range of brine environments that could form on the waste package surface, depending on temperature, relative humidity, and the presence of intact drip shields. For the expected case, with the drip shield function intact, expected brines are of the sodium nitrate, potassium nitrate, sodium chloride, or calcium nitrate types. Dust samples collected in the tunnels at Yucca Mountain have been analyzed and grouped to summarize the types of deliquescent brines that could form. Only a few of the dust samples analyzed indicate that a calcium nitrate type brine could form. Deliquescent brines cover a pH range from approximately 6 to 12, depending on brine type and the CO_2 partial pressure. The associated chloride concentration varies from 1 to 8 molal and decreases with increasing relative humidity. Dissolved fluoride concentrations vary from approximately 10^{-6} molal to 0.3 molal, depending on the individual brines. The nitrate concentrations are greater at lower relative humidity (higher temperature) and decrease at lower temperature (increasing relative humidity). As a result, the nitrate to chloride molar ratio will vary from approximately 0.4 to 26; i.e., into the beneficial range where nitrate acts as a localized corrosion inhibitor.

Currently, work is underway to evaluate the following:

- The amount and composition of dust on waste packages as well as the volume of brine and quantities of dissolved salts, and assess the significance of any acid-gas volatilization.
- Assess the deliquescence-related properties of ammonium salts.
- Study the effects of chloride-containing silicate minerals or minerals containing hydroxide, which can be replaced by chloride.
- Document the screening argument(s) for exclusion of localized corrosion of the waste package outer barrier due to the deliquescence of dust constituents.

As mentioned earlier, past and currently ongoing corrosion tests encompass the range of these predicted environments.

Appendix F

Communication Between the U.S. Nuclear Waste Technical Review Board and Congress

- Letter from David J. Duquette Chair, Executive Committee, to Congressman John M. Shimkus; August 11, 2004.
  Subject: Responses to questions related to testimony at a hearing of the Subcommittee on Energy and Air Quality on March 25, 2004

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

August 11, 2004

The Honorable John M. Shimkus
House of Representatives
Washington, DC 20515-1319

Dear Mr. Shimkus:

Thank you very much for your written questions related to my testimony on behalf of the Nuclear Waste Technical Review Board at a hearing before the Subcommittee on Energy and Air Quality on March 25, 2004. The Board's answers to the questions are enclosed.

As you know, the Board is charged by Congress with conducting an ongoing and independent review of the technical and scientific validity of activities undertaken by the Secretary of Energy related to the implementation of the Nuclear Waste Amendments Act of 1987.

Please do not hesitate to contact me or have your staff contact Bill Barnard, Board Executive Director, if you have questions related to the Board's responses to your questions.

Sincerely,

David J. Duquette
Chairman, Executive Committee

Answers to Questions from Representative John M. Shimkus

[On July 28, 2004, the Board sent a letter to the Department of Energy (DOE) conveying the Board's most recent findings on the potential for localized corrosion of waste packages during the thermal pulse due to the deliquescence of calcium chloride brines. These findings affect the issues raised in the following questions. A copy of the letter is attached and is referenced where appropriate in answers to the questions.]

1. In your testimony of March 25, 2004 you referred to the possibility that corrosion could lead to a "breach" or "breaking" of the waste packages proposed for Yucca Mountain. Can you please define what the terms "breach" and "breaking" mean and explain how such occurrences would affect public health and safety?

   Answer:

   By "breach," the Board meant penetration through the outer alloy-22 wall of the waste package. A breach that resulted in complete penetration of the waste package could allow radionuclides to exit the waste package. Many factors could affect radionuclide releases, including the extent and proliferation of corrosion, the amount of water that comes into contact with the corroded waste packages, and the mitigative or transmissive characteristics of the unsaturated and saturated zones. The Board has not conducted its own studies related to the effect on public health and safety of a breach of the waste package. However, the Board has referred to the difficulties inherent in making such estimates in several Board documents.

2. (a) Is this concern based on independent work performed by Board members or just on critique of work put forward by DOE and others? (b) How widely is this concern shared in the scientific community? (c) If available, please cite examples of independent research (by the Board or others) substantiating this concern.

   Answer:

   (a) *In accordance with its mandate established in the Nuclear Waste Policy Amendments Act of 1987, the Board evaluates the technical and scientific validity of the DOE's work related to the disposal, transportation, and packaging of spent nuclear fuel and high-level radioactive waste. Although the Board occasionally undertakes its own focused analysis of specific issues, the Board does not conduct experimental research directly. In reaching the conclusions in its October 2003 letter and November 2003 report on the potential for localized corrosion during the thermal pulse, the Board used the DOE's testing conditions and data on potential repository tunnel environments.*

On the basis of its interpretation of DOE and other data, the Board concluded that deliquescence-induced crevice corrosion would likely be initiated during the higher-temperature period of the thermal pulse. That conclusion was based particularly on corrosion tests conducted in an aqueous environment rich in calcium chloride. Test results showed clearly that corrosion would take place in that environment when temperatures range roughly between 140°C and 160°C. The results also suggested that the expected mitigating effect of the presence of nitrate ions might not be sufficient to inhibit the corrosion process fully.

However, as stated in the Board's July 2004 letter to the DOE, primarily on the basis of information presented at the Board's May 2004 meeting, it appears unlikely that dust that accumulates on waste package surfaces during the preclosure period would contain significant amounts of calcium chloride or that significant amounts of calcium chloride would evolve on waste package surfaces during the thermal pulse. Consequently, the calcium chloride-rich environment selected for corrosion tests does not appear representative of the conditions that can be expected on waste package surfaces in a Yucca Mountain repository. If calcium chloride is not present, calcium chloride-rich brines will not form by deliquescence, and crevice corrosion due to the presence of such brines in the temperature range of roughly 140°C to 160°C will not occur. Thus, the Board concludes that deliquescence-induced localized corrosion during the higher-temperature period of the thermal pulse is unlikely.

The Board is pleased that the DOE conducted the additional research needed to resolve this extremely important corrosion issue. However, this does not mean that the Board believes that all uncertainties related to corrosion of waste packages have been addressed. For example, in its July 2004 letter, the Board noted other corrosion issues that the Board believes require additional analysis, including (1) a possibility that when temperatures in repository tunnels fall below boiling, localized corrosion could occur in concentrated sodium chloride solutions; (2) the possible presence of ammonium ion and the implications of its presence for corrosion; and (3) the potential for nitrates to be aggressive corrodents in some circumstances. The Board believes that it is important to continue corrosion testing aimed at addressing uncertainties.

***(b)** The conclusion stated in the Board's October 2003 letter and November 2003 report that localized corrosion would likely be initiated if waste package surface temperatures were above 140ºC and if concentrated brines such as would be formed by the deliquescence of calcium chloride were present is consistent with research conducted by others in the scientific community.*

***(c)** Transcripts from the Board's May 2003, September 2003, and May 2004 meetings, which include information from several sources used by the Board to reach the conclusions in its October 2003 letter, its November 2003 report, and its July 2004 letter, are posted on the Board's Web site: www.nwtrb.gov.*

3. The fall 2003 letter and report you referred to in your testimony concludes that very aggressive chemistry conditions are likely to exist on the waste package surfaces during the thermal period. (a) In reaching this conclusion, has NWTRB considered the potential for mitigating factors that could make the chemical conditions more benign? (b) Specifically has the board considered the possibility of significant volatilization and removal of chloride in postulated brines as hydrogen chloride (hence reducing the likelihood of high chloride concentrations), the mitigating effects of the presence of aluminosilicate minerals associated with dust in the repository tunnels (and the ability to such minerals to buffer pH values), or scenarios in which conditions would cause the corrosion process, if initiated, to stifle rather than penetrating deep into the waste package material? (c) What is the board's view of these possibilities? Please explain.

   Answer:

   (a,b,c) *In reaching the conclusions presented in its October 2003 letter and November 2003 report on the potential for localized corrosion during the thermal pulse, the Board used the DOE's testing conditions and data on potential repository tunnel environments.*

   As explained in the answer to question number 2a, it appears unlikely that the dusts in repository tunnels will contain significant amounts of calcium chloride during the thermal pulse. The factors discussed in question 3 that might mitigate the effects of calcium chloride are therefore moot.

4. (a) Do the conclusions that you reached regarding the environment within the proposed repository and the potential impact on the waste packages take into account the need for a confluence of conditions to occur before the waste packages would be adversely impacted? (b) Has the Board specifically evaluated the probability of these conditions occurring? (c) Has the Board taken into account the time dependency of these conditions and what, specifically, is the likelihood that such conditions would occur along the time line required for this to be a concern? (d) Please explain, in detail, these evaluations and results.

   Answer:

   (a) *The Board stipulated that a combination of factors would be necessary for the initiation of deliquescence-induced localized corrosion. Specifically, the Board said that if waste package surface temperatures were above 140ºC and if concentrated brines such as would be formed by the deliquescence of calcium chloride were present in repository tunnels, localized corrosion would likely be initiated.*

   (b,c) *The Board has stated that on the basis of information presented at its May 2004 meeting, it appears unlikely that the dust in repository tunnels will contain significant amounts of calcium chloride during the thermal pulse. Consequently, as discussed above, deliquescence-induced localized corrosion of the waste packages is unlikely*

during the thermal pulse. However, the Board also stated in its July 2004 letter that the extent to which the DOE has characterized accurately the likely waste package environments is unclear at this point. The DOE's characterization of repository and waste-package environments will continue to be a major focus of the Board's technical and scientific review.

***(d)** The Board's evaluation is based on basic technical and scientific analysis, its own expert judgment, and research and analysis presented at Board meetings by the DOE and others.*

5. Does the Board accept the mandate (per NRC regulation 10 CFR Part 63) that the repository safety analysis must be probability-based?

   Answer:

   The Board's mandate is to review the technical and scientific validity of DOE activities. The Board's purview does not include policy or regulatory matters. The Board understands that performance estimates are probability based; however, the Board has stated consistently that the DOE's safety case could be strengthened by supplementing repository performance estimates with other lines of argument or evidence—an approach taken by other countries with nuclear waste disposal programs. The result could be increased confidence in the DOE's performance estimates.

6. (a) DOE has conducted total system performance assessments of Yucca Mountain that indicate, even if the waste package fails during the thermal period, the radiological consequences to the public will be a small fraction of the dose limit set forth in EPA and Nuclear Regulatory Commission (NRC) regulations. (b) Yet the NWTRB maintains that a costly design change (to maintain the repository temperature below boiling conditions at all times) needs to be made to prevent such a failure. (c) What safety analysis has NWTRB conducted to indicate that proceeding with the current design has a significant impact on public health and safety? (d) Alternately, what safety analysis has NWTRB conducted to indicate that such a design change will significantly enhance public health and safety? (e) Is NWTRB aware of analyses by NRC indicating that the formation of corrosive brines is independent of repository design temperature? What is NWTRB's view of this analysis?

   Answer:

   ***(a)** Estimates of radiological consequences due to waste package failure are highly dependent on underlying assumptions. At the Board's September 2003 meeting, the DOE presented simplified studies suggesting that under one set of assumptions, failure of the waste packages could result in exceedence of the dose limit; using different assumptions, the DOE calculated that the repository would meet the regulatory standard if the waste packages failed.*

(b,c,d) *The Board noted in its November 2003 report that data currently available indicate that perforation of the waste packages caused by localized corrosion is unlikely if waste-package surface temperatures are kept below 95°C. The Board has not conducted its own studies related to the effect on public health and safety of the DOE's current repository design; the Board's concerns have centered on avoiding potential problems with a major barrier (i.e., the waste package). The Board has stated many times and still believes that there are significant uncertainties associated with the high temperatures in the DOE's current repository design and that keeping temperatures below boiling in repository tunnels could decrease uncertainties and increase confidence in repository performance estimates. According to a 2002 DOE white paper on thermal operating modes, it is not clear that a low-temperature design would be significantly more costly in the long run than a high-temperature design.*

(e) *Data from the DOE and the NRC indicate that some corrosive brines could exist below 95°C. In its July 2004 letter, the Board requested that the DOE examine the likelihood that such brines might form and the mechanisms that might lead to the formation of such brines.*

7. (a) Is the Board cognizant of the significant expertise of the NRC and its consultants in this area and (b) is the Board prepared to accept NRC's findings regarding whether or not the DOE approach is safe and consistent with regulatory requirements?

   Answer:

   (a) *Yes.*

   (b) *The Board recognizes that the NRC has responsibility for a regulatory finding related to safety and consistency with regulatory requirements. The Board's statutorily established mandate is to evaluate the validity of technical and scientific activities undertaken by the Secretary of Energy and to make recommendations to the Secretary of Energy and Congress. The Board's purview does not include reviewing NRC activities or findings.*

Appendix G

U.S. Nuclear Waste Technical Review Board Strategic Plan: Fiscal Years 2004–2009

(Revised March 2004)

Statement of the Board

The Nuclear Waste Policy Amendments Act of 1987 directed the U.S. Department of Energy (DOE) to characterize one site, at Yucca Mountain in Nevada, to determine its suitability as the location of a permanent repository for disposing of spent nuclear fuel and high-level radioactive waste. The Act also established the U.S. Nuclear Waste Technical Review Board as an independent agency within the executive branch of the United States Government. The Act requires the Board to evaluate continually the technical and scientific validity of activities undertaken by the Secretary of Energy related to implementing the Act and to report its findings and recommendations to the Secretary and Congress at least twice yearly. The Board only can make recommendations; it cannot compel the DOE to comply.

Congress created the Board to perform ongoing independent and unbiased technical and scientific evaluation—crucial for public acceptance of decisions related to nuclear waste disposal. The Board strives to provide Congress and the Secretary of Energy with completely independent, credible, and timely technical and scientific program evaluations and recommendations achieved through peer review of the highest quality.

This strategic plan includes the Board's goals and objectives for fiscal years 2004 through 2009. During that period, the DOE plans to develop an application for authorization to construct a repository and to submit it to the U.S. Nuclear Regulatory Commission (NRC). During the next several years, important technical and scientific activities will be undertaken by the DOE aimed at (a) gaining a better understanding of the potential behavior of a Yucca Mountain repository, (b) developing a repository design, (c) reducing technical uncertainties, (d) confirming estimates of repository performance, and (e) developing and implementing plans for a waste management system that includes waste transportation, handling, and packaging and repository operations. In accordance with its statutory mandate, the Board will continue its evaluation of the technical and scientific validity of the DOE's work in these areas. In conducting its evaluation, the Board looks at how components of the repository and waste management systems interact with other elements of the systems. This "systems view" of repository and waste management activities will continue to be critically important because many crucial technical and scientific decisions will be made throughout this period.

Mission

The Board's mission, established in the Nuclear Waste Policy Amendments Act (NWPAA) of 1987 (Public Law 100-203), is to "…evaluate the technical and scientific validity of activities [for management of high-level radioactive waste] undertaken by the Secretary after the date of the enactment of the Nuclear Waste Policy Amendments Act of 1987…" By law, the Board will cease to exist not later than one year after the date on which the Secretary begins disposal of high-level radioactive waste or spent nuclear fuel in a repository.

Vision

By performing ongoing and independent technical and scientific peer review of the highest quality, the Board makes a unique and essential contribution to increasing the technical validity of DOE activities related to implementing the Nuclear Waste Policy Act (NWPA) of 1982. The Board also provides essential technical and scientific information to Congress and the public on issues related to the disposal, packaging, and transport of spent nuclear fuel and high-level radioactive waste. The Board performs technical and scientific evaluation of the DOE's work related to (a) gaining a better understanding of the potential behavior of a repository at Yucca Mountain, (b) developing a repository design for safe and efficient repository operations, (c) establishing a program for confirming estimates of repository performance, and (d) developing and implementing plans for a waste management system that includes waste transportation, handling, and packaging and repository operations.

Values

To achieve its goals, the Board conducts itself according to the following values.

- The Board strives to ensure that its members and staff have no real or perceived conflicts of interest related to the outcome of the Secretary's efforts to implement the NWPA.
- Board members arrive at their conclusions on the basis of objective evaluations of the technical and scientific validity of the Secretary's activities.
- The Board's practices and procedures are open and conducted so that the Board's integrity and objectivity are above reproach.
- The Board's findings, conclusions, and recommendations are technically and scientifically sound and are based on the best available technical analysis and information.
- The Board's findings, conclusions, and recommendations are communicated clearly and in time for them to be most useful to Congress, the Secretary, and the public.
- The Board encourages public comment and discussion of DOE activities and Board findings, conclusions, and recommendations.

Goals and Strategic Objectives

The nation's goals related to disposing of spent nuclear fuel and high-level radioactive waste were set forth by Congress in 1982 in the NWPA. The goals are to develop a repository or repositories for disposing of high-level radioactive waste and spent nuclear fuel at a suitable site or sites and to establish a program of research, development, and demonstration for disposing of such waste.

In 1987, the NWPAA limited repository development activities to a single site at Yucca Mountain in Nevada. The NWPAA also established the Board and charged it with evaluating the technical and scientific validity of the Secretary of Energy's activities associated with implementing the NWPA. The activities include characterizing the Yucca Mountain site and packaging and transporting spent nuclear fuel and high-level radioactive waste.

The Board's general goals have been established in accordance with its statutory mandate and

with congressional action in 2002 authorizing the DOE to proceed with the submittal of an application to the NRC for authorization to construct a repository at Yucca Mountain. The goals reflect the continuity of the Board's technical and scientific evaluation and the Board's systems view of the repository and of waste management activities.

General Goals of the Board

To accomplish its congressional mandate, the Board has established four general goals.

1. Evaluate the technical and scientific validity of activities undertaken by the DOE related to understanding, testing, analyzing, and modeling geologic and other natural components of a proposed Yucca Mountain repository system. Review DOE activities related to estimating and confirming the performance of the natural components of the repository system.

2. Evaluate the technical and scientific validity of activities undertaken by the DOE related to understanding, testing, analyzing, and modeling the engineered components of a proposed Yucca Mountain repository system. Review DOE activities related to estimating and confirming the performance of the engineered components of the repository system.

3. Evaluate the technical and scientific validity of activities undertaken by the DOE related to understanding and modeling interactions among the components of the natural and engineered repository systems, estimating and confirming the performance of the proposed repository system, and integrating scientific and engineering activities.

4. Evaluate the technical and scientific validity of activities undertaken by the DOE related to planning, integrating, and implementing a waste management system, including the transportation, packaging, and handling of spent nuclear fuel and high-level radioactive waste and the operation of a repository.

Strategic Objectives of the Board

To achieve its general goals, the Board has established the following long-term objectives.

1. Objectives Related to the Natural System

1.1. Evaluate the technical and scientific validity of data and analyses related to the contributions of the natural barriers to waste isolation in a Yucca Mountain repository.

1.2. Evaluate DOE analyses and investigations related to hydrologic, geologic, geotechnical, seismic, volcanic, climactic, biological, and other natural features, events, and processes at the Yucca Mountain site and at related analogue sites.

1.3. Review DOE efforts to increase fundamental understanding of the potential behavior of the repository in a natural system.

1.4. Evaluate DOE and other studies and analyses related to repository tunnel environments.*

1.5. Review DOE integration of technical and scientific activities related to the natural system.

1.6. Review DOE efforts to confirm estimates of natural-system performance, including tests of models and assumptions and the pursuit of independent lines of evidence.

2. Objectives Related to the Engineered System

2.1. Evaluate the technical and scientific validity of DOE data and analyses related to the contribution of the engineered system to waste isolation in a Yucca Mountain repository.

2.2. Evaluate DOE studies and analyses related to the tunnel environments that will affect the performance of waste packages.*

*This is a shared objective under the natural system and engineered system.

2.3. Assess DOE efforts to increase understanding of fundamental corrosion processes in a proposed repository.

2.4. Review waste package designs, including the performance attributes and technical bases for such designs, and assess the need to revise waste package designs on the basis of the results of ongoing technical and scientific studies.

2.5. Evaluate the integration of science and engineering in the DOE program, especially the integration of new data into repository and waste package designs.

2.6. Review DOE activities related to confirming the predicted performance of the engineered system.

3. Objectives Related to Repository System Performance and Integration

3.1. Evaluate the technical and scientific validity of the DOE's technical basis for its estimates of repository system performance.

3.2. Review the technical and scientific validity of DOE models used to predict repository system performance.

3.3. Evaluate DOE efforts to increase confidence in its estimates of repository performance.

3.4. Evaluate the technical and scientific validity of DOE efforts to gain a more realistic understanding of the interaction of the natural and engineered components of a repository system.

3.5. Evaluate the integration of science and engineering with performance assessment.

3.6. Evaluate the technical bases for the DOE's repository safety case, including efforts to integrate the safety case with multiple lines of evidence and performance confirmation.

3.7. Review the development of DOE plans and activities for performance confirmation.

4. Objectives Related to the Waste Management System

4.1. Review DOE efforts related to the interaction of components of the waste management system from a life-cycle systems perspective, including at-reactor storage, waste acceptance, transportation, and repository design and operations.

4.2. Review the technical and scientific validity of the DOE's plans for safely handling and packaging spent nuclear fuel and high-level radioactive waste for transport to a permanent repository and for disposal in a permanent repository.

4.3. Review the technical and scientific aspects of the DOE's transportation plans.

4.4. Review the technical and scientific validity of the DOE's plans for developing a transportation infrastructure.

4.5. Evaluate design and engineering of the facility components or subsystems that involve innovative features, assumptions, and approaches.

4.6. Review the process through which the DOE provides technical and scientific information to interested parties and includes interested members of the public in the development of waste management plans.

Achieving the Goals and Objectives

The NWPAA grants significant investigatory powers to the Board. In accordance with the NWPAA, the Board may hold such hearings, sit and act at such times and places, take such testimony, and receive such evidence as it considers appropriate.

At the request of the Board and subject to existing law, the NWPAA directs the DOE to provide all records, files, papers, data, and information requested by the Board, including drafts of work products and documentation of work in progress. According to the legislative history, in providing this access, Congress expected that the Board would review and comment on DOE decisions, plans, and actions as they occurred, not after the fact.

By law, no nominee to the Board may be an employee of the DOE, a National Laboratory, or DOE contractors performing activities involving high-level radioactive waste or spent nuclear fuel. The Board has the power, under current law, to achieve its goals and objectives.

In conducting its ongoing technical and scientific review, the Board takes a "systems view" of the repository and of waste management activities. That view considers how one element of the repository system affects another. Consistent with this approach, the Board has established four panels composed of three or four Board members. As described in the following paragraphs, the purviews of the panels correspond to the Board's general goals.

1. *Panel on the Natural System*

   Panel Goal. Evaluate the technical and scientific validity of activities undertaken by the DOE related to understanding, testing, analyzing, and modeling geologic and other natural components of a proposed Yucca Mountain repository system. Review DOE activities related to estimating and confirming the performance of the natural components of the repository system.

2. *Panel on the Engineered System*

   Panel Goal. Evaluate the technical and scientific validity of activities undertaken by the DOE related to modeling, understanding, testing, and analyzing the engineered components of a proposed Yucca Mountain repository system. Review DOE activities related to estimating and confirming the performance of the engineered components of the repository system.

3. *Panel on Repository System Performance and Integration*

   Panel Goal. Evaluate the technical and scientific validity of activities undertaken by the DOE related to understanding and modeling the interactions of natural and engineered repository system components, estimating the performance of the proposed repository system, confirming the performance of the proposed repository system, and integrating scientific and engineering activities.

4. *Panel on the Waste Management System*

   Panel Goal. Evaluate activities undertaken by the DOE related to planning, integrating, and implementing a waste management system, including the transportation, packaging, and handling of spent nuclear fuel and high-level radioactive waste and the operation of a repository.

Much of the Board's information-gathering occurs at open public meetings arranged by the Board. At each meeting, the DOE, its contractors, and other program participants present technical information according to an agenda prepared by the Board. Board members and staff question presenters during the meetings. Time is provided at the meeting for comments from members of the public and interested parties. The full Board holds three or four meetings each year. The Board's panels meet as needed to investigate specific issue areas. The majority of Board meetings are held somewhere in Nevada.

The Board also gathers information from trips to the Yucca Mountain site, visits to contractor laboratories and facilities, and meetings with individuals working on the project. Board members and staff attend national and international symposia and conferences related to the science and technology of nuclear waste disposal. From time to time, Board members and staff also visit programs in other countries to review best

practices, perform benchmarking, and assess potential analogues.

Although the Board's information-gathering activities are carried out primarily to further the Board's review, they often have the collateral benefit of promoting communication and integration of technical information within the DOE program and facilitating the dissemination of information among interested parties outside the program. Analyses are performed primarily by Board members and the Board's staff. When necessary, the Board hires special expert consultants to perform in-depth reviews of specific technical and scientific topics.

Crosscutting Functions

Several entities and agencies are involved in developing a system for safely packaging, transporting, and disposing of spent nuclear fuel and high-level radioactive waste in a geologic repository at a suitable site. As discussed in the following paragraphs, the Board's ongoing peer review is unique among the organizations involved in managing spent nuclear fuel and high-level radioactive waste.

- *Congress and the Administration, including the Secretary of Energy,* make decisions on national policy and goals and how they will be implemented. The Board's role in this process is to help ensure that policy-makers receive unbiased and credible technical and scientific analyses and information.

- *State and local governments* comment on and perform local oversight of DOE activities. The Board's oversight activities are different in that they are (1) unconstrained by any stake in the outcome of the endeavor besides the credibility of the scientific and technical activities, (2) confined to scientific and technical evaluations, and (3) conducted by individuals nominated by the National Academy of Sciences and expressly chosen by the President for their expertise in the various disciplines represented in the DOE program.

- *Other federal agencies* (in addition to the Board) with roles in the waste management program include the DOE, the NRC, the Environmental Protection Agency (EPA), the Department of Transportation (DOT), and the United States Geological Survey (USGS). The DOE and its contractors are responsible for developing and implementing waste management plans and for conducting analytical and research activities related to licensing, constructing, and operating a repository. The NRC is the regulatory body having responsibility for licensing the construction and operation of a proposed repository and for certifying transportation casks. The EPA is responsible for issuing radiation safety standards that the NRC uses to formulate its repository regulations. The DOT is responsible for regulating the transporters of the waste. The USGS participates in site-characterization activities at the Yucca Mountain site.

The Board's role and its systems approach are unique among these organizations. The Board performs ongoing independent review and expert oversight of the technical and scientific validity of the Secretary of Energy's activities relating to civilian radioactive waste management and communicates its findings and recommendations to Congress, the Secretary, and the public. The Board's technical and scientific evaluations complement the work of other agencies involved in achieving the national goal.

Key External Factors

Some factors that are beyond the Board's control could affect its ability to achieve its goals and objectives. Among them are the following.

- *The Board has no implementing authority.* The Board is by statute a technical and scientific review body that only makes recommendations to the DOE. Congress expected that the DOE would accept the Board's recommendations or indicate why the recommendations could not or should not be implemented. However, the DOE is not legally obligated to

accept any of the Board's recommendations. If the DOE does not accept a Board recommendation, the Board's recourse is to advise Congress or reiterate its recommendation to the DOE, or both. The Board's recommendations and the DOE's responses are included in Board reports to Congress and the Secretary.

- *Legislation and budget considerations could affect nuclear waste policy.* The level of funding provided to the Board affects its ability to comprehensively review DOE activities. Funding levels for the program also may influence activities undertaken by the DOE in a given year or over time. In addition, it is not possible to predict if legislation related to nuclear waste disposal will be passed in the future or how the Board might be affected by such legislation, if enacted.

The Board will evaluate the status of these external factors, identify any new factors, and, if warranted, modify the "external factors" section of the strategic plan as part of the annual program evaluation described below.

Evaluating Board Performance

The Board believes that measuring its effectiveness by directly correlating Board recommendations with improvements in the technical and scientific validity of DOE activities would be ideal. However, the Board cannot compel the DOE to comply with its recommendations. Consequently, a judgment about whether a specific recommendation had a positive outcome as defined above 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 measure its performance in a given year, the Board has developed performance measures. For each annual performance goal, the Board considers the following.

1. Did the Board undertake the reviews, evaluations, and other activities needed to achieve the goal?
2. 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 were met in relation to a specific goal, the Board's performance in meeting that goal will be judged effective. If only one measure was met, the performance of the Board in achieving that goal will be 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. If the goals are deferred, that will be noted in the evaluation.

The Board will use its evaluation of its own 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. The results of the Board's performance evaluation are included in its annual summary report.

Consultations

In developing its original strategic plan, the Board consulted with the Office of Management and Budget, the DOE, congressional staff, and members of the public and provided a copy of the plan to the NRC and to representatives of state and local governments. The Board solicited public comment and presented its strategic plan at a session held expressly for that purpose during a public Board meeting in Amargosa Valley, Nevada, on January 20, 1998. During 2003, the Board again solicited and received comment on its revised strategic plan and performance plan. Many of those comments are incorporated in this revision. Copies of the Board's strategic plan, annual performance plans, and performance-based budget for fiscal year 2005 are available in the Board's summary report for 2003 and on the Board's Web site: **www.nwtrb.gov**.

Appendix H
U.S. Nuclear Waste Technical Review Board Performance Evaluation
Fiscal Year 2004

Evaluating the Board's Performance

The Board believes that measuring its effectiveness by directly correlating Board recommendations with improvements in the technical and scientific validity of Department of Energy (DOE) activities would be ideal. However, the Board cannot compel the DOE to comply with its recommendations. Consequently, a judgment about whether a specific recommendation had a positive outcome as defined above, 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 measure its performance in a given year, the Board has developed the following performance measures.

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

2. 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 will be judged effective. If only one measure is met, the performance of the Board in achieving that goal will be 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. If the goals are deferred, that will be noted in the evaluation.

The Board will use its evaluation of its own 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. The results of the Board's performance evaluation are included in its annual summary report.

Board's Performance Evaluation for 2004

On the basis of the following evaluation and consistent with the performance measures described in the previous section, the Board's performance for 2004 was found to be effective overall. However, the Board did not have access to TSPA 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 under the evaluation of the specific performance goal.

The reliability and completeness of the performance data used to evaluate the Board's performance relative to its annual performance goals is high and can be verified by accessing the referenced documents on the Board's Web site: www.nwtrb.gov.

The Board's performance goals for fiscal year (FY) 2004 were developed to achieve the general goals and strategic objectives in its strategic plan for the years 2004–2009. The goals also have been established in accordance with the Board's statutory mandate and reflect congressional action in

2002 authorizing the U.S. Department of Energy (DOE) to proceed with developing an application to be submitted to the Nuclear Regulatory Commission (NRC) for authorization to construct a repository at Yucca Mountain. The Board's performance goals reflect the continuity of the Board's ongoing technical and scientific evaluation and the Board's efforts to evaluate program activities taking into account the interdependence of components of the repository system and the waste management system.

For purposes of this evaluation, the Board's performance goals for FY 2004 have been organized and numbered to correlate with appropriate strategic objectives in the Board's strategic plan for FY 2004–2009.

1. Performance Goals and Evaluation Related to the Natural System

1.1.1. Review the technical activities and agenda of the DOE's science and technology (S&T) program.

- Evaluation of 1.1.1: The Board held a panel meeting on January 20, 2004, at which it received an update on the S&T program. In a May 3, 2004, letter to the DOE, the Board commended the S&T program for including on its agenda study of the Peña Blanca analogue site in Chihuahua, Mexico. The Board commented on the importance of the S&T program in a letter to the DOE on November 30, 2004, and in its report to Congress and the Secretary of Energy dated December 30, 2004.

1.1.2. Monitor the results of flow-and-transport studies to obtain information on the potential performance of the saturated zone as a natural barrier in the repository system.

- Evaluation of 1.1.2: The Board held a two-day panel meeting on March 9–10, 2004, at which one day was devoted to reviewing activities undertaken by the DOE related to saturated zone flow and transport. The Board sent a letter to the DOE on May 3, 2004, in which it commented extensively on fluid flow and radionuclide transport and the potential of the natural barriers to provide a barrier to the migration of radionuclides. Understanding the interaction of the components of the natural system and how they act together to isolate waste was identified as a Board priority in its December 30, 2004, report to Congress and the Secretary of Energy.

1.1.3. Review DOE efforts to confirm estimates of natural-system performance and pursue independent lines of evidence, including tests of models and assumptions.

- Evaluation of 1.1.2: On March 9–10, 2004, the Board held a two-day panel meeting on the natural system at Yucca Mountain. During these two days, the Board heard several presentations on the DOE's approach to estimating the performance of the natural barriers and on supplementing those estimates with additional lines of evidence. Several of the presentations dealt with assumptions underlying the modeling of the natural system. In a May 3, 2004, letter to the DOE, the Board pointed out that unsaturated zone fluid flow and transport predictions are influenced significantly by assumptions inherent in the formulation of the active fracture model. The Board also noted that updating the site-scale model on the basis of these calculations could affect predictions of radionuclide transport times. In the same letter, the Board observed that multiple lines of evidence could be used to supplement conceptual understanding, models used to represent the concepts, and the scenarios predicted by the models. Understanding the interaction of the components of the natural system and how they act together to isolate waste was identified as a Board priority in its December 30, 2004, report to Congress and the Secretary of Energy.

1.2.1. Review DOE efforts to resolve questions related to possible seismic events and igneous consequences.

- Evaluation of 1.2.1: The Board received DOE updates on seismic issues at meetings held May 18, 2004, and September 20, 2004. In follow-up letters to the DOE, the Board noted that the DOE had made progress in developing realistic estimates of ground motions. The Board encouraged the use of sound physical principles to limit ground motions, the integration of technical and scientific studies and activities, and the submission of study results to external peer review. In its December 30, 2004, letter to Congress and the Secretary, the Board noted progress in this area. At its September 20, 2004, meeting, the Board was briefed by representatives of the Electric Power Research Institute on the results of preliminary short-term tests with synthetic magma indicating that the metal used for the waste packages (Alloy-22) may have significant corrosion resistance to some magmas. In a November 30, 2004, letter to the DOE following that meeting, the Board noted that the composition of magmas at Yucca Mountain vary widely. Consequently, the Board believes that the EPRI tests are early indicators, but do not provide a sufficient technical basis for determining the corrosion resistance of the waste package in magma. In the same letter, the Board reiterated that if the repository design is modified to mitigate the effects of igneous activity, such modifications should be evaluated for their effects on repository operation and performance. The Board listed volcanic consequences as an area requiring further study in its December 30, 2004, report to Congress and the Secretary.

1.3.1. Evaluate geologic, hydrologic, and geochemical information obtained from the enhanced characterization of the repository block (ECRB) at Yucca Mountain.

- Evaluation of 1.1.2: Evaluation of 1.3.1: The Board noted in its letter to the DOE dated November 30, 2004, that because several significant scientific issues related to a fundamental understanding of the Yucca Mountain site remain unresolved, maintaining access to the ECRB is important. The Board also observed that water collected in the ECRB and the possible presence of chlorine-36 continue to raise questions about water flow inside Yucca Mountain.

1.3.2. Evaluate data from the drift-scale heater test.

- Evaluation of 1.3.2: In the Board's November 30, 2004, letter to the DOE, the Board observed that the Drift-Scale Test, which was planned for 8 years, is currently in its "cool down" phase. Observations of hydrogeologic changes in response to heat fluxes in this test will be needed to evaluate models predicting repository performance.

1.3.3. Review plans and work carried out on possible analogues for the natural components of the repository system.

- Evaluation of 1.3.3: In its May 3, 2004, letter to the DOE, the Board observed that the Peña Blanca site in Chihuahua, Mexico, could be used as an analogue to test and evaluate Yucca Mountain modeling approaches, the conceptual understanding of the natural systems at the site, and the scenarios predicted by the models. The Board commended the S&T program for its plans to test Yucca Mountain modeling approaches at the Peña Blanca site.

1.3.4. Recommend additional work needed to address uncertainties, paying particular attention to estimates of the rate and distribution of water seepage into the repository under proposed repository design conditions.

- Evaluation of 1.3.4: The Board's May 3, 2004, letter to the DOE contains exten-

sive comments on work that could be undertaken or continued to address uncertainties related to the natural system, including large-scale hydraulic tests, improvements in characterization of the saturated alluvium, and a better empirical basis for predicting matrix diffusion. The letter also identifies areas of substantial unresolved uncertainty related to the natural system, including colloid-facilitated transport, the active fracture modeling approach, and boundary fluxes, and makes recommendations to reduce the uncertainties. In its July 28, 2004, letter to the DOE, the Board lists examples of uncertainties that need to be addressed to characterize better environments in repository tunnels post closure. Those uncertainties include the conceptual basis for the drift-scale thermohydrologic seepage analysis, the source of water in the ECRB, the effects of drift degradation, and potentially unrealistic parameters in the performance-assessment calculations of seepage.

1.4.1. Evaluate tunnel-stability studies undertaken by the DOE.

- Evaluation of 1.4.1: The Board observed in its July 28, 2004, letter to the DOE that the extent to which the DOE has characterized accurately the likely waste package environments (i.e. repository tunnel environments post-closure) is unclear at this time. The Board identified accurate characterization of repository tunnels as an area requiring additional attention and a major focus of the Board's ongoing technical and scientific review in its report to Congress and the Secretary, dated December 30, 2004. In its July 28, 2004, letter to the DOE, the Board identified tunnel stability as an uncertainty that needs to be addressed related to postclosure repository tunnel environments.

1.5.1. Review the DOE's efforts to integrate results of scientific studies on the behavior of the natural system into repository designs.

- Evaluation of 1.5.1: In its November 30, 2004, letter to the DOE, the Board observed that if the repository design is modified to mitigate the effects of igneous activity, such modifications should be evaluated for their effects on repository operation and performance. In a May 3, 2004, letter to the DOE, the Board reiterated its view that an integrated explanation is needed of how elements of the repository act as a system to isolate waste. The Board noted in an April 5, 2004, letter to the DOE that changes in the subsurface design will affect postclosure waste-package temperatures and could exacerbate "cold trap" effects near and in the repository tunnel turnouts. The Board went on to recommend that temperature and relative humidity calculations be revised to reflect repository design changes. The Board commented on the need for thorough integration and close cooperation among diverse technical disciplines (e.g., geochemists and corrosions scientists/engineers) in its July 28, 2004, letter to the DOE.

2. Performance Goals and Evaluation Related to the Engineered System

2.1.1. Monitor the DOE's studies related to the relative contribution of engineered barriers to repository performance.

- Evaluation of 2.1.1: At the Board's meeting on September 20, 2004, the DOE updated the Board on the total system performance assessment (TSPA) process. The TSPA includes estimates of repository performance based on the contributions of various elements of the repository system. The Board identified TSPA as a priority area of evaluation in

its December 30, 2004, report to Congress and the Secretary.

2.2.1. Review thermal testing and rock stability testing related to potential conditions in repository tunnels.

- Evaluation of 2.2.1: The Board heard DOE presentations on predicted conditions in repository tunnels during the thermal pulse at its May 18–19, 2004, meeting. In its July 28, 2004, letter to the DOE, the Board identified drift degradation as an important uncertainty affecting the accurate characterization of repository tunnel environments after closure of the repository.

2.2.2. Evaluate data from studies of the effects of corrosion and the waste package environment on the predicted performance of materials being proposed for engineered barriers.

- Evaluation of 2.2.2: The Board devoted most of its meeting on May 18–19, 2004, to a review of DOE activities related to corrosion testing and repository tunnel environments. In a July 28, 2004, letter to the DOE, the Board concluded that 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 waste packages due to deliquescence of calcium chloride salts. This conclusion also was included in the Board's report to Congress and the Secretary of Energy, dated December 30, 2004. In its July letter and December report, the Board also commented on additional corrosion issues, including the corrosion resistance of Alloy-22 in magma, the possibility of stress corrosion cracking of the titanium drip shield, and the need to carry out corrosion tests in environments that closely approximate expected conditions in repository tunnels. At its September 30, 2004, meeting, the Board was briefed by representatives of the Electric Power Research Institute on the results of preliminary short-term tests with synthetic magma indicating that the metal used for the waste packages may have significant corrosion resistance to some magmas. In a November 30, 2004, letter to the DOE following that meeting, the Board noted that the composition of magmas at Yucca Mountain vary widely. Consequently, the Board believes that the EPRI tests are early indicators, but do not provide a sufficient technical basis for determining the corrosion resistance of the waste package in magma. The Board suggested that further testing was needed in this area.

2.3.1. Review the progress and results of materials testing being conducted to address uncertainties about waste package performance.

- Evaluation of 2.3.1: See evaluation of 2.2.2.

2.3.2. Evaluate the DOE's efforts in identifying analogues for corrosion processes.

- Evaluation of 2.3.2. The Board is unaware of any DOE activities related to identifying natural or engineered analogues for corrosion process in 2004.

2.4.1. Monitor the DOE's development of analytical tools for assessing the differences between repository designs.

- Evaluation of 2.4.1. On January 20, 2004, the Board held a panel meeting on repository design, at which it received various updates and briefings on DOE activities in this area. The Board commented extensively on repository design in an April 5, 2004, letter to the DOE following the panel meeting. The Board is unaware of any DOE activities related specifically to developing analytical tools for assessing differences in repository designs. At the Board's meeting on September 20, 2004, the DOE updated the Board on the total system performance assessment

(TSPA) process. The TSPA includes estimates of repository performance *overall*. The Board identified TSPA as a priority area in its December 30, 2004, report to Congress and the Secretary.

2.4.2. Evaluate the accuracy and completeness of the technical bases for repository and waste package designs and the extent to which the DOE is using the technical bases for modifying repository and waste package designs.

- Evaluation of 2.4.2. On January 20, 2004, the Board held a panel meeting on repository design, at which it received various updates and briefings on DOE activities in this area. The Board commented extensively on repository design in an April 5, 2004, letter to the DOE following the panel meeting.

2.4.4. Evaluate the integration of the subsurface design and layout with thermal management and preclosure facility operations.

- Evaluation of 2.4.4. On January 20, 2004, the Board held a panel meeting on repository design, at which it received various updates and briefings on DOE activities in this area. The Board observed in an April 5, 2004, letter to the DOE following the panel meeting that changes that have been made in the subsurface repository design will affect postclosure waste-package temperatures. In its November 30, 2004, letter to the DOE, the Board encouraged the DOE to analyze how the aging of spent fuel in surface storage at Yucca Mountain would be used to achieve thermal goals as part of a clearly-articulated thermal management strategy. The Board also stated in that letter that it believes that waste handling and surface storage at Yucca Mountain should be viewed and analyzed as parts of an integrated waste management system that begins when waste is accepted for shipment at reactors and other sites and ends after placement of the waste in a repository. This thought was reiterated in the Board's December 30, 2004, report to Congress and the Secretary.

2.5.1. Assess the integration of scientific studies with engineering designs for the repository and the waste package.

- Evaluation of 2.5.1. In the Board's July 28, 2004 letter to the DOE, the Board emphasized the need for thorough integration and close cooperation among technical disciplines working on the Yucca Mountain program. In its November 30, 2004, letter to the DOE, the Board noted the need to integrate scientific and engineering activities, and to use TSPA to evaluate changes in engineering design or operations for their effects on the overall repository system. The Board noted specifically that repository design changes made to mitigate igneous activity should be evaluated for their effects on repository operation and performance.

3. Performance Goals and Evaluation Related to Repository System Performance and Integration
[Note: TSPA results were not presented by the DOE to the Board in 2004. The Board looks forward to receiving the results of TSPA in 2005. In the meantime, to be prepared to evaluate TSPA results, Board members and staff are reviewing analysis and modeling reports and technical basis documents that will be used to support TSPA-LA.]

3.1.1. Identify which technical and scientific activities are on the critical path to reconciling uncertainties related to the DOE's performance estimates.

- Evaluation of 3.1.1: The Board observed in a letter to the DOE dated November 30, 2004, that the DOE had made progress in developing realistic estimates of ground motions. The Board commented to the DOE in a July 28, 2004, letter that a significant corrosion issue had been addressed. These observations were reiterated in a report to Congress and the Secretary on December 30, 2004. In that report, the

Board also identified a number of issues that require additional attention, including a better understanding of the natural system, an improved understanding of postclosure repository tunnel environments, other corrosion issues, resolution of discrepancies between chlorine-36 studies, improvements in the modeling of volcanic consequences, and work undertaken by the S&T program.

3.1.2. Determine the strengths and weaknesses of TSPA.

- Evaluation of 3.1.2: The Board held a meeting on September 20, 2004, at which it received a comprehensive update from the DOE on the TSPA process. Following the meeting the Board sent a letter to the DOE observing that the presentations at the September meeting highlight the critical need to complete the testing and validation of the process computer models and methods that support TSPA. The Board suggested that TSPA could be used to determine the effects of changes in repository design on other components of the repository system. The Board also indicated that it would like to review the results of TSPA, the technical and integration problems associated with TSPA and model validation activities, and how TSPA activities will be affected by potential changes in the regulatory compliance period. TSPA was identified as a Board priority for the coming year in the Board's December 30, 2004, letter to Congress and the Secretary.

3.1.3. Evaluate the DOE's treatment of seismic and volcanism issues in TSPA.

- Evaluation of 3.1.3: See evaluation of 3.1.2.

3.2.1. Evaluate the DOE's quantification of uncertainties and conservatisms used in TSPA.

- Evaluation of 3.2.1: The Board noted in its May 3, 2004, letter to the DOE that the DOE's approach of dealing with uncertainties related to the performance of natural barriers by making very conservative assumptions tends to emphasize more-rapid advective transport processes. To address this problem, the Board recommended that the DOE work to increase its fundamental understanding of the behavior of the natural system.

3.2.2. Review new data and updates of TSPA models, and identify models and data that should be updated.

- Evaluation of 3.2.2: The Board noted the critical need to complete the testing and validation of process computer models and methods that support TSPA in its November 30, 2004, letter to the DOE.

3.3.1. Evaluate the DOE's efforts to create a transparent and traceable TSPA.

- Evaluation of 3.3.1: See evaluation of 3.1.2.

3.3.2. Evaluate the DOE's efforts to develop simplified models of repository performance.

- Evaluation of 3.3.2: The Board is unaware of any DOE activities in this area in 2004.

3.3.3. Evaluate the DOE's efforts to identify analogues for performance estimates of the overall repository system.

- Evaluation of 3.3.3: In its May 3, 2004, letter to the DOE, the Board observed that the Peña Blanca site in Chihuahua, Mexico, could be used as an analogue to test and evaluate Yucca Mountain modeling approaches, the conceptual understanding of the natural systems at the site, and the scenarios predicted by the models. The Board commended the S&T program for its plans to test Yucca Mountain modeling approaches at the Peña Blanca site.

3.4.1. Evaluate the DOE's efforts to analyze the contribution of the different engineered and natural barriers to waste isolation.

- Evaluation of 3.4.1. A Board panel held a two-day meeting on March 9–10, 2004, at

which the DOE presented substantial information related to the contribution of the natural barriers to waste isolation. The Board also participated in a field trip following the meeting. In its May 3, 2004, follow-up letter to the DOE, the Board observed that analyses presented by the DOE suggest that the natural system provides an effective barrier to migration of some radionuclides. However, the Board noted several key hydrogeologic features central to the analyses that are not well understood or are poorly constrained. The Board also reiterated its long-held view that an integrated explanation is needed of how elements of the repository act as a system to isolate waste and recommended that the DOE work to improve its basic understanding of how the natural barriers will perform. The DOE's analysis of the overall contribution of engineered and natural barriers is imbedded in the DOE's TSPA. The Board looks forward to receiving the results of the TSPA, which will illuminate the DOE's analysis of the contributions of the different barriers.

3.5.1. Evaluate technical aspects of value engineering (providing a needed function reliably and at the lowest cost) and performance-related trade-off studies, including criteria, weighting factors, and decision methodologies for such studies; how technical uncertainties are taken into account; and what factors are included or excluded from such studies and why.

- Evaluation of 3.5.1: This performance goal applies specifically to work conducted under a contact to produce a prototype waste package. The contract was awarded by the DOE later than anticipated. Consequently, the work was not undertaken in 2004.

3.6.1. Recommend additional measures for strengthening the DOE's repository safety case.

- Evaluation of 3.6.1: In a May 3, 2004, letter to the DOE, the Board restated its long-held view that an integrated explanation is needed of how elements of the repository act as a system to isolate waste. The Board suggested that such an explanation should be based on a fundamental understanding of the system and that multiple lines of evidence and argument can be used to supplement and evaluate TSPA models. These comments were reiterated in the Board's December 30, 2004, report to Congress and the Secretary.

3.7.1. Evaluate the DOE's efforts to develop a feedback loop among performance-confirmation activities and TSPA models and data.

- Evaluation of 3.7.1: The Board did not receive information from the DOE on performance-confirmation activities in 2004.

3.7.2. Monitor the DOE's proposed plans for performance confirmation to help ensure that uncertainties identified as part of the site recommendation process are addressed.

- Evaluation of 3.7.2: See evaluation for 3.7.1.

4. Performance Goals and Evaluation Related to the Waste Management System

4.1.1. Evaluate the operation of the entire repository facility, including the surface and subsurface components.

- Evaluation of 4.1.1: The Board held a panel meeting on January 20, 2004, devoted in its entirety to issues related to the design of the repository, including the surface and subsurface components. On April 5, 2004, the Board sent a follow up letter to the DOE, in which the Board commented extensively on technical and scientific factors affecting the DOE's repository design.

4.1.2. Monitor the identification of research needs to support improved understanding of

the interaction of components of the waste management system.

- Evaluation of 4.1.2: The Board referenced the importance of integrating design and operational factors in its letter to the DOE dated April 5, 2004. Specifically, the Board noted that design changes that have been made could affect waste package temperatures and create "cold trap" effects in the repository. The Board recommended that temperature and relative humidity calculations be revised to reflect design changes. The Board held a panel meeting on January 21, 2004, at which it received updates on the status of DOE transportation activities. In a March 28, 2004, follow-up letter to that meeting, the Board observed that waste acceptance may emerge as a key transportation planning consideration. The Board suggested that the DOE work with the utility industry on this important issue. The Board received updates on DOE transportation planning activities at a meeting held May 18–19, 2004, and a panel meeting held October 13–14, 2004. The Board was updated on repository design issues at its September 20, 2004, meeting. In the Board's November 30, 2004, letter to the DOE, the Board stated its view that waste handling and surface storage at Yucca Mountain should be viewed and analyzed as parts of an integrated waste management system. The Board noted that the DOE's presentations on waste handling operations illustrated the vital importance of integrating waste management activities as part of facility design. The Board suggested that among other things, the implications of aging of the waste at the Yucca Mountain site should be explained as part of a clearly-articulated thermal management strategy. In its letter to the DOE dated December 1, 2004, the Board suggested that to achieve successful integration of transportation planning activities, it is important for the DOE to identify the entity responsible for each system component as well as the integration of those components. The Board also observed that DOE presentations at the Board's October meeting indicated that substantial work remains to be done on integrating waste management system components. Similar comments were included in the Board's December 30, 2004, report to Congress and the Secretary. In the same letter, transportation activities and integrating the waste management system were included among Board priorities for the coming year.

4.1.3. Review the technical and scientific basis of the DOE's analyses of component interactions in various scenarios, including the degree of integration and redundancy across functional components over time.

- Evaluation of 4.1.3: See evaluation of 4.1.2.

4.1.4. Evaluate the effects of reduced receiving capacity at the repository surface facility on the nationwide transportation system.

- Evaluation of 4.1.4: The Board suggested that the DOE undertake a review and inventory of infrastructure and facility needs in its letter to the DOE dated March 29, 2004.

4.1.5. Review criteria for waste acceptance for storage to ensure that accepted material has been characterized suitably for subsequent disposal.

- Evaluation of 4.1.5: In its March 29, 2004, letter to the DOE, the Board suggested that the DOE and the utility industry work together to facilitate the determination of cask requirements and transport logistics that are compatible with the waste to be shipped. The Board also recommends a thorough review of waste inventory and acceptance assumptions.

4.2.1. Monitor the DOE's efforts to implement Section 180 (c) of the NWPA.

- Evaluation of 4.2.1: The Board observed in its March 29, 2004, letter to the DOE

that emergency response capability is seen by states and local communities as a vital component of transportation safety and security. The Board also noted that it will be important for the DOE to demonstrate that it has invested adequate preparation time and financial resources to emergency preparedness. Emergency-response was discussed at the Board's panel meeting on October 13–14, 2004. In a December 1, 2004, letter to the DOE following that meeting, the Board noted the difficulty of forecasting disruptive events, but suggested that the DOE's approach to security risk assessment appears to be organized appropriately. The Board observed that the DOE's 180(c) program appears to be based too much on funding formulas and not enough on ensuring adequate emergency-response capability. The Board recommended that the DOE define a minimally acceptable level of emergency response along each transport route.

4.3.1. Monitor the DOE's progress in developing and implementing a transportation plan for shipping spent nuclear fuel and high-level radioactive waste to a Yucca Mountain repository.

- Evaluation of 4.3.1: The Board reviewed DOE transportation activities at its meetings held January 21, May 18–19, and October 13–14, 2004. In its March 29, 2004, letter to the DOE, the Board stated that the DOE's transportation strategic plan lacks the necessary detail for truly understanding the DOE's transportation planning effort. In a letter dated July 28, 2004, the Board noted that the DOE had made real progress in planning a transportation system. The Board's December 1, 2004, letter to the DOE includes more extensive comments on the DOE's transportation plans. For example, the Board suggests that the DOE needs to focus its attention on transportation options within the state of Nevada for both rail and truck. In particular, the Board suggests that contingency plans need to be developed for higher levels of truck use in the event that a rail spur is not built or is delayed.

4.3.2. Review the DOE's efforts to develop criteria for decisions on transportation mode and routing.

- Evaluation of 4.3.2: The Board notes in its December 1, 2004, letter to the DOE that the DOE should ensure that the technical issues involved in route selection are identified and that sound methods for addressing the issues are developed and applied.

4.3.3. Evaluate logistics capabilities of the transportation system.

- Evaluation of 4.3.3: The Board suggested that the DOE undertake a review and inventory of infrastructure and facility needs in its letter to the DOE dated March 29, 2004.

4.3.4. Monitor progress in implementing new technologies for improving transportation safety for spent nuclear fuel.

- Evaluation of 4.3.4: The Board reviewed the DOE's model for estimating transportation risk at its meeting held October 13–14, 2004. The Board commented on this issue in a letter to the DOE dated December 1, 2004.

4.3.5. Evaluate the DOE's plans for enhancing safety capabilities along transportation corridors, and review the DOE's planning and coordination activities (e.g., route selection), accident prevention activities (e.g., improved inspections and enforcement), and emergency response activities.

- Evaluation of 4.3.5: See evaluation of 4.1.2.

Appendix I

U.S. Nuclear Waste Technical Review Board Performance Plan

Fiscal Year 2005

Goals and Strategic Objectives

The nation's goals related to disposing of spent nuclear fuel and high-level radioactive waste were set forth by Congress in the NWPA. The goals are to develop a repository or repositories for disposing of high-level radioactive waste and spent nuclear fuel at a suitable site or sites and to establish a program of research, development, and demonstration for disposing of such waste.

The NWPAA limited repository development activities to a single site, Yucca Mountain in Nevada. The NWPAA also established the Board and charged it with evaluating the technical and scientific validity of the Secretary of Energy's activities associated with implementing the NWPA. The activities include characterizing the Yucca Mountain site and packaging and transporting spent nuclear fuel and high-level radioactive waste.

The Board's general goals and strategic objectives, which are presented in the Board's strategic plan for fiscal years (FY) 2004–2009, have been established in accordance with its statutory mandate and with congressional action in 2002 authorizing the DOE to proceed with developing an application to be submitted to the NRC for authorization to construct a repository at Yucca Mountain. The Board's goals reflect the continuity of the Board's ongoing technical and scientific evaluation and the Board's "systems view" of the repository and of waste management activities.

The Board's performance goals for FY 2005, which are included in this document, have been developed to further the achievement of the Board's general goals and strategic objectives. The performance goals have been numbered to correlate with appropriate strategic objectives, and preliminary budget amounts have been allocated to each set of performance goals.

Board Performance Goals for FY 2005

1. Performance Goals Related to the Natural System and Strategy for Achieving the Goals

(Dollars in Thousands)

FY 03	FY 04	FY 05
795	794	800

PERFORMANCE GOALS

1.1.1. Review the technical activities and agenda of the DOE's science and technology effort.

1.1.2. Monitor the results of flow-and-transport studies to obtain information on the potential performance of the saturated zone as a natural barrier in the repository system.

1.1.3. Review DOE efforts to confirm estimates of natural-system performance and pursue independent lines of evidence, including tests of models and assumptions.

1.2.1. Review DOE efforts to resolve questions related to possible seismic events and igneous consequences.

1.3.1. Evaluate geologic, hydrologic, and geochemical information obtained from the enhanced characterization of the repository block (ECRB) at Yucca Mountain.

1.3.2. Evaluate data from the drift-scale heater test.

1.3.3. Review plans and work carried out on possible analogues for the natural components of the repository system.

1.3.4. Recommend additional work needed to address uncertainties, paying particular attention to estimates of the rate and dis-

tribution of water seepage into the repository under proposed repository design conditions.

1.4.1. Evaluate tunnel-stability studies undertaken by the DOE.

1.5.1. Review the DOE's efforts to integrate results of scientific studies on the behavior of the natural system into repository designs.

STRATEGY FOR ACHIEVING GOALS

The Board will accomplish its goals by doing the following.

- Holding three public meetings with the DOE and DOE contractor personnel involving the full Board, and holding meetings of the Panel on the Natural System as needed.
- Reviewing critical documents provided by the DOE and its contractors, including contractor reports, process model reports, and total system performance assessment (TSPA).
- Meeting with contractor principal investigators on technical issues, including those related to climate change, seismic and volcanic events, flow and transport in the unsaturated and saturated zones, seepage, and the biosphere.
- Observing relevant laboratory and site investigations, including those conducted in the exploratory studies facility (ESF), the ECRB, and at Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, and Sandia National Laboratories. Observing other field investigations and visiting potential analogue sites. Visiting countries with nuclear-waste disposal programs and attending national and international symposia and conferences.

2. Performance Goals Related to the Engineered System and Strategy for Achieving the Goals

(Dollars in Thousands)

FY 03	FY 04	FY 05
954	953	960

PERFORMANCE GOALS

2.1.1. Monitor the DOE's performance allocation studies.

2.2.1. Review thermal testing and rock-stability testing related to potential conditions in repository tunnels.

2.2.2. Evaluate data from studies of the effects of corrosion and the waste package environment on the predicted performance of materials being proposed for engineered barriers.

2.3.1. Review the progress and results of materials testing being conducted to address uncertainties about waste package performance.

2.3.2. Evaluate the DOE's efforts in identifying natural and engineered analogues for corrosion processes.

2.4.1. Monitor the DOE's development of analytical tools for assessing the differences between repository designs.

2.4.2. Evaluate the accuracy and completeness of the technical bases for repository and waste package designs and the extent to which the DOE is using the technical bases for modifying repository and waste package designs.

2.4.3. Evaluate the integration of the subsurface design and layout with thermal management and preclosure facility operations.

2.5.1. Assess the integration of scientific studies with engineering designs for the repository and the waste package.

STRATEGY FOR ACHIEVING GOALS

The Board will accomplish its goals by doing the following.

- Holding three public meetings with DOE and contractor personnel involving the full Board, and holding meetings of the Panel on the Engineered System as needed.
- Reviewing critical documents provided by the DOE and its contractors, including contractor reports, process model reports, and TSPA.

- Meeting with contractor principal investigators on technical issues.
- Reviewing DOE documents and databases, paying particular attention to design features developed to promote drainage, control ventilation, and protect workers in the exhaust end of the ventilation system.
- Reviewing the common database (literature, laboratory, and field data) and judging the adequacy of the database for a decision on repository development.
- Observing relevant laboratory investigations, including those conducted at Lawrence Livermore National Laboratory and Lawrence Berkeley National Laboratory. Visiting countries with nuclear-waste disposal programs and attending national and international symposia and conferences.

3. Performance Goals Related to Repository System Performance and Integration and Strategy for Achieving Performance Goals

(Dollars in Thousands)

FY 03	FY 04	FY 05
636	635	640

PERFORMANCE GOALS

3.1.1. Identify which technical and scientific activities are on the critical path to reconciling uncertainties related to the DOE's performance estimates.

3.1.2. Determine the strengths and weaknesses of TSPA.

3.1.3. Evaluate the DOE's treatment of seismic and volcanism issues in TSPA.

3.2.1. Evaluate the DOE's quantification of uncertainties and conservatisms used in TSPA.

3.2.2. Review new data and updates of TSPA models, and identify models and data that should be updated.

3.3.1. Evaluate the DOE's efforts to create a transparent and traceable TSPA.

3.3.2. Evaluate the DOE's efforts to develop simplified models of repository performance.

3.3.3. Evaluate the DOE's efforts to identify analogues for performance estimates of the overall repository system.

3.4.1. Evaluate the DOE's efforts to analyze the contribution of the different engineered and natural barriers to waste isolation.

3.5.1. Evaluate technical aspects of value engineering and performance-related trade-off studies, including criteria, weighting factors and decision methodologies for such studies and how technical uncertainties are taken into account.

3.6.1. Recommend additional measures for strengthening the DOE's repository safety case.

3.7.1. Evaluate the DOE's efforts to develop a feedback loop among performance-confirmation activities and TSPA models and data.

3.7.2. Monitor the DOE's proposed plans for performance confirmation to help ensure that uncertainties identified as part of the site recommendation process are addressed.

STRATEGY FOR ACHIEVING GOALS

The Board will accomplish its goals by doing the following.

- Holding three public meetings with DOE and contractor personnel involving the full Board and holding meetings of the Panel on the Repository System Performance and Integration, as needed.
- Reviewing critical documents provided by the DOE and its contractors, including contractor reports, process model reports, and the DOE's TSPA.
- Meeting with contractor's principal investigators on technical issues.

- Observing ongoing laboratory investigations, including those conducted at Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, Sandia National Laboratories, and the engineered-barrier test facility. Observing field investigations. Visiting countries with nuclear-waste disposal programs and attending national and international symposia and conferences.

4. Performance Goals Related to the Waste Management System and Strategy for Achieving the Goals

(Dollars in Thousands)

FY 03	FY 04	FY 05
795	794	800

Performance Goals

4.1.1. Evaluate the operation of the entire repository facility, including the surface and subsurface components.

4.1.2. Monitor the identification of research needs to support improved understanding of the interaction of components of the waste management system.

4.1.3. Review the technical and scientific basis of the DOE's analyses of component interactions under various scenarios, including the degree of integration and redundancy across functional components over time.

4.1.4. Evaluate the effects of reduced receiving capacity at the repository surface facility on the nationwide transportation system.

4.1.5. Review criteria for waste acceptance for storage to ensure that accepted material has been suitably characterized for subsequent disposal.

4.2.1. Monitor the DOE's efforts to implement Section 180 (c) of the NWPA.

4.3.1. Monitor the DOE's progress in developing and implementing a transportation plan for shipping spent nuclear fuel and high-level radioactive waste to a Yucca Mountain repository.

4.3.2. Review the DOE's efforts to develop criteria for decisions on transportation mode and routing.

4.3.3. Evaluate logistics capabilities of the transportation system.

4.3.4. Monitor progress in implementing new technologies for improving transportation safety for spent nuclear fuel.

4.3.5. Evaluate the DOE's plans for enhancing safety capabilities along transportation corridors, and review the DOE's planning and coordination activities (e.g., route selection), accident prevention activities (e.g., improved inspections and enforcement), and emergency response activities.

Strategy for Achieving Goals

The Board will accomplish its goals by doing the following.

- Holding three public meetings with DOE and contractor personnel involving the full Board, and holding meetings of the Board's Panel on the Waste Management System in appropriate areas of the country.

- Reviewing critical documents provided by the DOE and its contractors, including contractor reports, process model reports, and TSPA.

- Meeting with groups involved in implementing transportation plans, including the NRC, the Department of Transportation, railroad and trucking companies, nonprofit groups, the utilities, and other stakeholders. Visiting countries with nuclear-waste transportation and disposal programs and attending national and international conferences and symposia.

U.S. Nuclear Waste Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201
(Tel) 703-235-4473; (Fax) 703-235-4495
www.nwtrb.gov