U.S. Nuclear Waste Technical Review Board

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

March 1, 2006–December 31, 2007

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The Board appreciates the assistance of DOE in providing many of the graphics used in this report.

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

August 2008

The Honorable Nancy P. Pelosi
Speaker of the House
United States House of Representatives
Washington, DC 20515

The Honorable Robert C. Byrd
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 Pelosi, Senator Byrd, and Secretary Bodman:

The U.S. 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 directs the Board to report its findings and recommendations to Congress and the Secretary of Energy at least two times each 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 of 1982. This report summarizes the Board's major activities from March 1, 2006, through December 31, 2007. The report also includes a discussion of the Board's technical evaluation of work undertaken by the Department of Energy (DOE) during that period related to disposing of, packaging, and transporting spent nuclear fuel and high-level radioactive waste. The report appendices include Board correspondence, congressional testimony, Board performance plans and evaluations, and related materials.

The Board hopes that this information will provide a useful technical context for addressing issues related to managing the nation's spent nuclear fuel and high-level radioactive waste.

Sincerely,
{Signed by}

B. John Garrick
Chairman

U.S. Nuclear Waste Technical Review Board

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Executive Summary

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

Between March 1, 2006, and December 31, 2007, the period covered by this report, the Board focused its evaluation on five critical technical issues dealing with preclosure operations of the waste management system and on six critical technical issues dealing with postclosure performance of the proposed Yucca Mountain repository. The Board also explored in depth the crosscutting issue of thermal management. The Board's views on these issues are summarized below and are explained in greater detail in the body of this report.

The Context of the Board's Review

Over the last two years, the Office of Civilian Radioactive Waste Management (OCRWM) in DOE has made considerable progress in restructuring its repository development efforts. OCRWM reorganized its scientific work on the repository, centralizing it at Sandia National Laboratories (SNL). It redesigned completely the proposed repository's surface facilities, in part to minimize handling of bare commercial SNF. Key to that redesign was the Project's decision that most commercial SNF would be sent to the repository in standardized sealed transportation-aging-disposal (TAD) canisters, which would be loaded at utility sites. OCRWM also finalized the performance specification for the TAD canister system and initiated a procurement for detailed designs.

The Project successfully met key milestones that would enable it to fulfill a commitment to Congress to submit a License Application (LA) for constructing a repository to the U.S. Nuclear Regulatory Commission (NRC) no later than June 30, 2008. DOE published a

draft environmental impact statement for evaluating changes in the repository program that had taken place since 2002. It released two draft environmental impact statements to support decisions related to the construction of a rail line and the operation of a railroad in Nevada. Finally, it certified its document collection that now resides electronically on NRC's Licensing Support Network, which was established to facilitate the discovery process in anticipation of a hearing on the LA. The Board considers all of these achievements significant accomplishments for the program. (On June 3, 2008, after the period covered by this report, DOE submitted an LA to NRC.)

Preclosure Operations of the Waste Management System

Transportation-Aging-Disposal Canister Concept

The Board has followed closely the TAD canister development process and commented on it in a series of letters to the Project. The Board agrees that many of the advantages that OCRWM envisions for the TAD canister concept might be realized. But the Board also notes that hurdles must be overcome before the potential advantages of a canister-based system can be secured. The Board recommends that DOE carry out comprehensive analyses to understand better the implications of not achieving the 90 percent TAD canister utilization rate that has been assumed by the Project. Furthermore, the Board continues to encourage DOE to study actively all possible options for dealing with commercial SNF that already has been loaded in dual-purpose canisters—including direct disposal.

Surface Facility Operations

The Project's decision to adopt the TAD canister concept catalyzed its redesign of the surface facilities at the proposed repository. Both initiatives are responsive to the Board's concerns about the number of times that bare commercial SNF assemblies would have to be handled at Yucca Mountain.

Although the facility redesign effort addressed very well the issue of handling bare fuel, the Board believes that other issues still remain unresolved. For example, the Board thinks that the Project's preliminary estimates of throughput may be overly optimistic. The Board recommends that OCRWM represent throughput processes more realistically and evaluate measures that could improve throughput, including increasing the capacity of the Waste Handling Facility (WHF) pool to allow parallel removal and transfer of fuel in dual-purpose casks and increasing the number of welding stations in the WHF and the Canister Receipt and Closure Facility to eliminate potential choke points.

Preclosure Safety Analysis

The Project is required to prepare a Preclosure Safety Analysis (PCSA) of its surface and subsurface operations as part of the LA. As of the end of 2007, that effort had not yet been completed. The Board expressed its concerns about the Project's decision to develop a PCSA that combines deterministic and risk-informed probabilistic methodologies. Based on what the Board has seen, it is unclear at this point how OCRWM intends to address the uncertainties associated with the aggregation of risk across different activities.

Transportation

The Board remains concerned that the Project does not fully appreciate the ramifications of potential delays in the construction of a rail line to Yucca Mountain or the possibility that a rail line may never be built. DOE's declaration that the TAD canister would be the centerpiece of its waste management strategy implicitly made the Project dependent on the existence of a Yucca Mountain rail line. Given that no such line exists today and that construction of such a line may encounter significant challenges, the absence of a workable alternative for such a vulnerability is not prudent. Therefore, the Board believes that the Project should immediately and aggressively pursue a contingency plan in which the truck mode (heavy-haul or off-road) is considered within Nevada.

Waste Management System Integration

The Board conceives of a waste management system composed of four elements: waste acceptance, transportation, surface operations, and subsurface operations. It is imperative that the system be analyzed and evaluated as an integrated whole. One potentially important integrating methodology is OCRWM's Total System Model (TSM). The Board strongly supports the use of TSM, maintaining that it can play a valuable role in analyzing the operational interdependencies of the waste management system and the utility of the TAD canister concept. Nonetheless, the Board recommends several areas where the use of TSM could be strengthened, including adding a capability to evaluate "upset" conditions, such as equipment breakdowns, and to evaluate the effects of alternative thermal management strategies.

Postclosure Performance of the Proposed Repository System

Extensive field and laboratory studies as well as detailed analyses were undertaken by OCRWM to develop both qualitative and quantitative estimates of how a repository might perform hundreds of thousands of years into the future. The Project's efforts to develop those estimates have become increasingly sophisticated and evidence-based. The Board commends OCRWM for undertaking a broad suite of investigations, which often break new scientific and technical ground.

In evaluating the scientific and technical bases for the Project's estimates, the Board has identified six areas where improvements and enhancements still can be made. Although some additional work would be required to address Board concerns, the Board does not believe—with the possible exception of realistic waste degradation modeling—that this work would be especially difficult to carry out. In any event, completing this work could enhance the confidence that can be placed in the Project's performance estimates.

Infiltration Estimates

Water is the primary vehicle by which the radionuclides in the SNF and HLW might be transported out of the repository. Responding to a commitment made to Congress, the Board evaluated the technical basis underlying two different estimates of how much water infiltrates below the root zone at Yucca Mountain. One set of estimates was developed by the U.S. Geological Survey (USGS), the other by SNL.

The USGS estimates of infiltration are based on an extensive suite of site-specific data and are consistent with multiple independent lines of evidence. Furthermore, the Board's opinion is that the USGS program produced valuable results that are important for understanding the mountain hydrology and for building confidence in the estimated performance of the proposed repository.

SNL developed its estimates using a model that does not include consideration of all available site-specific data used by USGS, such as soil depth and soil and rock hydraulic parameters. Consequently, the SNL estimates of present-day infiltration at Yucca Mountain are approximately three times higher than the USGS estimates, and the SNL estimates are less consistent with independent lines of evidence, including measurements of temperature and salt (chloride) concentrations at depth within Yucca Mountain. However, the SNL approach has a more complete representation of uncertainties associated with relevant physical parameters—a methodological advantage over the USGS approach.

Infiltration estimates are used as input for OCRWM's Total System Performance Assessment (TSPA), a complex computer model designed to project the performance of the proposed repository into the far future. To make the SNL estimates compatible with observed site-specific data supporting related models in TSPA, the Project uses a statistical process that preferentially considers the lower end of the range of SNL infiltration estimates. As used by the Project, this statistical modification of the infiltration estimates does not have a strong technical basis, and thus, the Board does not endorse the use of the statistically modified SNL infiltration estimates in TSPA.

The Board believes that all available data should be used in assessing infiltration estimates, as was done in the USGS estimates. The Project also should continue its rigorous treatment of uncertainties, as was done by SNL.

Deliquescence-Induced Localized Corrosion

The outer shell of the Project's currently designed waste package is made up of Alloy 22, a corrosion-resistant nickel-based metal. Over the last several years, the Board has recommended that OCRWM examine whether salts found in the dust that would accumulate during tunnel ventilation could, by deliquescence at high temperatures, form brines that might initiate and promote localized corrosion. The Project has decided to exclude or "screen out" the process of deliquescence-induced localized corrosion from its TSPA.

After intensive review, including a two-day technical workshop in which scientists from a wide range of interested organizations participated, the Board set forth conditions that must be satisfied to support a technically defensible decision to screen out, based on low consequences, deliquescence-induced localized corrosion during the thermal pulse. Inhibitive nitrate-to-chloride ratios must be determined for the entire range of temperatures over which deliquescent brines may occur on waste package surfaces. The preferential migration of nitrate ions into a crevice on the waste package must be sufficient to maintain nitrate-to-chloride ratios that are inhibitive. The Board strongly recommends that OCRWM conduct investigations for determining whether these two conditions are satisfied.

Further, the Board notes that the dust settling on waste package surfaces during preclosure ventilation would contain significant amounts of organic materials and that reactions between the materials and nitrate in the dust could affect the amount of nitrate available to inhibit corrosion. The Board believes that the Project also should analyze the effects of

the full range of factors (e.g., organics in dust, acid-gas devolatilization, and radiolysis) that could influence whether inhibitive nitrate-to-chloride ratios persist under postclosure repository conditions.

Development of a Safety Case

For more than a decade, the Board has held that it is important for OCRWM to develop a structured presentation of the evidence, analyses, and lines of reasoning that can build confidence in the conclusions derived from TSPA. This set of arguments constitutes what is commonly called a "safety case." The Board endorses the Project's effort to develop a safety case, noting, for example, that the use of natural analogues can provide excellent tests of prevailing conceptual and numerical models of radionuclide transport and isolation.

Waste Degradation and Radionuclide Transport

If the waste package fails, the waste, in its various forms, may begin to degrade. The degradation process is complex, and the fate of the radionuclides in the waste is uncertain. The Project's implementation of TSPA therefore uses conservative assumptions about radionuclide transport that may often be unrealistic. On several occasions, the Board has observed that obtaining a better fundamental understanding of the entire transport process remains a productive avenue for additional scientific investigation.

Although the variables affecting radionuclide transport, such as temperature, pH, redox state, and ionic strength, can be enumerated, the Board does not minimize the difficulties associated with carrying out the research program that it recommends. Nonetheless, the Board restates its view that the key subset of issues associated with waste degradation and radionuclide transport deserves further attention because of the potentially significant effect that these phenomena might have on developing realistic estimates of repository performance.

Realistic Performance Assessments

Waste degradation and radionuclide transport is only one area where the Board believes that OCRWM's estimates of repository performance are unrealistic. In the past, the Board has called OCRWM's attention to the importance of eliminating, to the greatest extent possible, the use of "bounding assumptions," as opposed to realistic distributions of important parameters. Over the last two years, the Board has followed the development of the Project's performance-margin analyses, and it reaffirms its belief in the potential value of such analyses.

Bomb-Pulse Chlorine-36 at the Horizon of the Proposed Repository

Since mid-1996, the Board has followed closely Project investigations to determine whether elevated levels of bomb-pulse chlorine-36 are present at the horizon of the proposed repository. The presence of the isotope in undisturbed rocks at depth would provide incontrovertible evidence that at least some of the water that falls on Yucca Mountain moves rapidly through the unsaturated zone above the proposed repository.

Over the last seven years, the Board has urged OCRWM to resolve the apparent disagreement about this issue between Los Alamos National Laboratory, which believed that it found evidence suggesting the isotope's presence, and Lawrence Livermore National

Laboratory and the USGS, both of which failed to find any evidence of elevated bomb-pulse chlorine-36 levels. The Project has told the Board that it has abandoned efforts to reconcile the disparate findings. However, the Board still believes that the possible existence of bomb-pulse chlorine-36 at depth in Yucca Mountain remains an outstanding issue whose resolution could greatly enhance confidence in understanding fluid flow within Yucca Mountain.

The Crosscutting Issue of Thermal Management

How OCRWM plans to establish the temperature regime under which the proposed repository will operate strongly affects the acceptance of waste at generation sites as well as surface and subsurface operations at the facility. Thermal management also strongly influences projections of a repository's postclosure performance because the corrosion, near-field, and hydrologic models used in the TSPA all are temperature dependent.

Over the last two years, the Board's interactions with OCRWM on the thermal management issue have been productive. The Project is developing an integrated thermal management strategy using the TSM and waste package loading models to evaluate waste acceptance as well as surface and subsurface operations, including emplacement. It is considering different scenarios of assembly age, burnup, and throughput rates using actual assembly power decays rather than, as it has done in the past, a single decay rate based on a theoretical waste stream. The Board is encouraged by the progress that OCRWM recently has made in addressing its concerns related to this critical crosscutting issue.

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) under the Nuclear Waste Policy Act of 1982, as amended. Those laws require DOE to develop systems for disposing of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) produced by the nation's commercial nuclear power stations, nuclear defense complex, and research reactors. Currently, DOE, through its Office of Civilian Radioactive Waste Management (OCRWM), is working on a system that would consist of a geologic repository located at Yucca Mountain in Nevada, together with waste acceptance and transportation systems for bringing the waste to Yucca Mountain. The results of the Board's evaluation, along with its recommendations, must be reported at least twice yearly to Congress and the Secretary of Energy. This document is the first such report for 2008.

The Board's mandate to review the DOE's waste disposal project is broad. Between March 1, 2006, and December 31, 2007, the period covered by this report, the Board focused its evaluation on five critical technical issues dealing with preclosure operations of the waste management system and on six critical technical issues dealing with postclosure performance of the proposed Yucca Mountain repository. The Board also explored in depth the crosscutting issue of thermal management.

The Yucca Mountain Project made progress on achieving several important milestones, realized others, and established new ones. The Board considers all of these achievements significant accomplishments.

The Context of the Board's Review

On May 26, 2006, the Senate confirmed Edward Sproat, III, as Director of OCRWM. During the next 19 months, the Yucca Mountain Project made progress on achieving several important milestones, realized others, and established new ones. The Board considers all of these achievements significant accomplishments.

- In July 2006, Sproat testified before the Subcommittee on Energy and Air Quality of the Committee on Energy and Commerce in the U.S. House of Representatives. He stated that DOE would submit to the U.S. Nuclear Regulatory Commission (NRC)

no later than June 30, 2008, a License Application (LA) for constructing a repository at Yucca Mountain.[1] He noted that the "best achievable" schedule for beginning to receive waste would be 2017 (Sproat 2006).

- Building on an initiative that was launched in 2005, DOE made a series of decisions between July and October 2006 that significantly altered the design of the proposed repository's surface facilities. DOE's Energy Systems Acquisition Advisory Board authorized planning for construction of four structures: Initial Handling Facility (IHF), Receipt Facility (RF), Canister Receipt and Closure Facility (CRCF), and Wet Handling Facility (WHF). This design change reflects the Project's decision that most commercial SNF and all HLW should be sent to the proposed repository in standardized sealed transportation-aging-disposal (TAD) canisters that would not require repetitive handling of commercial SNF assemblies before their disposal (DOE 2006b). Earlier plans called for shipping SNF in various types of canisters to the proposed repository where, in preparing the material for disposal, workers would handle each of the bare SNF assemblies as many as four times in order to blend and package the fuel for disposal. DOE began developing a performance specification so that the materials used to fabricate the TAD canisters and to ensure that the projected performance of the canisters conformed to the assumptions of DOE's Total System Performance Assessment (TSPA).
- In October 2006, OCRWM completed the transition to Sandia National Laboratories (SNL) of the responsibility for managing and integrating all the Project's scientific activities related to postclosure performance of the proposed repository.
- In June 2007, OCRWM finalized the performance specification for the TAD system, which includes, among other things, a canister, a transportation overpack, a transfer cask, a storage overpack, and an aging overpack (DOE Office of Public Affairs 2007). OCRWM then initiated the procurement for the development of complete TAD system designs and safety analysis reports (SAR) for NRC certification under 10 CFR 71 and 10 CFR 72. Four proposals were received and are being evaluated.
- In October 2007, DOE published two draft environmental impact statements (EIS) to support decisions related to the construction of a rail line and the operation of a railroad within Nevada to transport SNF and HLW to Yucca Mountain (DOE 2007a, b). The first document evaluated the environmental impacts along one new corridor, the Mina route south of the town of Silver Springs. Further, updated information on the impacts along three other corridors–Carlin, Jean, and Valley Modified–which had been analyzed previously was evaluated to determine whether those corridors warranted additional detailed study. (Impacts along a fourth corridor, originating in the city of Caliente, had been evaluated extensively in 2002.)

  The second document evaluated the environmental impacts of constructing a rail line and operating a railroad along specific track alignments. Impacts along one set of

[1] DOE submitted the LA to NRC on June 3, 2008.

alternative alignments within the Mina corridor were evaluated, as were the impacts along another set of alternative alignments within the Caliente corridor.[2]

- In October 2007, DOE also released a draft Supplemental Environmental Impact Statement (SEIS) for the proposed repository at Yucca Mountain (DOE 2007c). The SEIS was prepared to reflect changes in the Project that have taken place since 2002. These changes include, among other things, the design of the surface facilities, the decision to use TAD canisters, and the choice of the "mostly rail" mode for transporting SNF and HLW. Further, additional information and updated analytical tools permitted refined analyses of transportation impacts, preclosure operational impacts, and estimates of postclosure repository performance.

Board Review of OCRWM's Technical and Scientific Investigations

Overview

Throughout the period covered by this report, two fundamental questions guided the Board's activities.

- Are the scientific and technical bases for OCRWM's assessments of the postclosure performance of the repository valid and transparent?
- Has OCRWM established a safety case that integrates the total waste management system, from waste acceptance at the generator sites, to preclosure operations at and below the surface of the repository site, to performance demonstration and confirmation, and, finally, to the closure of the repository?

To obtain answers to these questions, the Board needed to interact with the Project in a concerted manner that permitted in-depth technical exploration of the issues. Many of those interactions took place in public meetings and workshops. Transcripts of those meetings and workshops and copies of the presentations that were made are available on the Board's web site: www.nwtrb.gov.

In addition, small contingents of Board members and staff held seven fact-finding meetings with OCRWM and its contractors between March 2006 and December 2007. Project scientists and engineers presented ongoing scientific investigations and analyses, many of which contained preliminary results in draft form, which the Board is entitled to receive under the NWPAA. These fact-finding meetings were productive and enabled the Board to engage in the detailed and lengthy technical discussions that are necessary for understanding many of the fundamental methods of analysis used by the Project. In addition, several Board members and staff held separate talks with representatives of railroads, trucking companies, cask manufacturers, transportation logistics providers, and nuclear utilities. The purpose of these sessions was to gather first-hand information from key stakehold-

[2] Because the Walker River Paiute Tribal Council decided in April 2007 to renew past objections to the transportation of HLW and SNF through its reservation, the Mina route was eliminated from consideration. Although DOE acknowledged that the Mina route would have been, on balance, environmentally preferable and cost $500 million less, DOE proposed to construct a rail line and to operate a railroad along one specific rail alignment within the Caliente corridor.

Source: DOE

Figure 1. Yucca Mountain

ers who would be involved in designing and operating the waste-management system. All of these meetings were undertaken to improve the technical substance and relevance of the Board's public meetings. To the extent possible, major conclusions reached as a result of these interactions will be discussed in this report.

The Proposed Repository System

Yucca Mountain is a north-south trending ridge, rising approximately 300 meters (1300 feet) above the adjacent valleys in Nye County, Nevada. It is approximately 160 kilometers (100 miles) northwest of Las Vegas. The site is located on land controlled by three U.S. Government agencies: the Department of Defense, the Department of the Interior, and DOE. **Figure 1** is a photograph of Yucca Mountain, taken looking south.

Nuclear waste in its variety of forms must be moved to Yucca Mountain from more than 100 sites where it is currently stored. DOE has determined that most of the material should be moved by rail, although some waste may have to be moved by truck or barge relatively short distances from where it is stored to a rail head. The proposed repository site, however, is not served by a rail line. As noted above, the Project has drafted two EIS's to support its plans for developing a new rail line and operating a railroad to move the HLW and SNF from a rail junction, likely to be in Caliente. Based on estimates in the EIS's, a new rail line constructed on the Caliente corridor would be approximately 500 kilometers (330 miles) long and would require establishing a right-of-way involving 170 square kilometers (41,000 acres). Including the construction of support facilities and the purchase of rolling stock, creating the capacity to move waste to Yucca Mountain would cost in 2005 constant dollars approximately $2.7 billion.

The surface part of the repository system is a large complex containing several buildings for processing the HLW and SNF as well as concrete pads for aging some of that material until its disposition. **Figure 2** shows the layout for the proposed surface facilities. According to Project plans, waste will arrive at Yucca Mountain in a variety of forms—commercial SNF from nuclear power stations that is either in TAD canisters or in dual-purpose casks (DPC); uncanistered commercial fuel assemblies; canistered HLW produced at DOE's defense facilities or at the West Valley Plant; canistered SNF from the Navy's nuclear warships; and canistered DOE SNF.

Once the waste is received, it will be sent to one or more of four buildings for processing. HLW and Navy SNF will be placed in waste packages in the IHF and disposed of immedi-

Figure 2. Surface Facility Layout

Source: DOE

ately. DOE SNF will be placed in waste packages in the CRCF and also will be disposed of immediately. Commercial SNF in TAD canisters can be processed either at the RF or at the CRCF. Commercial SNF in DPC's can be handled at the RF or at the WHF. Uncanistered commercial fuel assemblies can be accommodated only in the WHF, where it will be put in canisters. The now-canistered commercial spent fuel will be sent to the CRCF, where the canisters will be placed in the waste packages, which then will be sealed. The waste packages will then be disposed of. Commercial SNF, whose thermal power is too high for the waste to be disposed of immediately, will be placed on aging pads until its thermal power has decreased to a level acceptable for disposal. After the commercial SNF's thermal output has dropped sufficiently, it will be returned either directly or, in the case of SNF in DPC's, indirectly through the WHF to the CRCF. There, it will be prepared for final disposal.

The subsurface part of the repository system consists of both natural features and engineered elements. They are expected to work together to limit the amount of water contacting the waste and to retard or contain any material released. The surficial soil and topography and the unsaturated volcanic tuff above the repository drifts (tunnels) limit the amount of water that percolates downward. The amount of water that enters the drifts is a fraction of the water that reaches the horizon where the proposed repository would be located.

The SNF and HLW are inside robust waste packages whose outer shell is composed of a corrosion-resistant nickel-based metal called Alloy 22. Covering the waste packages are overlapping titanium drip-shield segments, which, while they are intact, can divert water from coming into direct contact with the packages. Only after the waste packages corrode and the waste form degrades will the radionuclides in the SNF and HLW be exposed to liquid water. It is possible that their migration immediately outside the package may be physically and chemically retarded. Even if it is not, the radionuclides must travel outside the drifts through another thick layer of unsaturated rock before reaching the formation that includes the water table. Once in this saturated zone, the radionuclides may be transported to the accessible environment and taken up mostly by people, animals, and plants living in the area downgradient of the site. **Figure 3** on the next page is a schematic that summarizes how the subsurface features and elements are expected to isolate waste.

Standards and regulations promulgated by the U.S. Environmental Protection Agency (EPA) and NRC regulations require that DOE calculate how large a dose the "reasonably maximally exposed individual" who resides about 18 kilometers (11 miles) south of

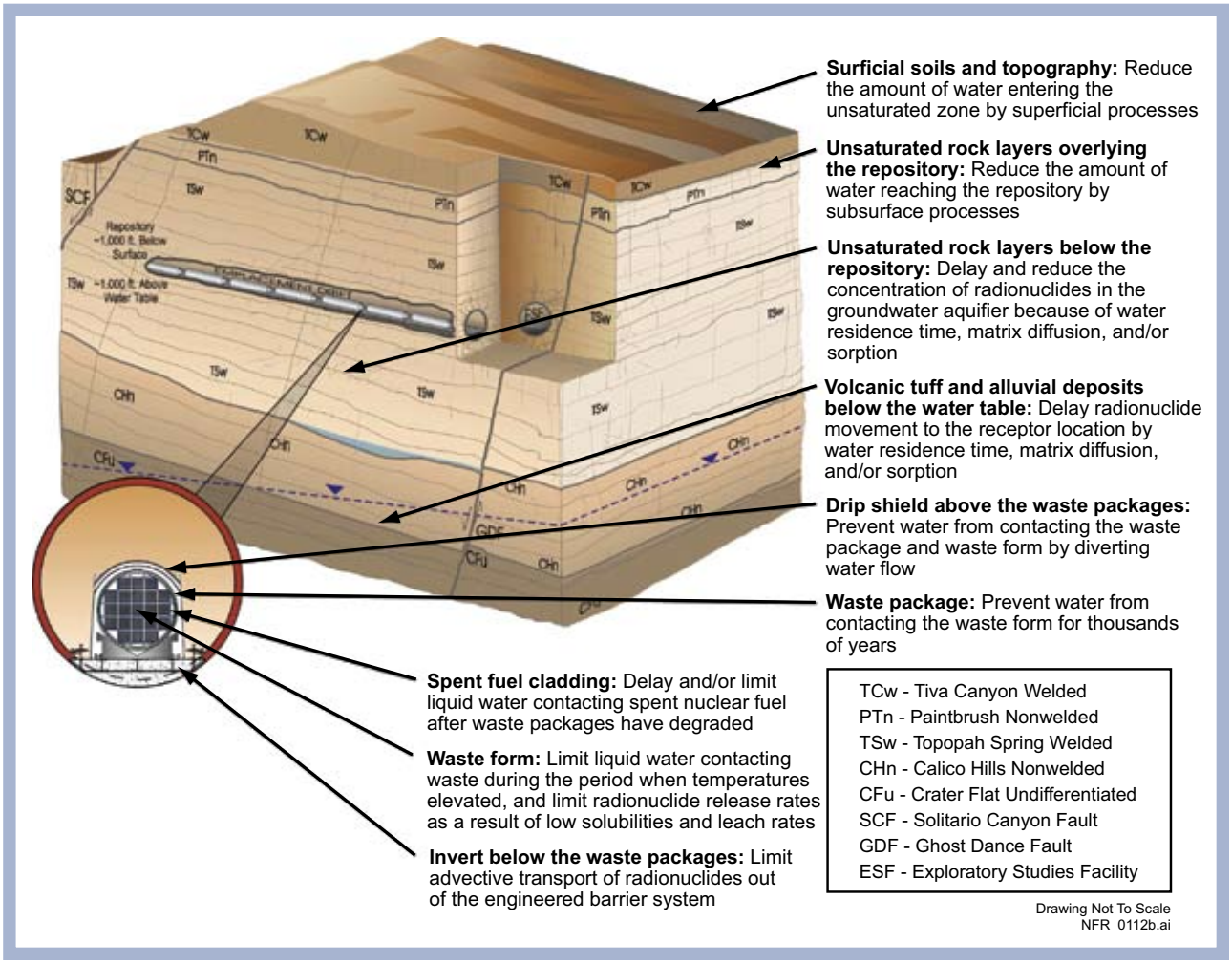


Figure 3. Subsurface Features at Yucca Mountain

Yucca Mountain will receive (40 CFR 197 and 10 CFR 63).[3] To do so, DOE must construct complex computer models of the proposed repository's postclosure behavior and exercise them in a TSPA. In addition, the standards and regulations require that DOE evaluate the operational safety risks to the public and workers in a Preclosure Safety Analysis (PCSA).

Preclosure Operations of the Waste Management System

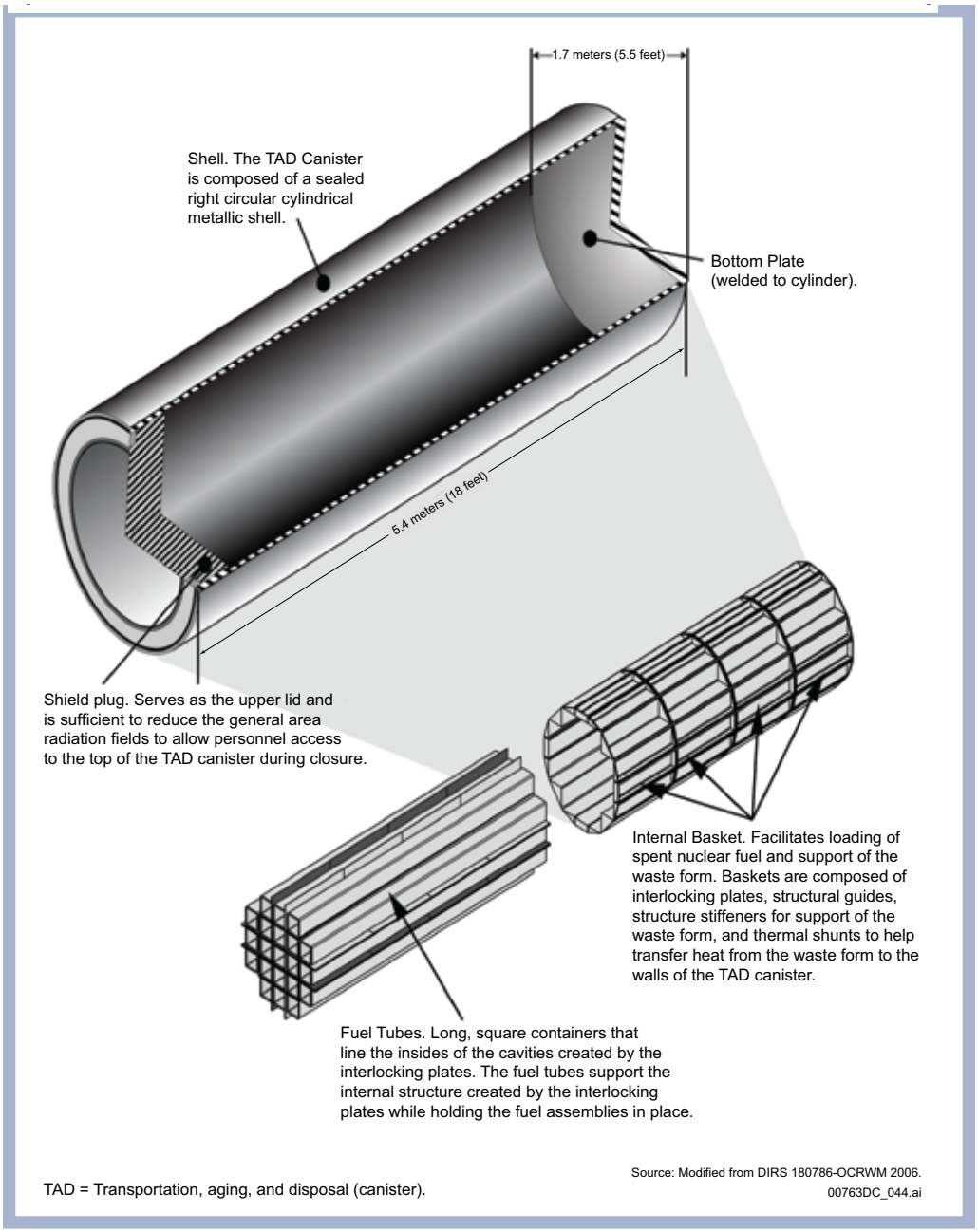
Transportation-Aging-Disposal Canister Concept

The TAD canister system could reduce the number of times individual assemblies are handled because the canister and its contents would be handled in a single action.

In 2005, DOE made a provisional decision to adopt the TAD canister concept. The following year, that decision was confirmed. **Figure 4** is a conceptual design of what a TAD canister might look like.

From the time that the TAD canister concept was first proposed, the Board held that it was promising (Garrick 2005b, c and NWTRB 2006a). "The TAD canister system could reduce the number of times individual assemblies are handled because the canister and its contents would be handled in a single action. This could improve facility throughput at Yucca Mountain and reduce the potential for accidents during handling operations.

[3] The U.S. Environmental Protection Agency is considering comments on its proposed environmental standards. Two key issues are what the permissible dose should be and the time period over which that dose cannot be exceeded. (For the proposed standard, see EPA 2005.)



Source: DOE

Figure 4. Conceptual Design of the TAD

The TAD canister system also has the potential to simplify the design and reduce the cost of repository surface facilities." (Garrick 2006a). Since then, the Board's views about the TAD canister concept, although tempered somewhat, have not changed fundamentally: The Board looks favorably on the technology but realizes that OCRWM still must address some important implementation issues. Of foremost importance to the Board are (1) the implications of the TAD canister concept for preclosure and postclosure thermal management at the potential repository; (2) the logistics of transporting TAD canisters to Yucca Mountain; and (3) how DOE will manage commercial SNF that is not packaged in a TAD canister.

At the Board's May 9, 2006, meeting in McLean, Virginia (NWTRB 2006b), an OCRWM official described the approach that will be used to develop and implement the TAD canister concept (Kouts 2006). From OCRWM's perspective, the concept offers important

advantages: The TAD canisters would standardize fuel handling, utilize utility fuel-handling experience, simplify operations at the repository, reduce low-level-waste production and worker radiation exposure, and lower the cost of building surface facilities at the proposed repository site. The private sector would be asked to provide detailed designs that would meet a suite of performance specifications, allowing the TAD canister system to satisfy NRC regulations for storage (10 CFR 72), transportation (10 CFR 71), and disposal (10 CFR 63). DOE would procure TAD canister system transportation overpacks and provide TAD canisters for acceptance of SNF directly from utility pools. Further, DOE has announced that it might offer economic incentives for encouraging utilities to purchase TAD canisters. In such cases, DOE also would provide storage/transportation overpacks to move the loaded TAD canisters to the proposed repository. In a complementary presentation, representatives from two nuclear industry trade associations noted that their members are committed to cooperating with DOE to bring the TAD canister concept to fruition (McCullum and Blee 2006).

The following year, at its January 24, 2007, and its September 19, 2007, meetings, both held in Las Vegas (NWTRB 2007 a, d), the Board received updates on the development process for the TAD canister system (Kouts 2007a, b). By the time the second meeting took place, a final performance specification had been issued, delineating the requirements that DOE will rely on in its LA. Subsequently, four cask vendors completed TAD-canister proof-of-concept designs, and DOE completed reviewing those designs. DOE initiated a procurement for developing complete TAD canister system designs and Safety Analysis Reports for NRC certification for storage and transportation. Four proposals were received. They are still being evaluated. The same two representatives of nuclear industry trade associations observed that the dialogue between their members and DOE had been positive and that agreements had been reached on a number of issues. The two representatives, however, cautioned that much work still needs to be done and that successful implementation of the TAD canister concept is by no means assured (McCullum and Blee 2007).

The Board commented on these developments in a series of letters to DOE.[4] In a June 14, 2006, letter (Garrick 2006a), the Board agreed that many of the advantages that OCRWM attached to the TAD canister concept might be realized. But the Board also noted that it had become apparent "that hurdles must be overcome for the potential advantages of a canister-based system to be realized. Particularly important is the timing of the availability of TAD canisters for storage at utility sites … If TADs are not available for use at utilities for at least 5-6 years, the quantity of spent fuel in dry storage [in containers other than TADs] at reactor sites will be significant."

. . . hurdles must be overcome for the potential advantages of a canister-based system to be realized.

In a January 16, 2008, letter (Garrick 2008), the Board again questioned OCRWM's projection that 90 percent of commercial SNF would be placed in TAD canisters. For that reason, the Board again recommended that "DOE carry out comprehensive analyses to understand better the implications of not achieving the 90 percent TAD canister utilization rate. Furthermore, the Board continues to encourage DOE to study actively all possible options for dealing with spent nuclear fuel in dual purpose canisters—including direct disposal." The Project has not yet provided the Board with any analysis that supports the 90 percent assumption.

[4] See also the Board's findings and recommendations in an earlier report (NWTRB 2006c).

Surface Facility Operations

During the period covered by this report, OCRWM devoted considerable energy to implementing the initiative, launched in 2005 and approved in 2006, to redesign the surface facilities at the proposed repository. Project representatives discussed the status of those efforts at three Board meetings. At the May 9, 2006, meeting, an OCRWM manager provided an overview of the process by which the DOE would switch its design basis to the new surface facilities (Harrington 2006 and NWTRB 2006b). He also explained the potential effects on the PSCA. At the January 24, 2007, meeting in Las Vegas, the Project manager reported that the basic facility layouts and material flows had been completed, that the "lumped mass structural model" for the CRCF had been finalized, and that the structural and system designs were in process (Harrington 2007 and NWTRB 2007a). He also described in very broad terms what the four major surface facilities might look like.

In an April 19, 2007, letter to OCRWM, the Board requested additional information about the design of the surface facilities. The Board also encouraged the Project "to evaluate surface-facility designs and operational concepts for opportunities to reduce the number of times waste is handled." The Board also urged OCRWM "to evaluate the safety, operational, and economic issues related to opening, unloading, and disposing of empty DPC's in comparison to possible direct disposal of DPCs in Yucca Mountain" (Garrick 2007b). In response, OCRWM observed in a November 6, 2007, letter that it had eliminated at least three and as many as six lifts. OCRWM, however, told the Board that the direct disposal of DPC's is not included in the LA that is being prepared, nor are there plans for preparing amendments to the LA, which might be submitted at a later date. OCRWM believes that there are important questions related to criticality that must be resolved before DPC's can be disposed of directly. Until then, OCRWM plans to cut open DPC's in the WHF and transfer the fuel assemblies to TAD canisters (Sproat 2007b). The Board notes that the disposal of commercial SNF in TAD canisters will require that the NRC grant the same burnup credit as for the direct disposal of DPC's. Additional work, however, will be needed to analyze whether the criticality controls within the DPC will eliminate potential events throughout the entire compliance period, which may last as much as one million years. The Board encourages the Project to undertake those additional analyses expeditiously.

A Project representative presented an update on facility design at the Board's September 19, 2007, meeting (Slovic 2007 and NWTRB 2007d). Although the description of the facilities had matured somewhat, very little detailed information was provided about the designs. Among the specifics that the representative did discuss were preliminary estimates of throughput for the various surface facilities. In a January 16, 2008, letter to OCRWM, the Board held that the preliminary estimates of throughput appeared "overly optimistic" (Garrick 2008). The Board recommends that OCRWM more realistically represent throughput processes. The Board also recommends that the Project evaluate a number of measures that could improve throughput, including increasing the capacity of the WHF pool to allow parallel removal and transfer of fuel contained in DPC's and increasing the number of welding stations in the WHF and the CRCF to eliminate potential choke points. Further, for assessing operational risk and the viability of the waste management system, the Board recommended that OCRWM develop a "series of realistic and detailed throughput analyses that go beyond a deterministic, steady-state approach. Such analyses should consider potential off-normal operational scenarios and should specifically address the

The Board held that the preliminary estimates of throughput appeared "overly optimistic." The Board recommends that OCRWM more realistically represent throughput processes.

throughput achieved by individual surface facilities, the integrated surface facility complex, and the waste management system as a whole."

The subject of engineering prototyping arose at the Board's September 27, 2006, meeting in Armagosa Valley, Nevada (NWTRB 2006e). In a December 14, 2006, letter, the Board strongly encouraged OCRWM to develop a robust prototyping program for what will be a first-of-a-kind undertaking. "Examples of specific elements that could benefit from engineering prototyping include waste package fabrication, loading, sealing, and emplacement; robotics; and drip-shield emplacement" (Garrick 2006b). In an August 13, 2007, letter to the Board (Sproat 2007a), OCRWM agreed with the Board's recommendations about prototyping. Waste package closure equipment, the waste package and pallet, and the drip shield are among the items for which prototypes are planned. Notwithstanding this response, the Board understands that the prototyping program has been deferred until at least fiscal year 2009. The Board restates its view that this should be one of the Project's most important priorities.

Finally, at a January 24, 2007, meeting in Las Vegas, the Board heard about work being undertaken by the Project on seismic ground motion (Dyer 2007 and NWTRB 2007a). The objectives of those investigations include the development of a seismic-hazard curve for the surface facility area to be used in the PSCA, based in part on updated preclosure ground-motion estimates, which benefited from recently collected geotechnical data. For several years, the Board has encouraged OCRWM to develop more-realistic estimates of ground motion for the preclosure period. (See, for example, NWTRB 2003a and Corradini 2003b.)

In an April 19, 2007, letter (Garrick 2007b), the Board observed that OCRWM's use of overly conservative estimates has driven the Project to design surface facilities whose walls are made of four-foot-thick steel-reinforced concrete. The Board reiterated its view that the Project still needed to develop more-realistic seismic ground-motion estimates. In a November 6, 2007, letter to the Board (Sproat 2007b), OCRWM explained that it was refining its seismic analyses. "In updating these ground motions, an alternate approach to incorporating site response has been implemented that results directly in a site-specific seismic hazard curve. In addition, reasonable limits to extreme (very low probability) ground motions at YM are directly incorporated." The Board is pleased with the direction that OCRWM is taking on this issue.

Preclosure Safety Analysis

OCRWM is preparing a PCSA, which must be carried out as part of the LA (10 CFR 63.112). As of the end of 2007, that effort had not been completed.

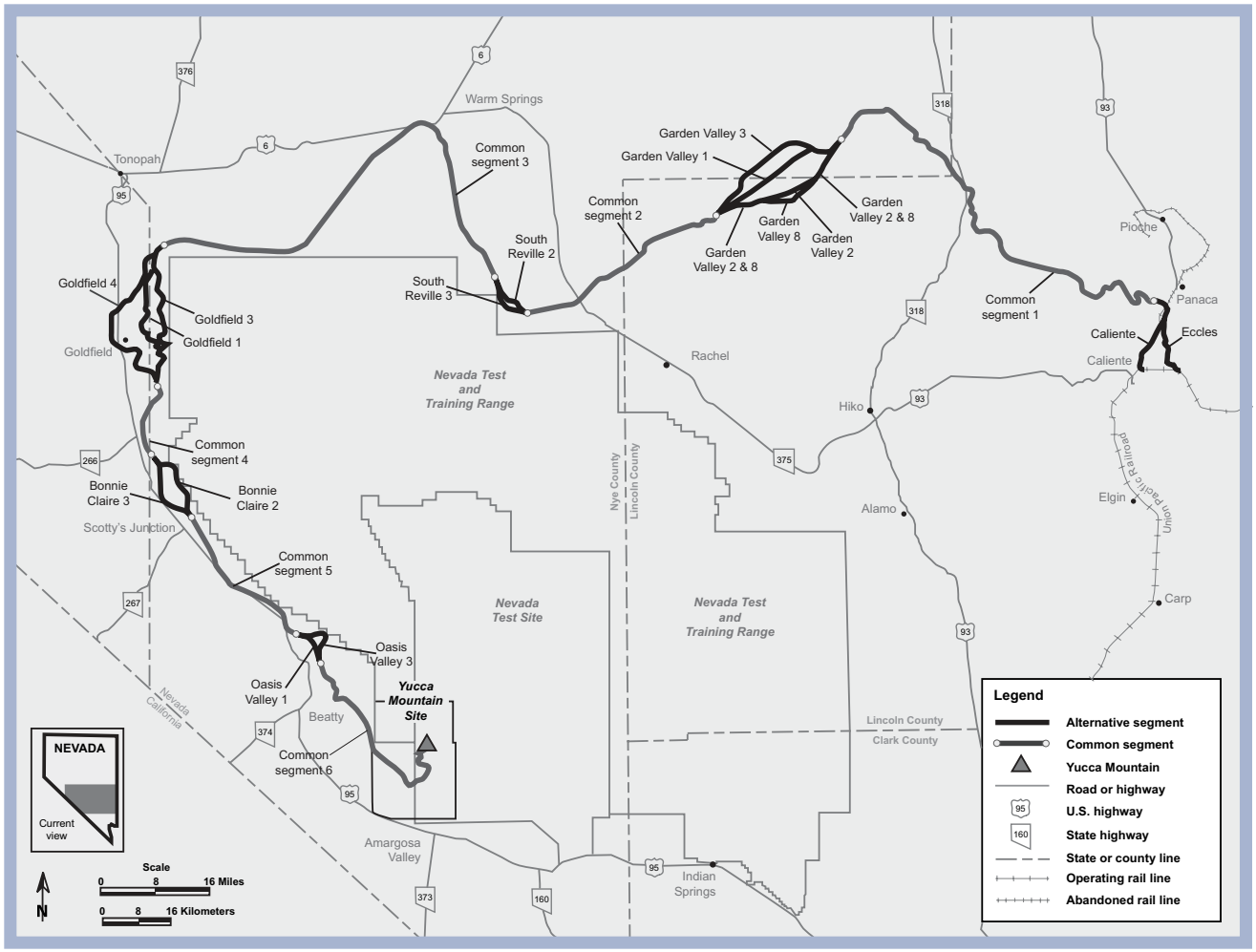
At the Board's September 19, 2007, meeting in Las Vegas (NWTRB 2007d), a Project analyst described the underlying philosophy and approach being taken (Frank 2007). In its January 16, 2008, letter to OCRWM (Garrick 2008), the Board expressed its concern that "the approach outlined for the development of the PCSA is a combination of deterministic and risk-informed, probabilistic methodologies. How [OCRWM] intends to address the uncertainties associated with the aggregation of risk is not clear to the Board. The Board would like [OCRWM] to explain in greater detail how the PCSA will address the remaining design uncertainties." As of the publication of this report, OCRWM has not provided such an explanation to the Board.

Transportation

For the last two years, the Project has cited budget constraints as a limiting factor in developing a transportation system to move HLW and SNF from generator sites to the proposed repository at Yucca Mountain. In addition to sponsoring cooperative agreements with state regional groups, such as the Council of Governments, and interacting with stakeholders at twice-a-year meetings of the Transportation External Coordination Working Group, OCRWM published two draft EIS's evaluating two rail corridors within Nevada and assessing the effects of choosing a specific rail alignment within two of them. The Project, however, was unable to move forward with any of its major procurements, especially those associated with constructing and operating a rail line within Nevada.

The Board remains concerned that the Project does not fully appreciate the ramifications of potential delays in the construction of a rail line to Yucca Mountain or the possibility that a rail line may never be built. When DOE declared that the TAD canister would be the centerpiece of its waste management strategy, this implicitly made the Project dependent on the existence of a Yucca Mountain rail line.[5] **Figure 5** illustrates the proposed rail route from Caliente, Nevada to Yucca Mountain.

Figure 5. Proposed Rail Route from Caliente, Nevada, to Yucca Mountain



Source: DOE

[5] The size and the weight of the TAD canister preclude the use of the truck mode unless states, including Nevada, issue special permits, perhaps for each shipment.

Given that no such line exists today and that construction of such a line may encounter significant challenges, the absence of a workable alternative for such a vulnerability is not prudent. Therefore, the Board believes that OCRWM should immediately and aggressively pursue a contingency plan in which the truck mode (heavy-haul or off-road) is considered within Nevada. Such an approach might include a lighter-weight TAD-like canister that can be transported on a truck chassis or other means of packaging and moving waste via truck from generator sites to Yucca Mountain. Although the Project asserts that these contingencies are being considered, the Board has seen no evidence that OCRWM is devoting sufficient effort to this problem.

Waste Management System Integration

The Board conceives of a waste management system composed of four elements: waste acceptance, transportation, surface operations, and subsurface operations. It is imperative that the system be analyzed and evaluated as an integrated whole.

The Board conceives of a waste management system composed of four elements: waste acceptance, transportation, surface operations, and subsurface operations. It is imperative that the system be analyzed and evaluated as an integrated whole. Although the Project has made sporadic efforts over the last two years to do that, it as often has continued to conduct much of its planning and assessments in a disaggregated fashion. (See, for example, Garrick 2007b.)

One potentially important integrating methodology is OCRWM's Total System Model (TSM). The Board heard two presentations on the TSM, the first at its May 9, 2006, meeting in McLean, Virginia (NWTRB 2006b), the second at its January 24, 2007, meeting in Las Vegas (NWTRB 2007a). At both meetings, a Project manager noted that TSM is a "tool to analyze the linkages, interactions, and synergies between [sic] Program functions (waste acceptance, transportation, and repository.)" (Kouts 2006, Kouts 2007b). He provided an overview of TSM's structure, described many of the key variables included in the model, and discussed illustrative results that had been obtained. He reported that TSM continues to be used as designs are refined to do the following:

- Evaluate alternative system configurations and processing capabilities.
- Identify potential disconnects between various components of the waste management system.
- Assess ways to minimize the size of aging pads.
- Support repository postclosure thermal response.

In two letters to OCRWM, the Board strongly supported the use of TSM. In a June 14, 2006, communication, the Board observed that "it applauds DOE's development and use of TSM and encourages additional enhancements of its capabilities" (Garrick 2006a). In the same vein, the Board held in an April 19, 2007, letter that TSM "can play a valuable role in analyzing the operational interdependencies of the waste management system and the utility of the transportation, aging, and disposal (TAD) canister" (Garrick 2007b).

Nonetheless, the Board recommended areas where the TSM could be strengthened. For example, in its June 14, 2006, letter:

> Board recommends adding to TSM the capability to evaluate "upset" conditions, such as equipment breakdowns or closure of transportation routes, but only after the reference case is established. Moreover, implementation of TAD will have implications for the thermal man-

agement strategy that do not appear to have been considered fully. Consequently, the Board encourages adding to TSM the functionality to model DOE's thermal-management strategy. That could be accomplished by developing a constraint on waste package emplacement that ensures compliance with DOE's line-load thermal limit for the underground facility. For existing capabilities, as well as those that might be added in the future, realism will be important, if the results of TSM analyses are to be credible. The Board encourages DOE to scrutinize the TSM input assumptions and parameter values to ensure that they realistically represent the system being modeled (Garrick 2006a).

OCRWM stated in an August 13, 2007, letter to the Board (Sprout 2007a) that it "will continue the integrated system engineering and analyses approach to gain a greater understanding of the interrelationships between subsystem components—waste acceptance, transportation, and repository operations."

The Board believes, however, that this response to the Board's findings and recommendations regarding the use and enhancement of TSM does not adequately address its concerns. Although the Project has increased its reliance on the use of TSM to improve understanding of the performance of an integrated waste management system, this modeling framework has yet to be utilized in a manner that is fully representative of the design and operating considerations that OCRWM must address to ensure a compatible and functional preclosure repository operation. Of particular importance for achieving this objective are the following:

- The use of TSM as a comprehensive tool for representing and evaluating performance of the entire preclosure waste management system, including its components (waste acceptance, transportation, surface facility handling, subsurface operations) and component interactions.
- Sufficient quality assurance of the assumptions and modeling environment that constitute TSM and the manner in which the model is applied.
- The ability to represent stochastic scenarios, reflective of normal variations in processing times associated with various waste management system components, as well as upset conditions, such as those associated with construction delays, accidents, equipment failure, natural disasters, and intentional acts.

Addressing these considerations will increase confidence that the preclosure waste management system will function efficiently and effectively.

Postclosure Performance of the Proposed Repository System

Extensive field and laboratory studies as well as detailed analyses were undertaken by OCRWM to develop both qualitative and quantitative estimates of how a repository might perform hundreds of thousands of years into the future. The Project's efforts to develop those estimates have become increasingly sophisticated and evidence-based. The Board commends OCRWM for undertaking a broad suite of investigations, which often break new scientific and technical ground.

In evaluating the scientific and technical basis for the Project's estimates, the Board has identified six areas where improvements and enhancements still can be made. Although some additional work would be required to address Board concerns, the Board does not believe—with the possible exception of realistic waste degradation modeling—that this

The Project's efforts to develop those estimates have become increasingly sophisticated and evidence-based. The Board commends OCRWM for undertaking a broad suite of investigations, which often break new scientific and technical ground.

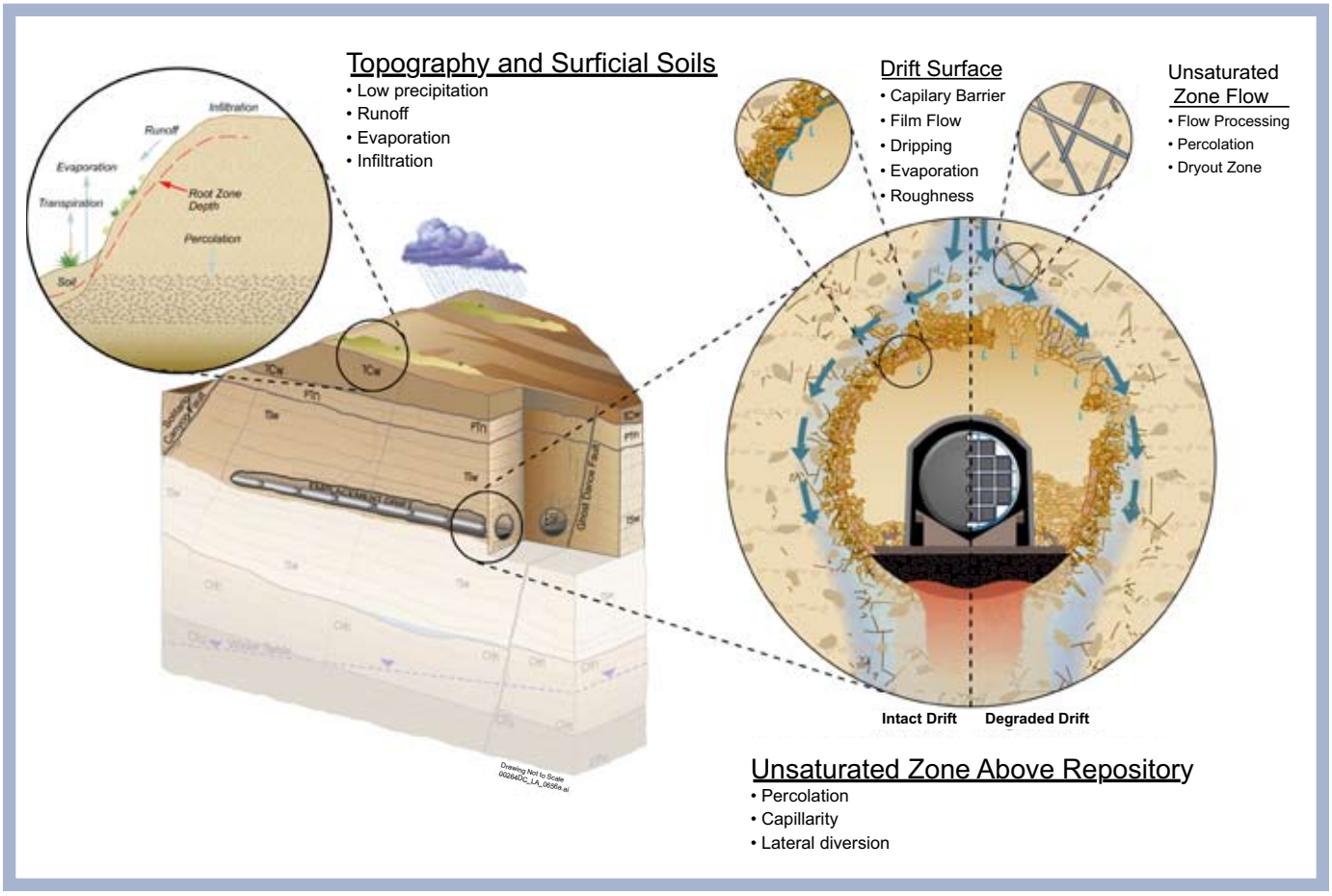
work would be especially difficult to carry out. In any event, completing this work could enhance the confidence that can be placed in the Project's performance estimates.

Capability of the Natural Barriers to Isolate and Contain Radionuclides

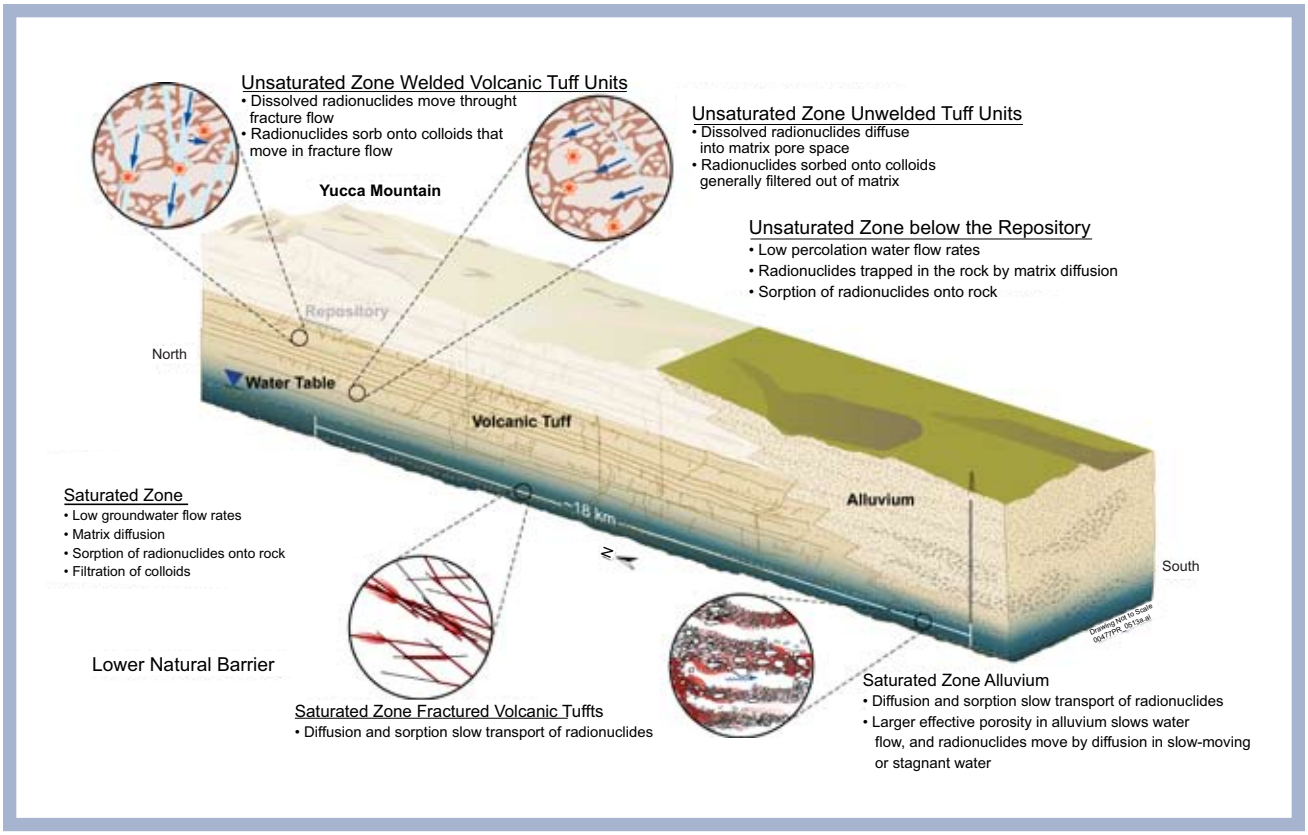
The potential natural barriers at Yucca Mountain may be grouped into two broad categories: the upper natural barrier and the lower natural barrier. The upper natural barrier is composed of the surficial soil and the unsaturated zone above the horizon where the proposed repository would be located. The lower natural barrier includes the unsaturated zone below the horizon of the proposed repository and the saturated zone. These natural barriers control the flow of water to the engineered elements of the repository system and subsequent radionuclide transport to the accessible environment, respectively. In addition, some rocks retard or otherwise slow transport of some radionuclides. However, rock heterogeneities, especially factures, zones of fracture concentration, and faults, can reduce the time required for radionuclides to reach the accessible environment. **Figure 6** and **Figure 7** depict these barriers.

During the period covered by this report, the Board reviewed certain aspects of OCRWM's work related to the upper and lower natural barriers. For example, at its May 15, 2007, meeting in Las Vegas (NWTRB 2007c), Project scientists gave talks on near-field chemistry (Brady 2007) and saturated-zone testing (Reimus 2007). Each of the presentations provided insights into OCRWM's technical and scientific activities.

Figure 6. Topography and Surface Soils



Source: DOE



Source: DOE

Figure 7. Saturated and Unsaturated Zones below the Repository.

The Board's most sustained effort was directed toward estimates of how much water infiltrates down from the surface to the horizon where the proposed repository would be located. The amount of water that infiltrates is an important variable in projecting long-term repository performance because water influences corrosion processes, affects the transport of any radionuclides that might be released from the waste package, and is the principal pathway through which the public, animals, and plants are exposed to possible releases from the repository.

OCRWM's Technical and Scientific Investigations Related to Infiltration

In March 2005, Secretary of Energy Samuel W. Bodman announced that e-mail had been discovered indicating that "certain employees of the U.S. Geological Survey (USGS) working on the Yucca Mountain Project may have falsified documentation of their work." The documentation in question related to computer modeling involving water infiltration (DOE Office of Public Affairs 2005). Testifying before the Committee on Government Reform of the House of Representatives the following month, Board Chairman B. John Garrick stated (Garrick 2005a):

> It would be inappropriate for the Board to draw any conclusions at this time about the significance [of the possible falsified documentation] for the technical work at Yucca Mountain… Answers to questions that might be raised…should await the completion of comprehensive investigations already underway at the Departments of Energy and Interior. The Board will follow the progress of those investigations, and when they are concluded, the Board will evaluate the significance of the results for the DOE's technical and scientific work. We will then report our findings to Congress and the Secretary of Energy.

In February 2006, OCRWM released a report detailing the results of its investigation (DOE 2006a). OCRWM maintained that the net infiltration ranges developed by the USGS were "consistent with groundwater recharge rates determined by other scientists studying other arid and semi-arid regions in the United States." Notwithstanding this conclusion, OCRWM said that it will "replace or supplement the infiltration modeling work, as needed, and will review or verify the supporting documentation…" (DOE Office of Public Affairs 2006; see also Runkle 2007).

As part of its response to questions about USGS infiltration estimates, OCRWM undertook two parallel investigations. First, OCRWM commissioned an independent review by the Idaho National Laboratory (INL) of both the technical validity of USGS infiltration estimates and the compliance of those analyses with quality assurance (QA) protocols. That review has been completed. The primary findings of the INL study are that the USGS infiltration estimates have a sound technical basis and that deficiencies associated with the USGS analyses are confined primarily to inconsistencies with some QA protocols. Concurrently with the INL effort, DOE contracted with Sandia National Laboratories (SNL) to develop a new procedure for calculating infiltration at Yucca Mountain that would enable OCRWM to replace USGS infiltration estimates in all future assessments of repository performance, if necessary. The work by SNL also has been completed. Thus, there are two sets of infiltration estimates for Yucca Mountain: the USGS estimates and the SNL estimates.

The Board published its findings in a December 2007 report (NWTRB 2007e). The Board's evaluation focused solely on the technical aspects of actions undertaken by the USGS and DOE in response to concerns raised by the e-mail and on the potential effects of those actions on the technical basis for OCRWM's estimates of performance at Yucca Mountain. The Board evaluation consisted of technical review of the following: (1) the "old" USGS estimates of infiltration and the underlying technical bases of those estimates; (2) the "new" SNL estimates of infiltration and the underlying technical bases of those estimates; (3) the effects of the SNL estimates as used in performance assessment calculations; and (4) the value and credibility of existing data that could be used to support infiltration estimates.

The Board's evaluation concentrated on five factors most significant to estimates of infiltration at Yucca Mountain:

- *Precipitation:* the principal source of water for infiltration at Yucca Mountain.
- *Evapotranspiration:* the sum of water loss due to evaporation and water loss due to uptake by plants.
- *Soil depth:* the thickness of unconsolidated sediment lying above bedrock.
- *Soil hydraulic properties of hydraulic conductivity and porosity:* parameters that describe how readily water can flow through soil at Yucca Mountain and the water-storage capacity of the soil, respectively.
- *Rock hydraulic conductivity:* the capability of water to flow through rocks at Yucca Mountain.

Figure 8 illustrates the geologic environment that controls the infiltration of water into the unsaturated zone above the horizon where the proposed repository would be located.

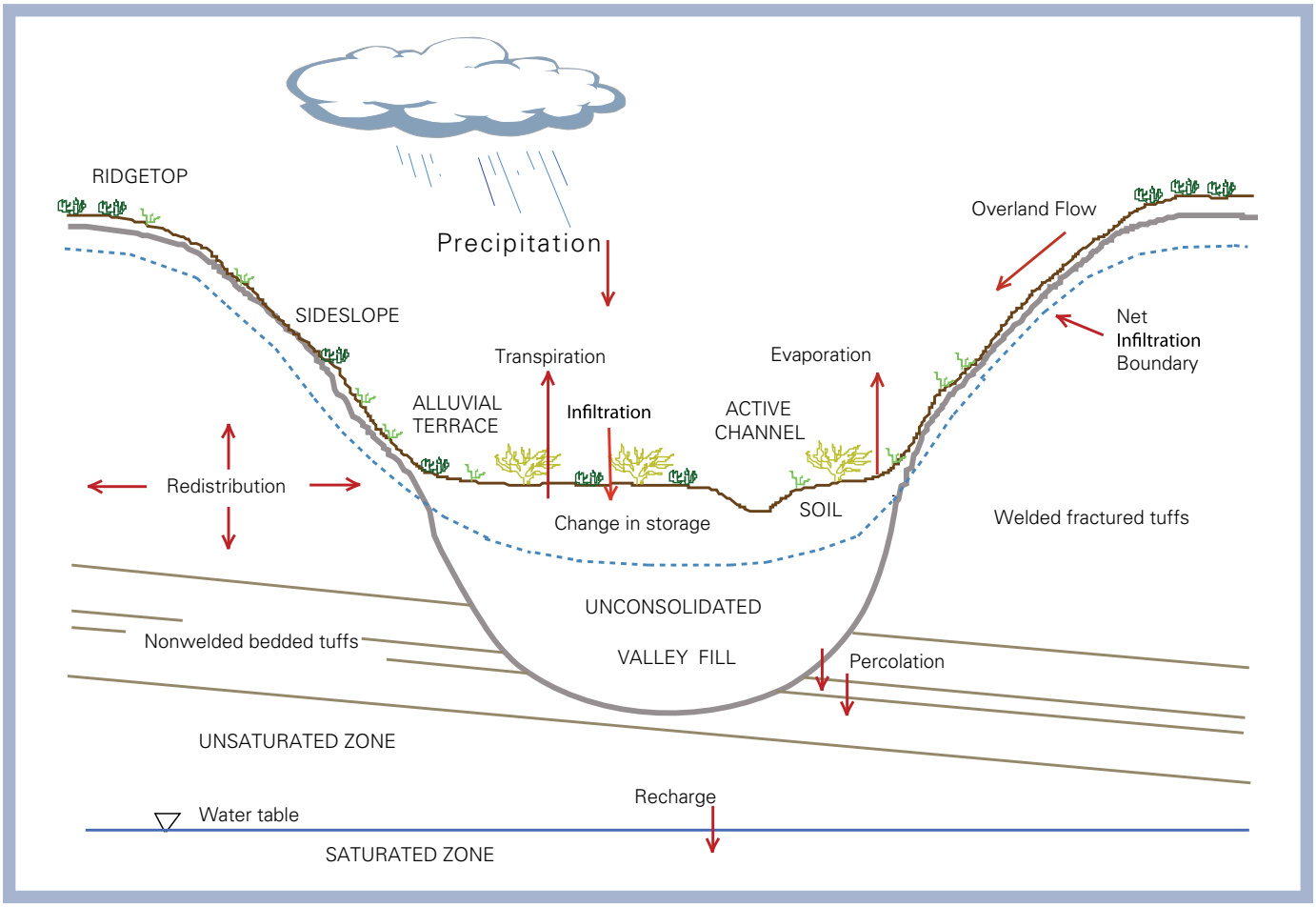


Figure 8. The Geologic Environment Controlling Infiltration.

In evaluating the technical basis supporting OCRWM's infiltration estimates, the Board engaged in various activities, including reviewing findings from investigations conducted by the Department of the Interior and DOE; reviewing DOE's technical assessments; and conducting field interviews with scientists and engineers at SNL, INL, and USGS. On March 14, 2007, the Board's Panel on Postclosure Performance held a one-day public meeting in Berkeley, California, on the scientific and technical bases of USGS and SNL estimates of infiltration (NWTRB 2007b). At that meeting, scientists from USGS, the Project, Los Alamos National Laboratory, SNL, and Lawrence Berkeley National Laboratory gave presentations on their findings and discussed the implications of these findings. For the present-day interglacial climate, the new SNL estimate of 14.3 mm/yr median annual infiltration is more than three times larger than the old USGS estimates of 3.6 mm/yr mean annual infiltration. For the monsoon climate state, new SNL estimates were about a factor of three greater than those developed by the USGS. For the glacial transition climate state, the SNL estimates were approximately two times greater than the USGS's results.

Board Findings and Recommendations Related to Infiltration

Calculating infiltration in a desert environment is a challenging technical and scientific undertaking. Infiltration is estimated using computer models in which factors such as rainfall, soil depth, water extraction from soil and rocks by plants and evaporation, and a host of other variables must be specified. Minor deficiencies in the USGS model were

identified by OCRWM and USGS reviewers, but no significant errors in USGS infiltration estimates were found. The Board found no significant errors in the computational approach used for infiltration estimates by either the USGS model or the SNL model.

. . . if all available relevant site-specific data at Yucca Mountain are used in both the USGS model and the SNL model, then repository performance estimates that are based on the infiltration estimates from either model should be essentially the same.

When the values of variables and the simulated natural processes are specified to be the same in the USGS and the SNL models, infiltration estimates from the two approaches are similar. The Board's opinion is that if all available relevant site-specific data at Yucca Mountain are used in both the USGS model and the SNL model, then repository performance estimates that are based on the infiltration estimates from either model should be essentially the same.

Information presented at the Board's March 14, 2007, panel meeting made clear that USGS estimates of infiltration are based on an extensive suite of site-specific data and are consistent with multiple independent lines of evidence. Furthermore, the Board's opinion is that the USGS program produced valuable results that are important for understanding the mountain hydrology and for building confidence in the estimated performance of the proposed repository.

In contrast, the SNL model does not include consideration of all available site-specific data that were used by USGS, such as soil depth, soil and rock hydraulic parameters, and the effects of evapotranspiration from shallow buried layers of bedrock. Consequently, SNL estimates of present-day infiltration at Yucca Mountain are approximately three times higher than the USGS estimates, and the SNL model results are less consistent with independent lines of evidence, including measurements of temperature and salt (chloride) concentrations at depth within Yucca Mountain. However, the SNL procedure has a more complete representation of uncertainties associated with relevant physical parameters—a methodological advantage over the USGS approach.

Infiltration estimates are used as input to estimates of potential long-term repository performance at Yucca Mountain in TSPA. To make the SNL estimates compatible with observed site-specific data supporting related models in TSPA, the Project uses a statistical process, called GLUE,[6] which preferentially considers the lower end of the range of SNL infiltration estimates. As used by the Project, the statistical modification of the infiltration estimates does not have a strong technical basis.

Although the effects on the regulatory process of QA infractions were not part of the Board's purview and therefore were not part of the Board's evaluation, the Board notes that compliance with QA procedures is an important part of the licensing process. However, even when scientific endeavors are not conducted in strict compliance with QA procedures, the fruits of those endeavors can have significant value. Conversely, strict observance of QA procedures is not by itself sufficient to guarantee sound technical and scientific analyses or data.

These findings led the Board to make the following recommendations (NWTRB 2007e).

- OCRWM should use all available site-specific data in its estimation of infiltration. Relevant USGS data found to have transparency or traceability QA discrepancies should be requalified and used in estimates of infiltration.

[6] As used by DOE, GLUE preferentially gives greater statistical weight to infiltration estimates that are more consistent with observed temperature and salt (chloride) measurements. See Beven and Binley (1992), SNL (2007), and Vogel et al. (in press).

- Because estimates of infiltration are necessarily imprecise, the Board recommends that OCRWM calibrate the infiltration model, using all relevant site-specific data.
- Because plant uptake of water from bedrock fractures is likely to occur at Yucca Mountain, the Board recommends that OCRWM include parameterization—including associated uncertainty—that represents evapotranspiration from shallow buried bedrock in its model.
- The Board does not endorse the use of the statistically modified SNL infiltration estimates in TSPA.

The Board's report on infiltration benefited from open and honest communication with involved scientists, all of whom demonstrated a strong personal commitment to developing a sound fundamental understanding of infiltration at Yucca Mountain.

Capability of the Engineered Barrier System to Isolate and Contain Radionuclides

The engineered barrier system (EBS) consists of man-made components designed to prevent the release of radionuclides. It includes the waste form,[7] waste package, drip shield, pallet, invert, and the drifts. Together, these elements of the EBS contain and isolate waste from the accessible environment. **Figure 9** on the next page presents a stylized drawing of the EBS.

OCRWM's Technical and Scientific Investigations Related to Deliquescence-Induced Localized Corrosion

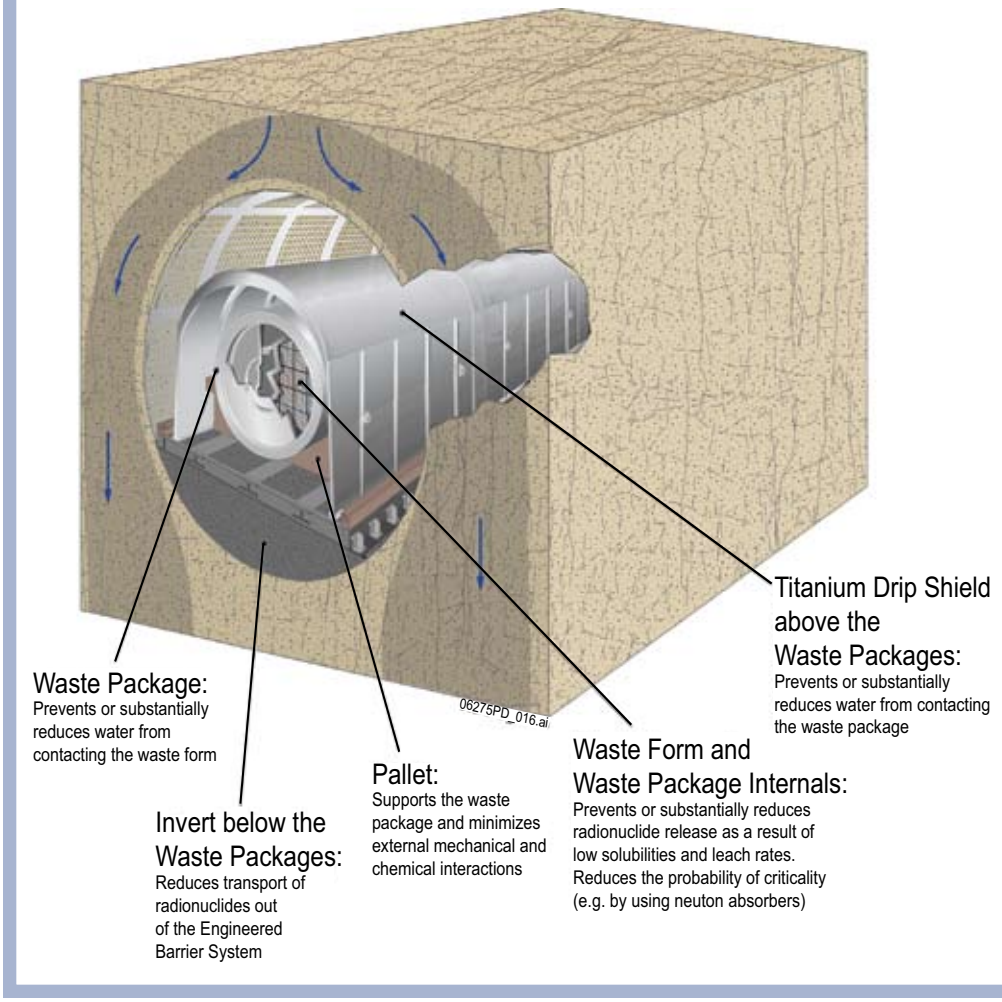
For the last few years, the Board has explored whether localized corrosion of the Alloy 22 waste package might occur at temperatures higher than approximately 140°C from the action of brines formed from deliquescent salts that could be present on waste package surfaces (Corradini 2003a, 2003c; NWTRB 2003b). After the meeting held in May 2004 (NWTRB 2004b), the Board concluded that deliquescence-induced localized corrosion due to calcium chloride brines during the higher-temperature period of the thermal pulse would be unlikely because of the improbability of such brines being present (Duquette 2004). Because at the time no other plausible brines were known to exist at temperatures above 140°C, the issue of localized corrosion due to brines formed from deliquescent salts seemed to be closed.

A January 2005 letter to the Board from then OCRWM Director Margaret Chu, however, reopened the issue (Chu 2005). The letter suggested that combinations of sodium and potassium nitrates and chlorides salts would deliquesce at atmospheric pressure at temperatures up to and exceeding 200°C, even in the low-relative-humidity environments likely to be present in a Yucca Mountain repository during the thermal pulse. Unlike calcium chloride, these salts are likely to be present in the dusts deposited on waste package surfaces during the preclosure period.

In a December 19, 2005, letter (Garrick 2005c), the Board stated that the technical information available at that time did not seem sufficiently compelling enough to support screening out deliquescence-induced localized corrosion. The Board's opinion was based on the lack of corrosion data above 150°C and the questionable relevance of

[7] The SNF waste form is surrounded by a robust zircaloy or stainless-steel cladding. Some of DOE's SNF is aluminum clad.

Figure 9. A Stylized Drawing of the EBS.



Source: DOE

corrosion-stifling data taken at significantly lower temperatures to corrosion at higher temperatures. To address in greater technical detail the question of whether this combination of salts might cause localized corrosion, the Board convened a two-day workshop in September 2006 (NWTRB 2006d). Twenty-two scientists and engineers, representing the Board, the Project, NRC, the Electric Power Research Institute, the State of Nevada, and Nye County, Nevada, participated in the workshop.

At the workshop, OCRWM reiterated its belief that deliquescence-induced localized corrosion would not occur. Therefore OCRWM would exclude it from the TSPA-LA models that project repository performance over long time periods. The Project based its decision to exclude deliquescence-induced localized corrosion on an event-tree analysis consisting of the following questions (BSC 2005):

1. Can multiple-salt deliquescent brines form at elevated temperatures?
2. If brines form at an elevated temperature, will they persist?
3. If deliquescent brines persist, will they be corrosive?
4. If deliquescent brines are potentially corrosive, will they initiate localized corrosion?
5. Once initiated, would localized corrosion penetrate the waste package's outer barrier?

The Project maintains that if the answer to any of the five questions is "no," then deliquescence-induced localized corrosion will not take place. The Board believes that this five-question approach is reasonable. For that reason, the workshop discussion was structured around the five questions. There seemed to be consensus among workshop participants that the answer to the first question is "yes." There was less consensus on the answers to the other questions, particularly the last two.

Board Findings and Recommendations Related to Deliquescence-Induced Localized Corrosion

The Board published its own findings and conclusions from the workshop in a January 12, 2007, letter to DOE (Garrick 2007a), to which was attached a 10-page report. In the report, the Board noted that there were at least six scenarios in which deliquescence-induced localized corrosion could be excluded, i.e., by which one or more of the five questions above could be answered "no" definitively. The Board also stated that demonstrating an adequate technical basis for screening out deliquescence-induced localized corrosion during the thermal pulse would require (a) determining the nitrate-to-chloride ratios that are inhibitive for the entire range of temperatures at which deliquescent brines may occur on waste package surfaces and (b) confirming the hypothesis that the preferential migration of nitrate ions into the crevice on a waste package is sufficient to maintain nitrate-to-chloride ratios that are inhibitive.

The Board's January 12, 2007, letter and its attached report contained the following additional findings:

- Cumulative damage due to the combined effects of deliquescence-induced localized corrosion and seepage-based localized corrosion merits some analysis.
- Including seepage-based localized corrosion in TSPA-LA while excluding deliquescence-induced localized corrosion is incongruous because the process (localized corrosion) is the same in both cases.
- Deliquescence-induced general corrosion of Alloy 22 should be included in TSPA-LA.
- Anomalies among recent experiments at high temperatures, such as unexpectedly high general corrosion rates and a maximum of general corrosion rate with respect to temperature, require explanation.
- Effects of waste package surface condition on the corrosion of the waste package surface may need more investigation.
- Including deliquescence-induced localized corrosion in TSPA-LA would add to its completeness, robustness, and credibility.

In a follow-up letter to OCRWM dated July 10, 2007 (Garrick 2007c), the Board pointed out that the dust settling on waste package surfaces during ventilation would contain significant amounts of organic materials and that reactions between these materials and nitrate in the dust could affect the amount of nitrate, which inhibits localized corrosion if present in large enough quantities relative to chloride. The Board stated that the Project should analyze the effects of the full range of factors (e.g., organics in dust, acid-gas devolatilization, and radiolysis) that could influence whether inhibitive nitrate-to-chloride ratios persist under repository conditions.

OCRWM responded to the Board's January 12, 2007, and July 10, 2007, letters in a November 20, 2007, letter (Sproat 2007c). Although the Board agrees with some of the points mentioned in the letter, in several instances OCRWM did not address points brought up by the Board. For example, in its January 12 letter, the Board addressed the apparent incongruity of excluding deliquescence-induced localized corrosion while including seepage-based localized corrosion despite the fact that both are the same process, i.e., localized corrosion. In its November 20, 2007, letter, the Project reiterated the differences in the environments between deliquescence-induced and seepage based localized corrosion. The Board concurs that the environments are quite different, but the processes are not. Regardless of whether NRC regulations allow a process to be split in two and one part to be discarded, doing so still remains incongruous.

In addition, the Project refers to components of the dust deposited on waste package surfaces as "reactants" or "limited reactants" in several places in its November 20 letter. Although the Board agrees that many components in the dust could be reactants, it seems that the principal reactants in general or localized corrosion would be either the water component of deliquescent brines or oxygen dissolved in the brines. Both water and oxygen are essentially limitless in supply. If they are consumed by the brine in corrosion reactions, they simply will be replenished rapidly by dissolution or deliquescence. The Board would welcome additional information from the Project about what other components of the dust undergo reactions. Finally, although OCRWM claimed that it had addressed Board concerns about the effects of organic materials on the nitrate-to-chloride ratio in the November 20 letter, the basis for this claim is unclear.

In sum, despite the workshop in September 2006 and the exchange of letters in 2007, the issue of deliquescence-induced localized corrosion, although apparently tractable, remains open.

In sum, despite the workshop in September 2006 and the exchange of letters in 2007, the issue of deliquescence-induced localized corrosion, although apparently tractable, remains open.

Development of a Safety Case

For more than a decade, the Board has held that it is important for OCRWM to develop a structured presentation of the evidence, analyses, and lines of reasoning that can build confidence in the conclusions derived from TSPA (Cohon 1997; Cohon 2000). This set of arguments constitutes what is commonly called a safety case. (See, for example, NEA 2002.)

At the Board's September 27, 2006, meeting in Amargosa Valley (NWTRB 2006e), Project scientists described efforts to assess barrier capability (Swift 2006), discussed cutting-edge scientific investigations (Peters 2006), illustrated how insights can be drawn from natural analogues (Brady 2006), and explained plans for performance confirmation using long-term testing and monitoring (Hansen 2006). Each of these activities can be a key component of a persuasive safety case. Analyses of barrier capability can reveal the extent to which the full system relies on complementary and overlapping capabilities to ensure performance. Cutting-edge science can provide additional insights into the potential performance of the proposed repository's natural and engineered systems. Analogues, such as the site at Peña Blanca in northern Mexico, can identify dominant mechanisms and processes that affect repository performance and can be used to test and evaluate TSPA models. Long-term testing and monitoring can address important uncertainties and provide a basis for improving key process models and performance assessments, thus enhancing confidence in performance projections.

In a December 14, 2006, letter to DOE (Garrick 2006b), the Board endorsed the development of a safety case. For example, the Board pointed out the following:

> Natural analogues of many relevant repository phenomena can be used to challenge and evaluate conceptual and numerical models. Analogues that have existed for periods of time commensurate with the regulatory compliance period proposed for the repository provide excellent cases for testing prevailing conceptual and numerical models of radionuclide transport and isolation.

Natural analogues of many relevant repository phenomena can be used to challenge and evaluate conceptual and numerical models.

But the Board noted in that December letter that OCRWM's safety case has not yet advanced to the point where it could increase confidence in the conclusions derived from TSPA. After the period covered by this report, OCRWM published its safety case. The Board is evaluating that document.

Additional Issues Related to Postclosure Performance of the Proposed Repository System

Waste Degradation and Radionuclide Transport

If the waste package fails, the waste, in its various forms, may begin to degrade. The degradation process is complex, and the fate of the radionuclides is uncertain. The Project's implementation of TSPA, therefore, uses assumptions about radionuclide transport that may often be unrealistic. On several occasions, the Board has observed that obtaining a better fundamental understanding of the entire transport process remains a productive avenue for additional scientific investigation. (See, for example, NWTRB 2006a and Garrick 2006a.) More specifically, research on topics such as secondary mineralization, matrix diffusion, colloid-facilitated transport, hydraulic properties of faults, or other processes that might significantly affect the rate at which dose-contributing radionuclides move from the repository to the environment could yield important insights.

In an August 13, 2007, letter to the Board, OCRWM enumerated the studies that could address the question of radionuclide transport out of the engineered barrier system and into the unsaturated zone below the proposed repository (Sproat 2007a). Although the Project did not disagree with the Board's position that such research could be valuable, it informed the Board that funding levels for this work were reduced in fiscal year 2007 and would be eliminated in fiscal year 2008 because of budget constraints.[8]

Although the variables affecting radionuclide transport, such as temperature, pH, redox state, and ionic strength, can be enumerated, the Board does not minimize the difficulties associated with carrying out the research program it recommends.

[8] OCRWM also described investigations being undertaken related to the incorporation of kinetics of filtration of irreversible colloids in the unsaturated and saturated zones through the "colloid diversity model." The Board realizes that these colloid studies may be interesting, but kinetics of filtration is a complicated problem. Generally, the Board is skeptical about whether treating colloids as chemical species using principles of chemical kinetics and equilibrium is an effective approach.

Nonetheless, the Board restates its view that the key subset of issues associated with radionuclide transport deserves further attention because of the potentially significant effect these phenomena might have on developing realistic estimates of repository performance.

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Realistic Performance Assessments

Radionuclide transport is only one area where the Board believes that OCRWM's estimates of repository performance are unrealistic. In the report published in 2006 (NWTRB 2006c), the Board went to great lengths to explain to OCRWM the importance of eliminating to the greatest extent possible the use of "bounding assumptions," as opposed to realistic distributions of important parameters. Following up on that report, in a December 14, 2006, letter to OCRWM (Garrick 2006b), the Board maintained:

> To increase confidence in repository performance estimates, TSPA should include consideration of all credible and consequential phenomena that significantly affect dose over the period of regulatory compliance…Assessing the realism of TSPA performance estimates can be challenging because some assumptions may be very conservative while others may be nonconservative. The performance-margin analyses identified [by OCRWM] can be very valuable in assessing the magnitude and effects of conservative and nonconservative aspects of TSPA.

In a November 6, 2007, letter (Sproat 2007b), OCRWM defended its use of bounding assumptions, noting that its approach "reflects international experience and Nuclear Regulatory Commission staff perspectives." OCRWM did commit, however, "to complete performance-margin analyses to evaluate the extent of conservatism and/or nonconservatism in the conservative compliance-focused analyses." The Board is pleased that DOE published its performance-margin analyses when it submitted the LA to NRC.

Presence or Absence of Bomb-Pulse Chlorine-36 at the Horizon of the Proposed Repository

Since mid-1996, the Board has followed closely Project investigations to determine whether elevated levels of bomb-pulse chlorine-36 are present at the horizon of the proposed repository. This question is not an academic one. The presence of the isotope in undisturbed rocks at depth would provide incontrovertible evidence that at least some of the water that falls on Yucca Mountain moves rapidly through the unsaturated zone above the proposed repository.

For the last seven years, the Board consistently has urged OCRWM to resolve the apparent disagreement about this issue between Los Alamos National Laboratory, which believed that it found evidence suggesting the isotope's presence, and Lawrence Livermore National Laboratory and the U.S. Geological Survey, both of which failed to find any evidence of elevated bomb-pulse chlorine-36 levels. (See, for example, NWTRB 2001.) The Board also has examined the Project-funded work carried out at the Harry Reid Center for Environmental Studies, University of Nevada, Las Vegas, which identified elevated levels of bomb-pulse chlorine-36 in some samples (NSHE 2006, Cizdziel 2007).

At the Board's January 24, 2007, meeting in Las Vegas, an OCRWM official described the efforts that had been made to reconcile the seemingly divergent findings (Dyer 2007). He

noted that, despite the best efforts of Project scientists, the question of whether elevated levels of bomb-pulse chlorine-36 are present at the proposed repository's horizon remains unanswered. Rhetorically asking where we stand right now, he observed:

> We're not pursuing the chlorine-36 issue further at the moment. We think we've adequately addressed it in the existing state of models that we have. It would appear that perhaps we need some advances in chlorine-36 technology before we can fruitfully use it in this arena.

Despite the best efforts of Project scientists, the question of whether elevated levels of bomb-pulse chlorine-36 are present at the proposed repository's horizon remains unanswered.

The Board does not find this argument persuasive. In its April 19, 2007, letter to DOE (Garrick 2007b), the Board noted that the possible existence of bomb-pulse chlorine-36 at depth in Yucca Mountain "remains an outstanding issue whose resolution could greatly enhance confidence in understanding fluid flow within Yucca Mountain." In a response in a November 6, 2007, letter, OCRWM downplayed the disagreement within its scientific team (Sproat 2007b). "The chlorine-36 studies can be viewed as consistent in one important aspect, which is that the studies conducted to date consistently indicate that fast pathways, as indicated by bomb-pulse chlorine, are either rare or non-existent." The Board does not agree with this characterization of the chlorine-36 studies and continues to be puzzled at OCRWM's apparent lack of interest in resolving this question.

The Crosscutting Issue of Thermal Management

In the Board's *Fifth Report to Congress* (NWTRB 1992), it focused on the crosscutting issue of thermal management—how OCRWM plans to establish the temperature regime under which the repository will operate. It noted that thermal management strongly affects waste acceptance as well as surface and subsurface operations. Thermal management also strongly influences projections of a repository's postclosure performance because EBS corrosion, near-field, and hydrologic models all are temperature dependent. The Board's interest in this subject has not waned over the last decade and a half. The Board recently has seen evidence that the Project has developed a technically sound basis for the thermal criteria and strategy it is using to govern its preclosure and postclosure plans, analyses, and evaluations.

In its previous report (NWTRB 2006c), the Board expressed concerns about the technical basis behind the Project's thermal management strategy. For example, the Board noted that the 11.8 kW/waste package limit appeared to be arbitrary. The Board recommended that OCRWM should "articulate in a transparent way" how it derived that and other criteria. The Board also observed that the implications for thermal management of the TAD canister concept did not seem to have been assessed fully. Finally, the Board was not persuaded that the "thermal-hydrologic models being used to predict postclosure temperature, relative humidity, and water vapor transport within the drifts have a strong technical basis." The Board, therefore, recommended that these models be reviewed by independent experts. Many of the same concerns were repeated in Board letters sent on June 14, 2006 (Garrick 2006a), and April 19, 2007 (Garrick 2007b).

In an August 13, 2007, letter to the Board (Sproat 2007a), the Project agreed with the Board that its thermal management strategy had to be clearly defined. OCRWM described work that was being undertaken, including studies of "thermal decay characteristics of waste and temperature limits at key locations such as the waste package wall

and drift wall." Further, it maintained that the performance specifications for the TAD canister concept, "while ensuring that the thermal performance of the TAD would be consistent with the current postclosure thermal management approach, would provide sufficient flexibility to accommodate alternative thermal management strategies." Finally, the Project informed the Board that "it does not plan to conduct an external review" of the thermal-hydrologic models.

Responding to the Board's August 13, 2007, letter (Sproat 2007b), OCRWM described in greater detail how the TAD performance specification would impose temperature limits for protecting SNF cladding and how it imposes "heat flux vs. canister-wall temperature" constraints. In addition, OCRWM pointed out that several operational approaches are planned for use at the repository as part of the thermal management strategy. These approaches include the following:

- Establishing a broad operational envelope for the emplacement process that satisfies the TSPA constraints.
- Allowing for the aging of TAD canisters to allow decay heat of the TAD canisters to achieve the thermal limits for emplacement.
- Blending low-thermal-power naval SNF and DOE HLW and SNF codisposal packages with commercial SNF to lower the average thermal power in the emplacement drift to meet thermal constraints.
- Accounting for the decay of waste from its date of actual emplacement and the effects of ventilation during the preclosure period.

OCRWM further noted that as part of this strategy, the capability of the surface facilities is considered with respect to the following:

- Designing facilities that can meet potential thermal limits for receipt and handling of the TAD canister.
- Accepting commercial SNF to meet DOE receipt rates.
- Evaluating the capabilities of the facilities for the rates associated with closure of the waste package and subsequent emplacement in the proper thermal arrangement.
- Evaluating the size of the aging facilities with respect to various waste streams.

The Board is encouraged by the progress that OCRWM recently has made in addressing the Board's concerns related to this critical crosscutting issue of thermal management.

Over the last two years, the Board's interactions with OCRWM on the thermal management issue have been productive. The Project is developing an integrated thermal management strategy using the TSM and waste package loading models to evaluate waste acceptance as well as surface and subsurface operations, including emplacement. It is considering different scenarios of assembly age, burnup, and throughput rates using actual assembly power decay rather than a single decay rate based on a theoretical waste stream as it has done in the past. The Board is encouraged by the progress that OCRWM recently has made in addressing the Board's concerns related to this critical crosscutting issue of thermal management.

Site Visits by the Board

Sweden and Finland

On August 21–25, 2006, a delegation of the Board met with representatives of the Swedish and Finnish nuclear waste disposal programs for spent nuclear fuel and visited a number of their facilities. The visit included tours of their proposed sites for deep geologic disposal and surface and underground research facilities; a tour of Sweden's canister laboratory and central long-term storage facility for SNF; a tour of one of Finland's two permanent repositories for LLW and ILW waste; a meeting with elected representatives from one of the two proposed sites for a final repository in Sweden; meetings with the regulatory authorities of both countries; discussions with the leadership and scientists/engineers involved in managing and researching disposal methodologies in both countries; and a meeting with representatives of the Swedish Council for Nuclear Waste (formerly KASAM), the Board's counterpart in Sweden.

Idaho National Laboratory

On June 6–7, 2007, a delegation of the Board visited the INL site and the INL operations office in Idaho Falls. The primary purposes of the visit were to observe and discuss activities having to do with the management and disposal of SNF and HLW.

A large number of activities directly related to Yucca Mountain are being conducted at the INL site by the INL operations office. All of the SNF from U.S. Navy aircraft carriers and submarines comes to the Naval Reactors Facility for inspection, storage, and eventual packaging and shipment to a repository for disposal. A reprocessing facility operated until 1992, and all the HLW from those operations remains stored there in tanks or silos in liquid or solid (calcine) form, respectively. Eventually, this HLW has to be treated and packaged for shipment to a repository. In addition, a large amount of DOE-owned SNF from research, defense, and other programs is stored on the INL site. Eventually, all this material will go to a deep geologic repository for disposal. INL is in charge of the entire disposal program for DOE-owned spent fuel and therefore is responsible for characterizing and categorizing such spent fuel and defining plans for its disposal at Yucca Mountain, including designing and creating prototypes of the canister for containing the spent fuel. Finally, INL is developing criticality-control materials for disposal, performing corrosion tests on the materials, and developing robotic welding and inspection equipment to be used at Yucca Mountain.

Board Plans for 2008

When Congress authorized the establishment of the NWTRB in the NWPAA, it included a provision stating that the Board would cease functioning no later than one year after the date on which the Secretary of Energy begins disposal of HLW or SNF in a repository (NWPAA 1987). DOE's submittal of the LA to NRC will not change the Board's congressionally mandated role. In particular, the Board will continue to conduct technical evaluations of DOE's progress in understanding how the engineered and natural systems of the repository would work together to isolate radionuclides and how realistic DOE's performance estimates are. The Board also will review DOE's repository and surface facility designs and DOE's program for managing spent nuclear fuel and high-level radioactive waste before closure of the proposed repository. In conducting its evaluation, the Board

will maintain its focus on "technical validity." The Board leaves to NRC the judgment of whether the arguments and predictions contained in the LA comply with and satisfy that agency's regulations.

In 2008, the Board intends to hold three public meetings to ensure that it is being kept current on OCRWM's technical and scientific activities. In addition, several more fact-finding meetings will take place. The Board also plans to pursue with the Project the open issues that have been enumerated above.

Finally, the Board has initiated a series of extensive systematic analyses looking both at the technical bases used by OCRWM to project postclosure performance of the proposed repository at Yucca Mountain and at the preclosure operations of the entire waste management system. As appropriate, the Board will communicate the findings and recommendations that derive from those analyses later this year.

Abbreviations and Acronyms

Board	U.S. Nuclear Waste Technical Review Board
CRCF	Canister Receipt and Closure Facility
DOE	U.S. Department of Energy
DPC	dual-purpose cask
EBS	engineered barrier system
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
HLW	high-level radioactive waste
IHF	Initial Handling Facility
INL	Idaho National Laboratory
LA	License Application
NEA	Nuclear Energy Agency
NRC	U.S. Nuclear Regulatory Commission
NWPAA	Nuclear Waste Policy Amendments Act of 1987
NWTRB	U.S. Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
PCSA	Preclosure Safety Analysis
Project	Yucca Mountain Project
QA	quality assurance
RF	Receipt Facility
SAR	Safety Analysis Report

SCC	stress-corrosion cracking
SEIS	supplemental environmental impact statement
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
TAD	transportation-aging-disposal
TSM	Total System Model
TSPA	Total System Performance Assessment
USGS	U.S. Geological Survey
WHF	Wet Handling Facility

Glossary of Terms

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.

analogue (analog) A phenomenon that can provide information on or add understanding to aspects of repository performance. Analogues are of two types: natural and anthropogenic. Natural analogues occur through natural phenomena. Anthropogenic analogues result from human activity. An "archaeological analogue" is an anthropogenic analogue resulting from the activities of ancient cultures.

barrier A natural or engineered system that prevents or mitigates the movement of radionuclides toward the accessible environment.

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

bomb-pulse See **chlorine-36.**

bounding analysis Extreme parameter estimates used to project repository performance.

burnup A measure of reactor fuel consumption expressed as the percentage of fuel atoms that have undergone fission, or the amount of energy produced per unit weight of fuel.

cladding The outer layer of a nuclear fuel rod.

chlorine-36 (36Cl) A long-lived radioactive isotope of chlorine produced by irradiation of natural chlorine, argon, or other materials by cosmic rays or neutrons. Atmospheric testing of nuclear weapons in the 1950's temporarily increased concentrations of chlorine-36. The resulting "bomb-pulse" levels of chlorine-36 can sometimes serve as a tracer to determine how rapidly precipitation from the 1950's has moved through soil and rocks such as those present at Yucca Mountain.

colloid A state of subdivision of matter in which the particle size varies from that of true "molecular" solutions to that of coarse suspensions with the diameter of the particles lying between 10^{-7} and 10^{-5} centimeters.

conservative Projections of repository performance using parameters and models that systematically underestimate the system's ability to isolate and contain waste.

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

criticality The condition in which a fissile material sustains a nuclear reaction. Criticality occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle.

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**

drift An underground opening or tunnel that is used for access/egress, to facilitate repository construction, ventilation, and transportation and emplacement of nuclear waste.

drip shield Barriers placed over and around waste packages to divert water from the packages and deflect falling rocks from impacting the waste package.

engineered barrier system (EBS) The constructed components of a disposal system designed to retard or prevent releases of radionuclides from the underground facility. Such components include waste forms, fillers, waste containers, shielding placed over and around such containers, and backfill materials.

fault A plane in the earth along which differential slippage of the adjacent rocks has occurred.

fuel rod An engineered structure that consists of a rod or tube, typically made of zircaloy, into which fuel material, usually in the form of uranium oxide pellets, is placed for use in a reactor. Many rods or tubes, which are mechanically linked, form a fuel assembly or fuel bundle.

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.

groundwater Subsurface water as distinct from surface water.

high-level radioactive waste (HLW) 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.

infiltration The flow of a fluid into a solid substance through pores or small openings; specifically, the movement of water into soil or porous rock.

invert The natural or engineered floor configuration of a tunnel or an underground opening.

License Application (LA) 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.

line-load Two distinctly different emplacement strategies for waste packages within an emplacement drift. A line load refers to placement so that the waste packages are virtually end-to-end or nearly touching. Point load refers to placement such that the packages are separated by a least 2m.

localized corrosion Corrosion that takes place at discrete sites—for example, in waste package crevices.

matrix The solid framework of a porous system.

matrix diffusion The migration of higher concentrations of dissolved chemicals from more permeable zones to zones that are less permeable and that have lower concentrations of the same dissolved chemicals.

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

natural barriers Attributes of the earth that tend to isolate radionuclides from the human-accessible environment.

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.

Nuclear Waste Policy Act (NWPA) 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 (NWPAA) The federal statute enacted in 1987 that amended the Nuclear Waste Policy Act by limiting repository site-characterization activities to Yucca Mountain, Nevada; establishing the Office of the Nuclear Waste Negotiator to seek a state or Indian tribe willing to host a repository or monitored retrievable storage facility; creating the Nuclear Waste Technical Review Board; and increasing state and local government participation in the waste management program.

overpack A container used for transporting and/or storage of canisters that do not meet the applicable NRC or Department of Transportation requirements.

percolation flux The movement of water through the repository horizon per unit area per unit time.

performance assessment A complex computer-based analysis that projects how well the entire repository system will isolate and contain waste and what the human health consequences will be if waste reaches the biosphere.

performance confirmation The tests, experiments, and analyses that are conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the repository performance objectives for the period after permanent closure will be met.

performance-margin analysis A type of performance analysis in which particular parameters are varied to obtain insights into their effect on waste isolation and containment and human health.

performance specification A set of instructions that outlines the functional requirements for a specific component or process.

postclosure The time after the closure of the geologic repository.

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

process models Conceptual and mathematical models of a particular process (e.g., unsaturated-zone flow) that reflects the phenomena of interest. The models then can be abstracted (simplified) for use in performance assessments.

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

radionuclide An atomic nucleus that is radioactive.

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

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 an earth vibration.

source term The compositions and the kinds and amounts of radionuclides that make up the source of a potential release of radioactivity from the engineered barrier system to the host rock.

spent nuclear fuel (SNF) Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by chemical reprocessing.

SNF assembly See **fuel rod.**

thermal-management strategy A plan for maintaining the temperatures of the waste form, the cooling system, the facility, and the natural and engineered barrier systems within design limits.

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.

thermohydrology The study of coupled water and heat flow.

Total System Model (TSM) A tool for analyzing the linkages, interactions, and synergies between waste acceptance, transportation, and the repository. A model capable of integrating and analyzing the waste management system performance, alternative system solutions, and program and policy impacts.

Total System Performance Assessment (TSPA) Term used by the U.S. Department of Energy to describe the particular performance assessments conducted to determine whether the proposed Yucca Mountain repository complies with the relevant regulatory requirements for waste isolation and containment and protection of human health.

transparent Easy to detect or observe. The use of clear language and easily understood concepts and/or assumptions to arrive at credible, traceable, and logical conclusions.

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

waste form The radioactive waste materials and any encapsulating or stabilizing matrix. Examples include used reactor fuel elements and borosilicate glass "logs."

waste form degradation The result of chemical and physical changes that occur when the waste form is exposed to the local environment.

waste management system All elements of the system involved in the management of radioactive wastes.

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

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Appendix A

Nuclear Waste Technical Review Board Members

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 the 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 Engineers 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's academic experience includes adjunct professorships at UCLA and Vanderbilt University, lecturer at MIT, and serving on the National Commission of the Accreditation Board for Engineering and Technology and several university advisory committees.

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 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 is also the founder and former chairman of Visual Risk Technologies. Dr. Abkowitz brings to the Board expertise in managing the risks associated with accidents, intentional acts and natural disasters, as well as the operational risks of integrated systems. He has a specific interest in hazardous materials transportation safety & security, and in risk mitigation using 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. He is the author of a recent book entitled, *Operational Risk Management—A Case Study Approach to Effective Planning and Response*, published by John Wiley & Sons, and has appeared on National Public Radio, Fox National News, and CNBC discussing various risk management topics of national importance.

Dr. Abkowitz has been inducted into Chi Epsilon and the National Society of Sigma Xi. He received the Distinguished Service Award in 1996 from the Transportation Research Board and the Team Excellence Award in 2006 from the Tennessee Department of Transportation.

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 a 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 University 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 lives in Macatawa, Michigan, and Coronado, California.

Thure E. Cerling, Ph.D.

Dr. Thure E. Cerling was appointed to the 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 occurring 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.

David J. Duquette, Ph.D.

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

Dr. Duquette is the John Tod Horton 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 230 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, the American Society for Metals, and the Electrochemical Society. He is also a member of The Minerals, Metals and Materials Society.

Dr. Duquette has 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). In1968, 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 Distinguished University Professor at Vanderbilt University, where he is the Director of the Vanderbilt Institute for Energy and the Environment. He has a shared appointment in the Department of Civil and Environmental Engineering and the Department of Earth and Environmental Sciences there. He previously was a professor at the University of Virginia for many years.

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 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); Langbein Lecturer, American Geophysical Union (2002); Fellow, Geological Society of America (2005), and Virginia Outstanding Scientist (2007).

He has chaired the Board on Earth Sciences and Resources of the National Research Council (2003 to present); the National Research Council Committee to Review the WATERS science plan (2007-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 *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 lives in Nashville, Tennessee.

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 Science and 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 a member of the MIT undergraduate committee working on curriculum development and recruitment. He is president of Kadak Associates, a consulting firm specializing in safety assessments, 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 1997, 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, Dr. Kadak was a member of the Advisory Committee on External Regulation of DOE Nuclear Safety for the U.S. department of Energy. 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 lives in Barrington, Rhode Island.

Ronald M. Latanision, Ph.D.

Dr. Ronald M. Latanision was appointed to the 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 Corporate Vice President and Director, Mechanics and Materials, of the engineering consulting firm, Exponent 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 2004 Henry B. Linford Award from the Electrochemical Society; the 2001 T.P. Hoar Award from the British Institute of Corrosion, and the Willis Rodney Whitney Award from the National Association of Corrosion Engineers in 1994. He was elected a Distinguished Alumnus of The Ohio State University College of Engineering in 1991 and an Honorary Alumnus of MIT in 1992. In 2007, he was named Distinguished Chemist of the Year by the New England Institute of Chemists.

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 was 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 Nicole J. Kim Professor of Engineering 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. His contributions 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 treating 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.

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 programs currently used by various government agencies and the private sector.

Dr. Mosleh is a Fellow of the Society for Risk Analysis (SRA), and the recipient of several scientific achievement awards. He has been a consultant and a technical advisor to many 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 lives in Columbia, Maryland.

William M. Murphy, Ph.D.

Dr. William M. Murphy was appointed to the U.S. Nuclear Waste Technical Review Board on March 20, 2006, by President George W. Bush.

Dr. Murphy is Professor in the Department of Geological and Environmental Sciences at California State University, Chico. His research focuses on geochemistry, including the interactions of nuclear wastes and geologic media. From 1988 to the time that he joined the University faculty in 2000, Dr. Murphy worked at the Center for Nuclear Waste Regulatory Analyses. Dr. Murphy worked previously (1986-1988) at the Basalt Waste Isolation Project at Hanford, Washington.

Dr. Murphy serves on the Steering Committee for the Symposium on the Scientific Basis for Nuclear Waste Management. He was representative from the U.S. in the Natural Analogue Working Group, and he holds a position as administrative judge on the Atomic Safety and Licensing Board Panel of the U.S. Nuclear Regulatory Commission.

In 1974, Dr. Murphy received a B.S. in earth sciences from the University of California, Santa Cruz. He received an M.S. in geology from the University of Oregon in 1977, and a Ph.D. in geology from the University of California, Berkeley in 1985.

Dr. Murphy resides in Davis, California.

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

Dr. Henry Petroski was appointed to the U.S. 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 research focuses on the interrelationship between success and failure in engineering design. He also has a strong interest in the nature of invention, as well as in the history and evolution of technology. 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); the Civil Engineering History and Heritage Award from the American Society of Civil Engineers (1993); and the Washington Award from the Western Society of Engineers (2006). 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, the Institution of Engineers of Ireland, the American Academy of Arts and Sciences and is a member of the American Philosophical Society 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); and *Success through Failure: The Paradox of Design* (2006). 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 magazine of the American Society for Engineering Education. He has published more than 75 refereed journal articles in such publications as *International Journal of Facture, Engineering Fracture Mechanics, Journal of Applied Mechanics,* 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

Meetings of the Nuclear Waste Technical Review Board

Meetings of the Nuclear Waste Technical Review Board

May 9, 2006 — **Spring Board Meeting**
McLean, Virginia
Transportation, aging, and disposal (TAD) canister concept
Capacity of Yucca Mountain

September 25–26, 2006 — **Workshop on Localized Corrosion**
Las Vegas, Nevada
Localized corrosion of Alloy 22

September 27, 2007 — **Fall Board Meeting**
Las Vegas, Nevada
Yucca Mountain Safety Case

January 24, 2007 — **Winter Board Meeting**
Las Vegas, Nevada
Department of Energy updates

March 14, 2007 — **Panel Meeting on Infiltration**
Berkeley, California
DOE infiltration estimates

May 15, 2007 — **Spring Board Meeting**
Arlington, Virginia
DOE updates
Nuclear waste disposal issues

September 19, 2007 — **Fall Board Meeting**
Las Vegas, Nevada
DOE updates
Surface facility design and operation
Preclosure Safety Analysis

Appendix C

Nuclear Waste Technical Review Board Panels and Technical-Issue Leads

Nuclear Waste Technical Review Board Panels and Technical-Issue Leads

Panels[†]

Preclosure Operations

Howard Arnold, Chair
Mark Abkowitz
Andy Kadak
Henry Petroski

Gene Rowe*
Bruce Kirstein
Daniel Metlay
John Pye
Karyn Severson

Postclosure Performance

George Hornberger, Co-Chair
Ron Latanision, Co-Chair
Thure Cerling
David Duquette
Andy Kadak
William Murphy

David Diodato*
Bruce Kirstein*
Carl Di Bella

System Integration

Mark Abkowitz, Chair
Andy Kadak
Ali Mosleh

Daniel Metlay*
Carl Di Bella
David Diodato
John Pye
Gene Rowe
Karyn Severson

Technical-Issue Leads

Source Term

William Murphy, Lead
David Diodato*
Carl Di Bella
Bruce Kirstein

Corrosion

David Duquette, Lead
Bruce Kirstein*
Carl Di Bella

Natural System

Thure Cerling, Lead
David Diodato*

Thermal Management

Andy Kadak, Lead
John Pye*
Carl Di Bella
Bruce Kirstein
Gene Rowe

Transportation

Mark Abkowitz, Lead
Daniel Metlay*
Carl Di Bella
Gene Rowe
Karyn Severson

Surface Facilities

Henry Petroski, Lead
Gene Rowe*
John Pye
Karyn Severson

Dose Assessment

John Garrick, Lead

Performance Assessment

Ali Mosleh, Lead
David Diodato*
Bruce Kirstein
Daniel Metlay

[†]John Garrick is ex-officio a member of all Board Panels.
*Staff Coordinator(s)

Appendix D

Nuclear Waste Technical Review Board Publications

Nuclear Waste Technical Review Board Publications

Technical Evaluation of U.S. Department of Energy Yucca Mountain Infiltration Estimates: A Report to Congress and the Secretary of Energy.
December 2007.

In this report, the U.S. Nuclear Waste Technical Review Board presents its evaluation of revised DOE estimates of water infiltration at Yucca Mountain. The infiltration estimates were revised because violations of quality assurance procedures were alleged to have been committed by U.S. Geological Survey employees involved in gathering and analyzing infiltration data at Yucca Mountain in the 1990's.

Report to Congress and the Secretary of Energy.
January 2007.

This report contains summaries of Board findings and recommendations contained in the following: letters to the Director of the Office of Civilian Radioactive Waste Management (OCRWM) following Board meetings held in February, May, and September 2006, a letter and enclosures sent to the Director of OCRWM following a Board workshop on deliquescence-induced localized corrosion in September 2006, and testimony presented in May 2006 by the Board's Chairman before the Senate Energy and Natural Resources Committee.

Report to Congress and the Secretary of Energy.
June 2006.

In this report, the Board summarizes its major activities from January 1, 2005, through February 28, 2006. During that period, the Board focused its attention on the Project's efforts to develop post-closure performance estimates for the repository it proposes to construct at Yucca Mountain in Nevada. 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 fiscal years 2005-2006, and its performance evaluation for 2005.

Letter Report to Congress and the Secretary of Energy.
December 2005.

In this letter report to Congress and the Secretary of Energy, the Board presents its views on the status of some important issues related to the technical basis for DOE activities related to the waste management system, the engineered system, the natural system, the repository system, and the assessment of the performance of the systems. The Board also outlines issues that it expects may continue to be of interest in the future.

Report to Congress and the Secretary of Energy.
May 2005.

In this report, the Board summarizes its major activities from January 1, 2004, through December 31, 2004. During that period, the Board focused on the Department of Energy's efforts to develop a system for accepting, transporting, and handling high-level radioactive waste and spent nuclear fuel before disposal in the repository proposed for Yucca Mountain. 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 2005, and its performance evaluation for 2004.

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

This letter and attachments constitutes the Board's second report to Congress and the Secretary of Energy for calendar year 2003. This letter 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.

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

Technical report supporting Board conclusions in October 21, 2003 letter to the DOE related to the potential for localized corrosion of waste packages during the thermal pulse.

Report to the Secretary of Energy and the Congress.
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 Secretary of Energy and the Congress.
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.

Letter report summarizing the Board's evaluation of the DOE's technical and scientific investigation of the Yucca Mountain site.

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 Secretary of Energy and the Congress.
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 the 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 alterna-

tive repository designs, including ventilated low-temperature designs that have the potential to reduce uncertainties and simplify the analytical bases for determining site suitably 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.

Board Completes 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.

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 underway 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: 1996 Findings and Recommendations.
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 Nuclear Regulatory Commission. 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 (SKB) 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: January to December 1993.
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 OCRWM's 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 (ninth in the NWTRB series) 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 (eighth in the NWTRB series) focuses on the exploratory studies facility 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 seventh 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 Office of Civilian Radioactive Waste Management's (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 sixth 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 man-

agement 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 fifth 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 fifteen 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 fourth report provides update on the Board's activities and explores in depth the following areas: exploratory studies facility (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 Environmental Protection Agency, the Nuclear Regulatory Commission (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 third 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 second 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 perspec-

tives 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 first report sets the stage for the Board's evaluation of the Department of Energy's (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

Nuclear Waste Technical Review Board Correspondence with the Department of Energy

Nuclear Waste Technical Review Board Correspondence with the Department of Energy

In addition to published reports, the Board periodically writes letters to the Director of the Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM). The letters typically provide 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 OCRWM. For archival purposes, three Board letters written during the period covered by this report are reproduced here.

OCRWM typically responds to the Board's reports and letters, indicating its plans to respond to the Board's recommendations. Included here are OCRWM's responses that were received during calendar year 2006. Inclusion of these responses does not imply Board concurrence.

- Letter from Paul M. Golan, Principal Deputy Director, OCRWM, to B. John Garrick; May 5, 2006.

  Subject: DOE's responses to recommendations in the December 19, 2005, and March 6, 2006, letters.

- Letter from B. John Garrick to Paul M. Golan, Acting Director, OCRWM; June 14, 2006.

  Subject: DOE's participation at the May Board meeting.

- Letter from Edward F. Sproat, III, Director, OCRWM, to B. John Garrick; August 21, 2006.

  Subject: DOE's responses to recommendations in the June 14, 2006, letter.

- Letter from B. John Garrick to Edward F. Sproat, III, Director, OCRWM; December 14, 2006.

  Subject: DOE's participation at the September Board meeting.

- Letter from B. John Garrick to Edward F. Sproat, III, Director, OCRWM; January 12, 2007.

  Subject: Comments following the Board's September 2006 Workshop on Localized Corrosion.

- Letter from Edward F. Sproat, III, Director, OCRWM, to B. John Garrick; November 20, 2007.

  Subject: DOE's response to recommendations in the January 12, 2007, letter.

- Letter from B. John Garrick to Samuel W. Bodman, Secretary, DOE; February 13, 2007.

  Subject: Comments following the Board's January 2007 meeting.

- Letter from Samuel W. Bodman, Secretary of Energy, to B. John Garrick; April 10, 2007.

  Subject: DOE's responses to recommendations in the February 13, 2007, letter.

- Letter from B. John Garrick to Edward F. Sproat, III, Director, OCRWM; April 19, 2007.

  Subject: DOE's participation at the January Board meeting.

- Letter from Edward F. Sproat, III, Director, OCRWM, to B. John Garrick; November 6, 2007.

  Subject: DOE's responses to recommendations in the April 19, 2007, letter.

- Letter from B. John Garrick to Edward F. Sproat, III, Director, OCRWM; July 10, 2007.

  Subject: Additional comments on the Board's September 2006 Workshop on Localized Corrosion.

- Letter from Edward F. Sproat, III, Director, OCRWM, to B. John Garrick; August 13, 2007.

  Subject: DOE's response to the Board's *Report to Congress and the Secretary of Energy, January 1, 2005, to February 28, 2006.*

Department of Energy
Washington, DC 20585

QA: NA

May 5, 2006

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

Dear Dr. Garrick:

Thank you for your December 19, 2005, and March 6, 2006, letters providing the Nuclear Waste Technical Review Board's (Board) comments on the information presented by the U.S. Department of Energy at the Board's meetings on November 8-9, 2005, and February 1, 2006, respectively. Our responses to each of the Board's letters are enclosed.

We appreciate the opportunities to inform the Board of the progress of the Civilian Radioactive Waste Management Program. The Department continues to benefit from the constructive views of the Board, and we look forward to further dialog on the repository and related issues.

Sincerely,

Paul M. Golan
Principal Deputy Director
Office of Civilian Radioactive
Waste Management

2 Enclosures

Printed with soy ink on recycled paper

ENCLOSURE 1

U.S. DEPARTMENT OF ENERGY RESPONSES TO THE
DECEMBER 19, 2005, LETTER FROM THE
NUCLEAR WASTE TECHNICAL REVIEW BOARD

Program Overview

The Board emphasized the need for close coordination and cooperation with the utilities to ensure compatibility of the transportation, aging, and disposal (TAD) canister design(s) with the fuel loading facilities at reactor sites. The Department agrees and activities are ongoing to develop a performance specification for the TAD canister which involve interactions between the Department and the nuclear industry. The Department will consider preclosure operations, handling, transportation, aging, and postclosure performance in development of the specification.

The Department agrees that the thermal management strategy must be clearly defined to provide the technical basis for waste acceptance, transportation, waste handling, and waste emplacement. Postclosure near-field and in-drift conditions affecting performance of the engineered and natural barriers are being addressed in the postclosure elements of the thermal management strategy. This includes the thermal decay characteristics of the waste and temperature limits at key locations such as the waste package wall and drift wall. The Department will consider the Board's recommendation for external review of the TAD canister system development.

Science Update

The Department agrees that post-test characterization, especially of longer term *in-situ* tests, can provide valuable and insightful information leading to refinement of process models and reduction of uncertainty. Regarding the Drift Scale Test and the moisture-monitoring activity behind the bulkhead in the Enhanced Characterization of the Repository Block (ECRB), technical work plans are being developed for post-test characterization activities. For the Drift Scale Test, near-term activities include re-entry, retrieval of sample materials, collection of additional samples, and photography. Longer term activities will include coring, rock-bolt pull tests, and investigation of spalling at the drift crown. The objectives for these activities include better understanding of thermal-hydrologic-chemical-mechanical effects on repository performance. Evaluation of the ECRB bulkhead moisture data is planned for fiscal year 2007 to better understand the impact of seepage and condensation processes that occur in the near-field and host-rock.

The Department appreciates the Board's continued support of ongoing scientific investigations by the Office of Science and Technology and International (OSTI). These investigations are focused on evaluating the representation of conservatism in natural barrier system contributions to waste isolation and repository performance. For example, scientific studies at the Peña Blanca natural analog site have yielded valuable data on seepage in unsaturated tuff.

The Department agrees that host-rock thermal conductivity is a key rock property affecting the prediction of thermal-hydrologic conditions in the repository. From sensitivity analyses performed using the Multiscale model [*Multiscale Thermohydrologic Model (ANL-EBS-MD-000049, REV 03)*, Section 8.1], host-rock thermal conductivity and percolation flux are identified as the two principal natural-system parameters affecting peak temperatures and boiling duration. Other model parameters, such as waste package proximity to the edge of the repository layout, are also important.

The *in situ* measurements of thermal conductivity were acquired for the purpose of validating the geostatistical model used to calculate the bulk thermal conductivity of repository units. The model has been developed based on site-specific data including geophysical well logs, physical property measurements on rock cores from surface boreholes, and laboratory thermal conductivity measurements. Because a sequential Gaussian simulation is used, the model provides an appropriate representation of the spatial variability and uncertainty of the underlying data, especially the key input parameters (i.e., matrix thermal conductivity and lithophysal porosity). Both parameters contribute to the spatial variability and uncertainty in the model results, though the dominant influence is from matrix thermal conductivity. Whereas *in situ* tests are useful in evaluating the effects of discontinuities such as lithophysal cavities, laboratory tests are used to measure matrix thermal conductivity, the dominant contributor to spatial variability and uncertainty.

The *in situ* test results are not part of the basis for spatial variability and uncertainty in the model results. The reason is that *in situ* tests by their nature (and cost) cannot be performed over nearly as broad a range of spatial distribution and stratigraphic facies as can be performed using geophysical well logs and core samples. Thus, additional *in situ* tests would not be a practical way to improve the model treatment of spatial variability and uncertainty.

The *in situ* thermal conductivity test results are point measurements that corroborate the geostatistical model. All test results are within the range of values derived from the model. One of the test results is slightly above 1.5 standard deviations of the model-derived mean and the others are within 1 standard deviation. Additional confidence in the model is gained by the validation of methods and models used to estimate matrix thermal conductivity, lithophysal porosity, matrix porosity, and bulk density. The latter two are used to estimate the former two, which are used to obtain bulk thermal conductivity. The Department believes that an acceptable level of model validation has been achieved; and, while potentially useful, further *in situ* thermal conductivity tests are not necessary for this purpose.

The Department shares the Board's view that fundamental understanding of the source term including oxidation, dissolution, and transport is important for predicting repository performance. Current models of these processes provide an adequate level of this understanding for regulatory total-system dose assessment, but the Department plans to continue OSTI investigations in this area for possible future use.

The OSTI Source-Term Thrust Area is dedicated to scientific studies relevant to spent nuclear fuel (SNF) and nuclear waste glass and the critical processes within the waste package and drifts that affect potential radionuclide release from the waste forms and from the engineered barrier

system. This program is focused on developing a basic understanding of the fundamental mechanisms of radionuclide release and a quantification of the release as repository conditions evolve over time. The Thrust Area is an integrated set of about 15 research projects involving multiple national laboratories and universities, as well as international collaboration. These projects focus on (1) dissolution mechanisms and rates for SNF, (2) formation and properties of secondary uranyl phases, (3) waste-form and waste-package interactions, and (4) modeling studies to synthesize the understanding of the chemical and physical processes. Integration of the research in this area will be ongoing throughout its progress to determine how the information developed could be used for the Yucca Mountain Project.

There are two ongoing activities related to analyses of Cl-36. The first activity documents the work on the Cl-36 validation activities performed by Lawrence Livermore National Laboratory, U.S. Geological Survey, and Los Alamos National Laboratory that have previously been presented to the Board. A draft report is in review.

The second activity is an independent study of Cl-36 conducted under a Cooperative Agreement between the Department and the University and Community College System of Nevada (UCCSN). The UCCSN scientists collected samples from the Exploratory Studies Facility in 2005, investigated experimental techniques, and started testing rock samples in 2006.

Drip Shield Design

The Department agrees that it is important to evaluate factors that will influence the final drip shield design well in advance of repository closure. The Department plans to fabricate prototype drip shields to evaluate operational envelopes and design and installation tolerances in the performance confirmation drifts.

Localized Corrosion of the Waste Package

The Department has noted the Board's continued concern regarding screening out from the Total System Performance Assessment (TSPA) localized corrosion initiated by deliquescent brines formed at high temperatures (160°C – 220°C) from airborne dust deposited on the waste package surfaces. We reiterate that the initiation of localized corrosion of Alloy 22 by brine from deliquescent salts has been excluded on the basis of low consequence.

Although the possibility of multisalt deliquescent brine formation at elevated temperatures in the repository does exist, studies show the brines would not be stable due to acid degassing (see *Screening of Features, Events and Processes in Drip Shield and Waste Package Degradation [ANL-EBS-PA-000002 REV 02]* and *Analysis of Dust Deliquescence for FEP Screening [ANL-EBS-MD-000074 REV 01]*). As acid degassing occurs, typically rapidly at first, the pH increases to near-neutral or alkaline values. Further degassing can result in dryout, producing an assemblage of less-deliquescent salts that yield a higher pH solution (decreasing the likelihood of localized corrosion initiation) when redeliquescence occurs. In addition, the presence of carbonate anions, as well as nitrate anions, inhibit the initiation of localized corrosion on Alloy-22. The limited volume of brine and retention of brine by capillarity in the dust assemblage would also inhibit localized corrosion initiation on dust-covered surfaces. Furthermore, analysis shows that even if localized corrosion initiates, the corrosion products

formed would consume some of the aqueous brine phase, thus limiting local corrosion propagation. It is on the bases of the overall analysis, as documented in the referenced reports, that localized corrosion due to dust deliquescence has been excluded from the TSPA.

In further support of the dust deliquescence analysis, the Department is in the process of investigating stifling at higher temperatures (i.e., under dust deliquescence exposure conditions), including the effects of limited availability of reactants. The tests will use methods intended to address the relationship between the amount of dust containing deliquescent salts on the waste package surface and the extent of damage that may occur.

The recent high-temperature corrosion data and their applicability can be discussed at the upcoming corrosion workshop.

Total System Model

The Department is pleased that the Board believes that the Total System Model (TSM) has significant potential for simulating and understanding the performance of the waste management system. The Department is prepared to support additional interactions with the Board to further understanding of the capabilities and limitations of the TSM in conducting probabilistic assessments, optimizing the waste management system, and analyzing "what if" operational scenarios.

The results of TSM analyses were used to inform the Department regarding the decision to evaluate a primarily canister-based system using TADs for commercial SNF. Insights from the TSM analyses included, but were not limited to, factors such as dose, thermal management, and waste handling.

Additional TSM analyses are currently underway to support the development of a recommended design solution as part of the Departmental process for formally evaluating and approving the change in technical baseline from a primarily bare fuel handling approach to a primarily canister-based approach. Documentation of these additional TSM analyses is scheduled for completion this summer.

The Department recognizes that information obtained from the utilities is important to the quality of the TSM analyses and success of the primarily canister-based approach. In January 2005, the Department completed a voluntary survey of all reactor operators to gather updated site-specific data, e.g., their respective capabilities to load and transport SNF needed for planning transfer of SNF from each reactor site to the waste management system. Approximately 75 percent of the site operators responded.

The Department has also provided information on the new approach to the cask vendors and nuclear utilities and is evaluating technical issues related to development and licensing of TADs raised by cask vendor and utility representatives. The Department is committed to continuing the close coordination with cask vendor and utility representatives, not only in the development of the performance-based specification for TADs, but also in the subsequent design of the TADs.

Conservatism in the Total System Performance Assessment for the License Application

The Department's approach to the TSPA reflects international experience, Nuclear Regulatory Commission (NRC) staff perspectives, and unique challenges of modeling transport in partially saturated fractured rock. The Department believes that the performance assessment supporting the postclosure compliance analyses is reasonable for this application and has been developed cautiously. However, we recognize the Board's perspective that some aspects of the model might be considered unrealistic. Because the approach that the Department is using for postclosure performance assessment has evolved over many years through interaction with NRC staff, and is reflected in the Yucca Mountain Review Plan, it is an integral part of our approach to the license application. The Department is currently undertaking development of a best-estimate total system performance assessment. This best-estimate analysis would be used (1) as a management and communication tool, (2) to build confidence in the estimate of repository performance in the compliance-based analysis, and (3) to quantify and help understand the degree of overall conservatism in the TSPA. We believe this will help to address directly the Board's concerns.

ENCLOSURE 2

U.S. DEPARTMENT OF ENERGY RESPONSES TO THE
MARCH 6, 2006, LETTER FROM THE
NUCLEAR WASTE TECHNICAL REVIEW BOARD

New Organization

The Department recognizes your interest in the restructuring of the Office of Civilian Radioactive Waste Management (OCRWM) organization. OCRWM is being reorganized to create a more project-focused approach in the accomplishment of its critical mission. The organizational changes are designed to improve and streamline the structure and processes to more effectively manage the Program through the design, licensing, construction, and operations phases. It should be noted that while the managers of functional responsibilities report to the Director, significant responsibilities will be delegated to the managers. It is the Director's role to hold each manager accountable; accountability is critical for any organization, any program, or any system to be successful.

Realistic Analysis of Repository Performance

The Department is currently undertaking development of a best-estimate Total System Performance Assessment (TSPA) that will allow it to investigate conservatism in the component models and build confidence in the postclosure compliance analyses. It is, however, important to recognize that the process models the Department has developed are consistent with information available at the time the models were completed. Some of these models are based on scientific understanding developed over two decades. In the face of large uncertainty or alternate conceptual models, the Department and its contractors will continue to use a "cautious, but reasonable" approach for postclosure compliance analyses to assure that the predicted risk (i.e., the dose to the reasonably maximally exposed individual) is not underrepresented and is not inappropriately diluted.

The Department has experience in evaluating repository performance over the period of peak dose, having done such analyses for the viability assessment, the site recommendation, and the final environmental impact statement. Recent postclosure performance assessment activities and modeling have focused primarily on a 10,000-year compliance period. The Department plans to conduct postclosure performance assessment analyses over the period of peak dose in accordance with final regulations, once they are promulgated.

Radionuclide Transport

The Department considers there to be ample information regarding the processes affecting the rate of transport under a range of environmental conditions that are expected in the waste package and the invert. As noted in the presentations, this transport is a function of the mode of degradation of the waste package and the expected environmental conditions, both of which are uncertain. Treatment of this uncertainty has been appropriately included in the models affecting source term releases as presented to the Board. The Department agrees, however, that there is benefit in continuing research in this area to enhance the understanding and evaluate the

representativeness of the current results under a reasonable range of repository-relevant conditions. These conditions could be affected by the introduction of the transportable, ageable, and disposable canister concept.

The forms of ^{237}Np and ^{242}Pu expected to exit the Engineered Barrier System (EBS) were discussed in the February meeting. The form of ^{237}Np is a dissolved radionuclide transported by either diffusive or advective processes through the EBS and into the host rock. The form of transported ^{242}Pu is both dissolved and colloidal. As presented in the meeting, the significance of these different forms depends on the particular scenario class and the antecedent degradation conditions of other elements of the EBS (notably the waste package and drip shield) and the waste form type (i.e., high-level waste glass or commercial spent nuclear fuel). The Department welcomes additional discussion on this subject in the future to ensure the Board's questions and concerns are adequately addressed.

Sensitivity of Dose Results to Different Models

The presentation by Dr. Michael T. Ryan was focused on dose models, in particular biokinetic and dosimetric models. For a given intake of radionuclides, these models determine the expected dose. These models generally reflect well accepted dose transfer coefficients published by such bodies as the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP). While these organizations recognize the large uncertainty of such models, they are widely used and accepted by regulatory bodies and agencies that implement the ICRP and NCRP recommendations; i.e., the U.S. Nuclear Regulatory Commission and the U.S. Environmental Protection Agency (EPA). The difference in inhalation and ingestion dose is in part affected by the biokinetic and dosimetric models mentioned above and other assumptions related to the biosphere. The Department is, as noted previously, currently undertaking development of a best-estimate TSPA that will allow it to assess conservatism in component models such as dosimetric analyses, and we look forward to interactions with the Board on how best to address this issue.

Natural Correlations of Parameters

The Department considers the range of possible advective transport times to be consistent with the range of observations presently available and reasonably represents the current state of knowledge of unsaturated and saturated zone transport. For example, these observations include potentially disparate findings of carbon-14 ages in perched water zones in the unsaturated zone of greater than 10,000 years and possible "bomb-pulse" (less than about 50 years) chlorine-36 observations in samples taken from the Exploratory Studies Facility. This range is reasonably and appropriately captured in the unsaturated zone transport model presented to the Board.

The inferred decoupling of seepage and percolation identified in the Board's comments reflects the assumptions made in the analysis presented in the February 1, 2006, meeting. In the case of the seepage sensitivity analysis, the assumptions associated with whether the drifts were collapsed or not were significantly different. This results in a significant difference in the likelihood and amount of seepage expected. The percolation sensitivity analysis was applied only to the case where the drifts were assumed to have collapsed. In this case, over the range of different percolation values investigated, the resulting differences in seepage amount did not significantly affect the rate of release of dissolved radionuclides because of the range of

solubility values used in the analysis. This result and observation is discussed in the report that the Department submitted along with the comments to EPA on the proposed rule. Again, the Department welcomes additional discussion with the Board to explain better its perspectives on the correlations.

Compliance Period

The Department is focused on the technical adequacy of the data, parameters, analyses, and models regardless of the time period for the compliance analysis. The Department is also focused on understanding the impact of uncertainty on the results of the relevant analyses and models that support the compliance evaluation and continues to apply the "cautious, but reasonable" philosophy recommended by the National Academy of Sciences and the regulatory guidance contained in the applicable regulations. In addition, as noted above, we are currently undertaking a best-estimate TSPA to build confidence in the estimate of repository performance in the compliance-based analysis and to quantify the degree of overall conservatism in the TSPA.

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

June 14, 2006

Mr. Paul M. Golan
Acting Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Golan:

On behalf of the Nuclear Waste Technical Review Board, I thank you and the other Department of Energy (DOE) staff who participated in the Board's meeting on May 9, 2006, in Washington, D.C. The Board welcomed the opportunity to review technical and scientific issues important to the Yucca Mountain program.

The major topic of the meeting was DOE's proposal to use a transportation, aging, and disposal (TAD) canister system for most commercial spent nuclear fuel. Without the TAD canister, planned operations at the surface facilities of a repository at Yucca Mountain would likely involve removing individual spent-fuel assemblies from transportation casks and placing them in waste packages for disposal or in storage casks or site-specific canisters for aging, which could result in handling an individual assembly as many as four times. The TAD canister system could reduce the number of times individual assemblies are handled because the canister and its contents would be handled in a single action. This could improve facility throughput at Yucca Mountain and reduce the potential for accidents during handling operations. The TAD canister system also has the potential to simplify the design and reduce the cost of repository surface facilities. For these reasons, the Board considers the TAD concept promising.

It became apparent at the meeting that hurdles must be overcome for the potential advantages of a canister-based system to be realized. Particularly important is the timing of the availability of TADs for storage at utility sites. At present, at-reactor spent-fuel storage pools are becoming filled and utilities are purchasing casks for on-site dry storage. Some of these are dual-purpose casks (or use dual-purpose canisters), which can be used for both storage and transport. If TADs are not available for use at utilities for at least 5-6 years, the quantity of spent fuel in dry storage at reactor sites will be significant. How DOE deals with these storage casks and the spent fuel remaining in the spent-fuel pools for blending to DOE requirements will determine whether the TAD concept can accomplish its objective, i.e., avoiding handling of individual fuel assemblies for reblending at Yucca Mountain.

bjg056vf

Also of importance is that the TAD canister concept would be part of a license application for a repository at Yucca Mountain. While performance specifications are being developed for the TAD canister, a final determination on the acceptability of the TAD for disposing of spent fuel will not be known until the conclusion of the licensing proceeding for Yucca Mountain. Therefore, there is considerable risk to DOE, utilities, and cask vendors in moving forward with design and fabrication of TAD canisters without knowing whether they will be approved by the Nuclear Regulatory Commission (NRC) for disposal in a repository at Yucca Mountain.

Complicating this question is DOE's insistence that it can accept only bare fuel ("uncanisterized" fuel) according to its interpretation of contracts it has with utilities. Consequently, using DOE's own bases for acceptance, it appears that DOE will not accept canister-based fuels, which is contrary to the essence of the TAD concept. The Board also was told that, by law, DOE is not permitted to provide TADs to utilities for dry-cask storage. Thus, while the Total System Model (TSM) assumes that it will be possible to place 90 percent of spent fuel at utility reactors in TADs, this assumption may not be realistic because of blending limitations at reactor sites and the amount of fuel in non-TAD storage containers. The Board believes that these fundamental issues need to be understood better and resolved to allow a proper technical assessment of the TAD approach to managing spent fuel for the Yucca Mountain repository.

The Board is interested in the performance specification for the TAD canister and its relationship to the postclosure thermal-management strategy. The Board has a continuing interest in consistency in the multiscale model analysis and the identification of limiting conditions for the thermal loading of the repository. The Board believes that these analyses are keys to understanding postclosure conditions and that such understanding is needed for properly assessing repository performance as it relates to water ingress and temperature limits on materials, drifts, and possible failure modes.

The Board notes that the success of the TAD concept appears to rely on construction and use of a rail line through Nevada for moving transportation casks from existing rail lines to the Yucca Mountain site. The Board has commented previously on the need for contingency planning in the event that construction of the rail line is delayed. To the extent that adoption of the TAD concept also causes changes in the design of the Yucca Mountain surface facilities, DOE's ability to process legal-weight truck casks could be reduced. If so, contingency planning for a rail line delay would be even more important.

Finally, as an overarching concern, the Board believes that the existing litigation between DOE and the nuclear utilities is a significant impediment to the technical resolution of key issues regarding TAD canisters and the overall spent-fuel management system leading to disposal. The Board strongly urges DOE and the utilities to resolve their contractual differences with a sense of the urgent need for finding a waste-management solution.

DOE's TSM analyzed various scenarios involving use of TAD canisters, and the results of some of those analyses were presented at the meeting. The Board applauds DOE's development and use of TSM and encourages additional enhancements of its capabilities. TSM is an excellent tool for evaluating the performance of the waste management system from acceptance to emplacement and under alternative designs, operating assumptions, and constraints. Greater use of TSM is particularly important at this time, because the tool is demonstrating its value in identifying potential disconnects between various components of the waste management system. The Board would like to see a base (reference) case analysis that reflects current system realities and the design of the planned surface facilities at Yucca Mountain. TSM should be used to focus designers on credible scenarios for judging the viability of the waste management system, the design of the surface facilities (including aging pads), and the ability of the utilities to blend fuel so that the size of the aging pads can be minimized.

In addition, the Board recommends adding to TSM the capability to evaluate "upset" conditions, such as equipment breakdowns or closure of transportation routes, but only after the reference case is established. Moreover, implementation of TAD will have implications for the thermal management strategy that do not appear to have been considered fully. Consequently, the Board encourages adding to TSM the functionality to model DOE's thermal-management strategy. That could be accomplished by developing a constraint on waste package emplacement that ensures compliance with DOE's line-load thermal limit for the underground facility. For existing capabilities, as well as those that might be added in the future, realism will be important, if the results of TSM analyses are to be credible. The Board encourages DOE to scrutinize the TSM input assumptions and parameter values to ensure that they realistically represent the system being modeled.

The presentation on surface-facility design did not provide sufficient information for the Board to make any assessment of its feasibility or safety. The Board is interested in the details of the surface-facility design. For example, the Board would be interested in the number of receiving bays under consideration, their function, size of spent-fuel storage pool, dry cask handling facilities, provisions for handling failed fuel, anticipated processing rates, processing uncertainties, and key assumptions. The expectation is that TSM will be used to validate this design. The Board looks forward to receiving and reviewing the documents that support the upcoming CD-1 decision on the design of the surface facilities. The Board hopes to see these documents before the CD-1 submittal.

Despite recent efforts by DOE to reorganize the OCRWM program with the intent of improving Yucca Mountain Project management, the Board remains concerned about whether the appropriate level of Project integration is being achieved. In particular, no definable office exists whose duty and authority is to ensure technical interaction and problem resolution among and between functional elements of preclosure and postclosure activities. We also note that many of the key positions in the new organization chart are either unfilled or filled with people in "acting" positions. For the success of the new organizational approach, we strongly recommend that these positions be filled as soon as possible.

Finally, the Board is concerned that the newly announced Global Nuclear Energy Partnership (GNEP) may negatively affect the technical and scientific focus on Yucca Mountain.

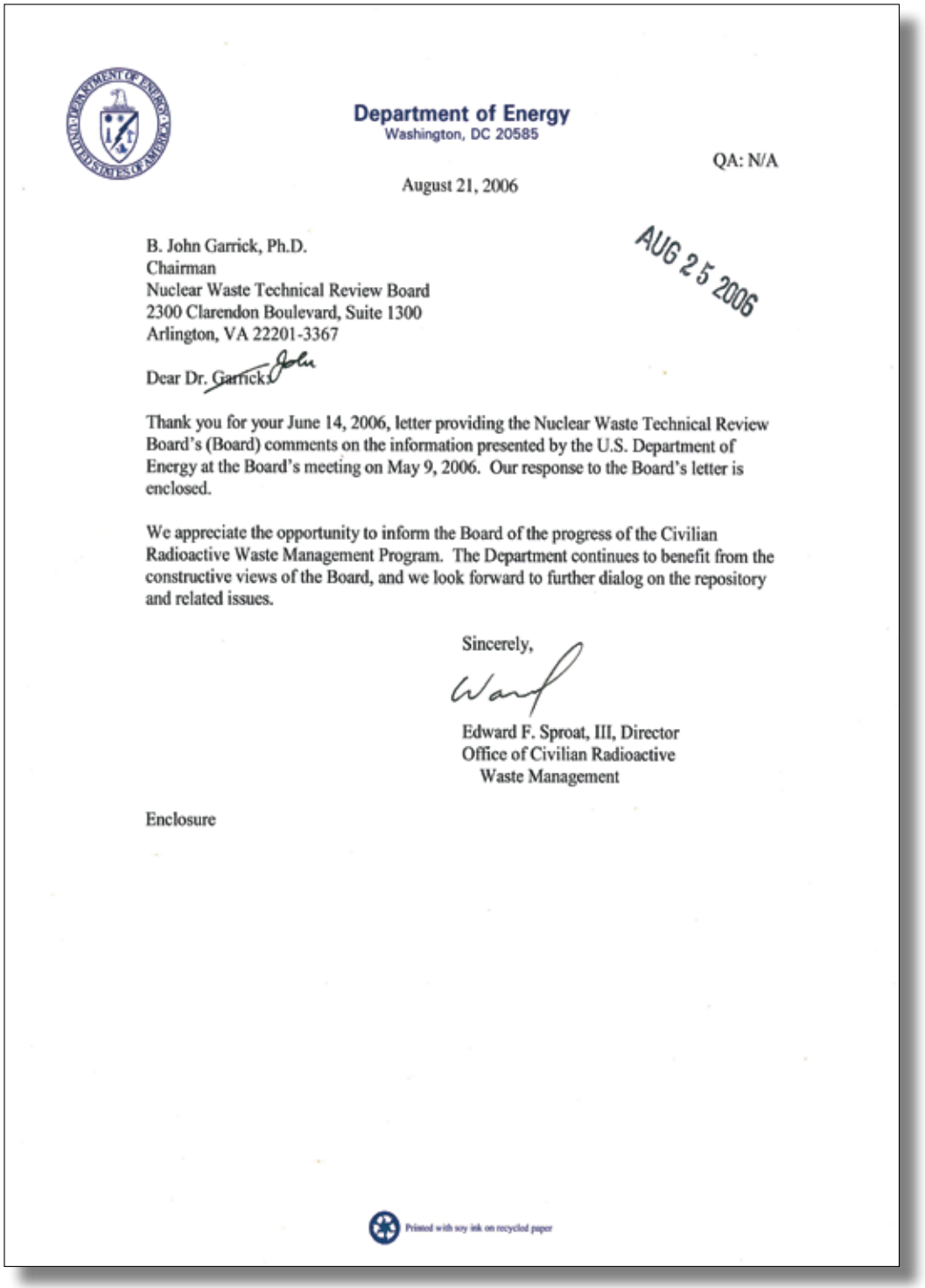
We encourage the Project to monitor the developments in GNEP to be sure that any effects that might occur can be accommodated: for example, a change in the waste form for disposal in the future. The Board would like to have a briefing on the status of this program and possible effects on the Yucca Mountain project.

We look forward to future meetings with DOE during which we can address issues raised in this letter as well as other technical and scientific issues that the Board identifies that pertain to a repository for high-level radioactive waste and spent nuclear fuel repository at Yucca Mountain.

Sincerely,

{Signed by}

B. John Garrick
Chairman



Department of Energy
Washington, DC 20585

QA: N/A

August 21, 2006

AUG 25 2006

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

Dear Dr. Garrick:

Thank you for your June 14, 2006, letter providing the Nuclear Waste Technical Review Board's (Board) comments on the information presented by the U.S. Department of Energy at the Board's meeting on May 9, 2006. Our response to the Board's letter is enclosed.

We appreciate the opportunity to inform the Board of the progress of the Civilian Radioactive Waste Management Program. The Department continues to benefit from the constructive views of the Board, and we look forward to further dialog on the repository and related issues.

Sincerely,

Edward F. Sproat, III, Director
Office of Civilian Radioactive
Waste Management

Enclosure

Printed with soy ink on recycled paper

U.S. DEPARTMENT OF ENERGY RESPONSES TO THE JUNE 14, 2006, LETTER FROM THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

Development and Deployment of Transport, Aging, and Disposal Canister Systems

The Department agrees with the Board's view that the early availability and implementation of transport, aging and disposal canister (TAD)-based systems for additional at-reactor storage of spent nuclear fuel are important to ensure that the benefits of the TAD system are realized at the Yucca Mountain facilities. The Department is considering incentives to ensure that the cask vendor community develops TAD-based systems in a timely fashion, as well as incentives to encourage early deployment of these systems at utility sites.

In developing these concepts to encourage the early development and deployment of TAD-based systems, the Department recognizes that, until the conclusion of the Nuclear Regulatory Commission licensing proceedings for Yucca Mountain, there will be some risk that TAD systems developed in accordance with the Department's performance specifications may not ultimately prove disposable, but no more than any other existing canistered waste form. We believe that by developing robust performance requirements, this risk can be managed. It is the Department's intent to ensure that any risk with respect to the ultimate disposability of the TAD canister be appropriately considered and managed as we refine our acceptance process and criteria.

Compatibility of Transport, Aging, and Disposal Canister with Standard Disposal Contract

The Department understands that the utilization of TAD-based systems for the acceptance of spent nuclear fuel may require modifications to the disposal contracts that the Department has with the utilities. The Department believes that it will be able to address these issues with the majority of utilities, and that the goal of receiving 90 percent of the first 63,000 metric tons of spent nuclear fuel at Yucca Mountain in TADs is reasonable. We will design the surface facilities with enough flexibility and redundancy such that a variance from the 90 percent target can be accommodated.

Transport, Aging, and Disposal Canister Performance Specification Relationship to Postclosure Thermal Management Strategy

The Department understands that the Board is interested in how the TAD canister performance specification relates to the Department's postclosure thermal management strategy. The performance specification is being developed taking into account all the system requirements from waste acceptance to final disposal. Accordingly, it has been our intent to incorporate requirements that, while ensuring that the thermal performance of the TAD canister system would be consistent with the Department's current postclosure thermal-management approach, would provide sufficient flexibility to

accommodate alternative postclosure thermal management strategies. If, as a result of further analyses, the current postclosure thermal management approach is altered, we believe that such changes can be accommodated by altering the manner in which the TAD canister system is operated (i.e., by decreased surface aging), rather than by requiring changes to the TAD canister design.

Rail Line Contingency Planning

In a Record of Decision published in April 2004, the Department selected "mostly rail" as the mode of transport both nationally, and in the State of Nevada. The "mostly rail" option includes an expectation that some truck shipments will be made. In a Supplement Analysis to the *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-0250F), the Department considered the potential environmental impacts of shipping legal-weight truck casks on railcars. This scenario involved shipments from generator sites to an intermodal transfer station that would be constructed and operated in Nevada and the subsequent transportation of those casks to a repository at the Yucca Mountain site by legal-weight trucks. In the event that the rail line is not completed when the repository begins operations, these truck transportation options would still be available for initial shipments to Yucca Mountain and will have been fully planned and ready for completion by that time. A full range of transportation contingencies are also being considered for shipment of TAD canisters in the event that the Nevada rail line is not available when the repository begins operations. However, we are planning the project to ensure that the rail line will be available at least one year before the repository begins operation.

Impact of Spent Fuel Litigation on Transport, Aging, and Disposal Canister Development

The Department disagrees with the Board's representation that the existing litigation between the Government and the nuclear utilities over the delay in beginning the acceptance of spent nuclear fuel in 1998 is a significant impediment to the technical resolution of key issues regarding TAD canisters and the overall spent fuel management system leading to disposal. While the Department continues to encourage and support the resolution of the existing lawsuits through negotiated settlements, only the utilities can determine how they choose to resolve these disputes. Nonetheless, the Department believes that, although they may be complicated by the ongoing litigation, meaningful technical discussions can and do take place. This was demonstrated by recent technical interactions with the industry on the development of the TAD system performance requirements. We will continue to pursue a collaborative design approach with the private sector.

Total System Model Analyses

The Department appreciates the Board's support for the Total System Model (TSM) as a tool to understand waste management system performance. The Department plans to continue the integrated systems engineering and analyses approach to gain a greater

understanding of the interrelationships between the subsystem components: waste acceptance, transportation, and repository operations. These continuing analyses are expected to provide additional insights as design details are further refined and operational scenarios are more fully defined, but will be sequenced to occur as details and scenarios are deemed ripe for consideration to ensure that realistic representations of the waste management system are analyzed.

As the Board is aware, the Department directed Bechtel SAIC Company, LLC, in October 2005 to update the repository surface facility design and operating concepts for the Yucca Mountain Project to adopt a primarily canister-based approach utilizing the TAD system. In compliance with the Departmental directives for this undertaking, a revised critical decision-1 (CD-1) package was prepared for submittal to the Department's Energy Systems Acquisition Advisory Board (ESAAB) to document and obtain approval for the revised approach. The thorough internal Departmental review and the approval process have been completed.

The CD-1 package contains a suite of documents describing the revised Project technical approach, cost, and schedule, along with documents for impact analysis. Now that approval of the CD-1 package by the ESAAB has been obtained, the baseline or "base (reference) case" analyses, including Total System Model results, will be updated to further analyze design scenarios, and specific details such as fuel blending and aging pad sizing.

The Department plans to continue a stepwise approach using the TSM tool to evaluate interrelationships and system responses with the transportation program. Throughout the TSM design evolution, the Department has briefed the Board on the inherent TSM capabilities to study upset conditions. The TSM design objectives are to ensure this flexibility is available by using an object oriented design approach and commercial off-the- shelf software to build the TSM. As the transportation program further refines its planning bases, logistics, and operational scenario, the Department will use TSM analyses with the same systems analysis approach to gain an understanding of the TAD-based system. Those future TSM studies of transportation scenarios will abstract data from transportation subsystem models when those model results are mature enough to establish realistic scenarios that merit evaluation.

Surface Facility Design

The Department appreciates the Board's interest in the surface facility design. Now that we have formal approval from the Department to implement the canister-based approach, we will commence preliminary design, and develop the design and safety analysis needed to support a License Application. We will also provide presentations to the Board describing in detail the design concept for the canister-based approach, including facility functions, layouts, and other items discussed in the Board's letter, as well as the results of the preliminary safety analyses.

The Board's expectation that the TSM is being used to validate the conceptual design is part of our ongoing work in this area. While not complete, the validation of the design concepts using the TSM is occurring at this time. As the design moves through the preliminary design process, the TSM will continue to be used to ensure that the design will meet the Department's requirements.

New Organization

The Department understands the Board's concerns with the Office of Civilian Radioactive Waste Management's (OCRWM) new organization and, in particular, the lack of a specific office with the responsibility for Project integration. As was discussed at the Board meeting, while the individual office directors are responsible for coordinating between offices, the Director, OCRWM, retains the ultimate responsibility to ensure overall Project integration. Upon my confirmation as Director, I began an assessment of the OCRWM structure, processes and competencies. The Board will be informed of the results of my assessment at a future meeting.

Relationship of Global Nuclear Energy Partnership and Yucca Mountain

The Department's Global Nuclear Energy Partnership (GNEP) is a closely coordinated long-term effort between multiple Program offices and national laboratories. One element of GNEP seeks to realize technologies that could enhance various aspects of the waste management system. There is no near-term impact of GNEP on Yucca Mountain. This is because there is no definition of the ultimate waste form and waste package that will result from the GNEP process. This information will not be developed until some time in the future. When it eventually becomes available, the resultant waste package will be qualified for disposal in Yucca Mountain; and an application for a license amendment will be submitted to allow disposal in the repository. The Department remains fully focused and will continue forward with the technical and scientific efforts to license and operate a geological repository at Yucca Mountain to address the spent fuel management of the current generation of nuclear reactors.

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

December 14, 2006

Mr. Edward F. Sproat III
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Sproat:

Thank you very much for attending the U.S. Nuclear Waste Technical Review Board meeting in Amargosa Valley, Nevada, on September 27, 2006, at which the Office of Civilian Radioactive Waste Management (OCRWM) presented its safety case for a high-level radioactive waste and spent nuclear fuel repository at Yucca Mountain. Your update on the OCRWM milestones and objectives related to submitting an application to the Nuclear Regulatory Commission for construction of the repository was very informative, as were your comments on what will be needed to begin repository operation in 2017. The Board also appreciated your participation throughout the meeting and hopes that you found the technical exchanges useful.

The Board believes that the information presented by OCRWM at the meeting may indicate an evolving understanding of the importance of a safety case in building confidence in the Department of Energy's estimates of repository performance. However, the presentations also made clear that work remains to be done in developing key elements of a comprehensive safety case. To be credible and effective in supporting the safety case, each element requires conceptual clarity and strong programmatic commitment. Preclosure operations can have significant implications for postclosure performance; therefore, the integration of preclosure activities with postclosure issues, such as repository design and thermal management, requires careful consideration. Some observations on OCRWM's safety case follow.

Key Elements of the Safety Case

An effective safety case should include a total system performance assessment (TSPA) supplemented by additional lines of evidence and argument, including performance-margin analyses, natural analogs, and a well-thought-out performance-confirmation plan.

- TSPA provides quantitative estimates of repository performance that are the core of the safety case. It is the primary tool for analyzing coupled interactions among multiple barriers that affect radionuclide transport, including the engineered barrier system, the unsaturated

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zone, and the saturated zone. To increase confidence in repository performance estimates, TSPA should include consideration of all credible and consequential phenomena that significantly affect dose over the period of regulatory compliance. Given the importance of TSPA, the Board is especially interested in the results of new repository system performance assessments and how they affect the repository safety case.

- Assessing the realism of TSPA performance estimates can be challenging because some assumptions may be very conservative while others may be nonconservative. The performance-margin analyses identified at the meeting can be very valuable in assessing the magnitude and effects of conservative and nonconservative aspects of TSPA.
- Natural analogs of many relevant repository phenomena can be used to challenge and evaluate conceptual and numerical models. Analogs that have existed for periods of time commensurate with the regulatory compliance period proposed for the repository provide excellent cases for testing prevailing conceptual and numerical models of radionuclide transport and isolation.
- The purpose of performance confirmation is to critically evaluate analyses and assumptions underlying performance estimates. Thus, the performance-confirmation plan should identify in detail what elements of the performance assessment are to be evaluated, how the elements will be tested or monitored, how information from testing and monitoring will be evaluated, what actions will occur as a result of those evaluations, and how frequently such evaluations will occur.
- Repository design and preclosure operations have significant implications for post-closure repository performance. How decisions related to preclosure operations have been integrated into the postclosure safety case is unclear.

Science and Technology

Over the course of repository licensing, construction, and operation, there will be important opportunities for continuous learning and improvement in scientific and technical areas. For example, as pointed out by your staff, prediction of coupled thermal, hydrological, mechanical, and chemical processes poses significant scientific and technical challenges. Together, these phenomena are the environmental controls on waste package and waste form degradation. Thus, they are significant for radionuclide isolation and migration and for dose levels. Investigations currently supported by the science and technology program have the potential over the long term to improve fundamental understanding in key areas and consequently to improve understanding of the repository's ability to isolate radionuclides. It is important that support for investigations sponsored by the Science, Technology and Management group is sustained and that formal links are established between these efforts and performance-confirmation planning. At the meeting, contractor staff identified a long-term science program, which also can help further the goal of continuous learning and improvement.

Engineering Prototyping

As mentioned at the meeting, the efficacy of engineering designs—including operational processes—can be tested using prototyping. This is especially important in the case of the Yucca Mountain repository because many of the engineered elements are first-of-a-kind designs.

Examples of specific elements that could benefit from engineering prototyping include waste package fabrication, loading, sealing, and emplacement; robotics; and drip-shield emplacement. Experience gained from engineering prototyping will enable OCRWM to identify potentially high-consequence design and operational flaws in an orderly and efficient manner. For example, contemporary industrial experience has shown that metal fabrication defects can be susceptible to localized corrosion. This has important implications for performance of the repository waste packages. Many engineering design specifications are important to TSPA calculations. Consequently, engineering prototyping can serve as an integrating mechanism and a cross-check for TSPA. Finally, engineering prototyping can be helpful as the repository program moves its focus from research and analysis to implementation.

Thank you again for participating in the Board's meeting on the repository safety case. We look forward to additional interactions with you and your Yucca Mountain Project team on this important topic.

Sincerely,

{Signed by B. John Garrick}

B. John Garrick
Chairman

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

January 12, 2007

Mr. Edward F. Sproat III
Director, Office of Civilian Radioactive Waste Management
U. S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Sproat:

The U. S. Nuclear Waste Technical Review Board's (Board) Panel on the Engineered System conducted a public Workshop on Localized Corrosion of Alloy 22 on September 25-26, 2006, in Las Vegas. Workshop participants included employees and contractors of the Department of Energy, the Nuclear Regulatory Commission, the Center for Nuclear Waste Regulatory Analyses, the Electric Power Research Institute, Nye County, and the State of Nevada. Three Board members, a Board contractor, and I participated in the entire workshop, and three other Board members attended part or all of the workshop.

Following the workshop, Dr. Ronald Latanision and Dr. David Duquette, the two Board members who co-facilitated the workshop, assembled their comments on the issue of screening out deliquescence-induced localized corrosion. Those comments, with which the Board concurs, are attached. As is evident from the attached comments, significant uncertainties in evolution of environments and of corrosion behavior at high temperatures persist, and there are apparent contradictions among some experimental results. Continuing research in deliquescence-induced localized corrosion is clearly warranted.

Unlike deliquescence-induced localized corrosion, which the Project plans to screen out of the total system performance assessment (TSPA), seepage-induced localized corrosion is not screened out of TSPA. Why seepage-induced localized corrosion and deliquescence-induced localized corrosion are not treated consistently in TSPA remains puzzling to us. The important question is, "Does including deliquescence-induced localized corrosion significantly affect the dose received by the reasonably maximally exposed individual?" Even if the effect is not significant, including this phenomenon would add to the completeness, robustness, and credibility of TSPA.

Sincerely,

{Signed By}

B. John Garrick
Chairman

Attachment

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SCREENING OUT DELIQUESCENCE-INDUCED LOCALIZED CORROSION
Comments Based on Information Conveyed at the Board's
September 25-26, 2006, Workshop on Localized Corrosion of Alloy 22

Background

Individuals with a wide range of expertise participated in the workshop to help address the issue of localized corrosion of Alloy 22. Unfortunately, a definitive consensus about whether localized corrosion would occur at waste package crevices did not emerge. The majority of the workshop dealt with the possibility of accumulated dust functioning as a crevice and causing localized corrosion. Considerable data were presented but there was no general agreement on a number of the key issues. Those attending the workshop seemed to have a genuine interest in evaluating the feasibility of the Yucca Mountain waste package design.

As we are all aware, DOE has screened out deliquescence-induced localized corrosion of the waste package's Alloy-22 outer barrier in the repository environment at temperatures to ~200°C. DOE's screening-out approach is based on a decision-tree or events-tree analysis consisting of the following questions [BSC 2005]:

1. Can multiple salt deliquescent brines form at elevated temperatures?
2. If deliquescent brines form at an elevated temperature, will they persist?
3. If deliquescent brines persist, will they be corrosive?
4. If deliquescent brines are potentially corrosive, will they initiate localized corrosion?
5. Once initiated, would localized corrosion penetrate the waste package outer barrier?

According to DOE, if the answer to *any* of these questions is NO, then localized corrosion of the waste package's outer barrier due to deliquescence can be screened out, i.e., excluded from consideration in the total system performance assessment for license application (TSPA-LA).

We agree that DOE's approach is reasonable.

The Board has conducted public meetings on deliquescence-induced localized corrosion twice. The first meeting, which was part of a May 2004 meeting of the Board in Washington, D. C., was on the topic of localized corrosion caused by deliquescence of inorganic divalent chloride compounds, e.g., calcium chloride. On the basis in large part of information conveyed at that meeting, the Board concluded that significant amounts of calcium chloride were unlikely to accumulate on waste package surfaces during the

preclosure period and therefore, that significant corrosion during the subsequent thermal pulse due to corrosive calcium-chloride-rich brines formed by the deliquescence of calcium chloride would be unlikely [NWTRB 2004]. In that case, then, the answer to the first question was NO, so there was no need to address the next questions.

The second public meeting was a day-and-a-half corrosion workshop held on September 25-26, 2006, in Las Vegas, Nevada. The workshop focused on deliquescence-based localized corrosion of Alloy 22 at high temperatures. The issue arose because of the determination made by DOE that salt mixtures containing sodium and potassium nitrates and chlorides would deliquesce at atmospheric pressure at temperatures up to and exceeding 200°C, even in the low-relative-humidity environments likely to be present in a repository in Yucca Mountain during the thermal pulse [DOE 2004]. Unlike calcium chloride, these salts are likely to be present in the dusts deposited on waste package surfaces during the preclosure period. The workshop was held because the Board had expressed its opinion, in December 2005, that the technical information available at that time did not seem sufficiently compelling to support screening out deliquescence-based localized corrosion [NWTRB 2005a]. The Board's opinion was based on the lack of corrosion data above 150°C and the questionable relevance of corrosion-stifling data taken at significantly lower temperatures to corrosion at higher temperatures.

Workshop Observations

Workshop participants seemed to agree that the answer to the first question was YES. There was less consensus on the other questions, particularly the last two.

DOE's and EPRI's positions are that the answers to the final two questions are NO. Their positions appear to rely on the role of nitrates both in the deliquescence process and in mitigating corrosion, based on the following observations/assumptions:

1. The chemical environment that may exist on the package surfaces is a solution of a multisalt assemblage containing NaCl, $NaNO_3$, KNO_3 and $Ca(NO_3)_2$ [Bryan 2006]. These salts are found in small amounts in airborne dusts in the Yucca Mountain vicinity.

2. Any stable chloride-containing brines formed by deliquescence at high temperatures must have significant fractions of nitrates [Rebak 2006].

3. Brines formed by deliquescence at high temperatures may change with time, e.g., by degassing HCl or HNO_3 [Bryan 2006; King 2006]. Degassing may result in a decrease in the amount of brine, an increase in pH, and an increase in the nitrate-to-chloride ratio.

4. Only limited amounts of salt and brine are available to initiate corrosion. Calculations indicate that the upper bound of brine volume in the dust deposited on waste package surfaces can be only 1.8 $\mu L/cm^2$, resulting in a brine layer ~18μm thick, assuming no geometric isolation due to inert dust

particles. (Note that these calculations are for 120°C; volumes should be less at higher temperatures). DOE claims that much of the brine would be held in the dust by capillary forces and that rapid mass transport in the dust would hinder establishing chemical gradients. DOE believes that these effects, coupled with the small volume of aggressive brine, would prevent initiation of localized corrosion [Brown 2006].

5. If corrosion does initiate, progression of corrosion will be stifled because of (a) obedience to a power law corrosion rate for localized corrosion propagation, with the time exponent in the power law being 0.5 or less; (b) physical retention of brine in the corrosion products; and (c) chemical sequestration of brine components in the corrosion products [Brown 2006].

Several possibly conflicting, or at least confusing, data sets and opinions were presented during the corrosion workshop. Among these were the following:

Localized corrosion of Alloy 22 was reported in Na-K-Cl-NO_3 brines at 160°C and at 220°C. NO_3/Cl ratios of 7.4 and NO_3 concentrations as high as 18.5 molal were not sufficient to inhibit localized-corrosion initiation [Rebak 2006].

Alloy 22 general corrosion rates on the order of 1 μm/yr and as high as 10 μm/yr were reported in Na-K-Cl-NO_3 brines at 150 – 180°C. However no localized corrosion was observed in these studies [Yang 2006].

Contrary to the apparent implicit assumptions of many workshop attendees that conditions on waste package surfaces during the decline of the thermal pulse evolve slowly and are in thermodynamic equilibrium, corrosion environments may be cyclic because of changes in barometric pressure and differential condensation/evaporation due to temperature-difference-driven gas flows along the drift [Walton 2006].

EPRI presented an analysis that raises questions about whether any nitrate-containing salts would be present in airborne dusts in the vicinity of Yucca Mountain [Arthur 2006; King 2006]. (If no nitrate salts are present, deliquescence would not occur at high temperatures, and the answer to the first question would be NO.)

Although degassing of Na-K-Cl-NO_3 brines can be made to occur under certain laboratory conditions, the range of temperatures within which degassing would occur *under conditions that would pertain in a Yucca Mountain repository* is unclear. Rates of degassing are highly uncertain, and it is not known whether HCl or HNO_3 preferentially degasses. Degassing was observed in one set of experiments [Yang 2006], but not in another set [Rard 2006].

Initial salt concentrations will not support localized corrosion, because high concentrations of nitrates will effectively displace HCl in crevices [King 2006]. HNO_3 is a passivator and will inhibit localized corrosion.

If localized corrosion is initiated, the deepest penetration that will occur will be only on the order of 5 mm after 200 years, assuming diffusive limitation of mass transfer that result in a power-law growth rate with an idealized exponent of 0.5. Experimental results suggest a power-law exponent closer to 0.1, resulting in wall penetration of less than 1 mm in 2,000 years [King 2006].

Apparent stifling of crevice corrosion propagation was reported in 5M NaCl/2x10^{-4}M $CuCl_2$ solutions, at 95°C [He 2006].

Stifling of localized corrosion will occur because of cathode current capacity, electrolyte resistance, and incompatibility of anode/cathode coupling [Payer/Kelly 2006].

Crevice corrosion was shown to arrest in 4M NaCl solutions at 100°C [Payer/ Kelly 2006].

Discussion

That there are considerable differences of opinion related to the interpretation of experiments conducted to date is obvious. For example, the apparent contradiction in results of localized vs. general corrosion reported by Rebak and Yang was explained by differences in experimental techniques. The experiments presented by Rebak were conducted in autoclaves where acid gases were allowed to reflux, while Yang's experiments were conducted under environmental conditions where gaseous species were allowed to evolve (degas) and were captured in a condenser. The condenser solutions became acidic with time, indicating evolution of acid gases. Few of the experiments that were conducted were performed in environments expected to be found in the repository. For example, the He and Payer/Kelly experiments were conducted in chlorides alone (no nitrates) and at temperatures well below anticipated surface temperatures of the waste packages. Nevertheless, it is possible to address the possibility of screening out localized corrosion during the thermal pulse, based on reasonable interpretations on scientific and engineering results obtained to date, with the *caveat* that experiments and tests currently under way may provide new evidence that will further advance the state of knowledge of the repository environment and its potential effects on the waste packages.

For discussing the possibility of initiating and propagating localized corrosion on waste packages in a repository environment, understanding the current state of the art for the initiation and propagation of localized corrosion in aqueous chloride solutions is important. Passivity on metals and alloys is effected by maintaining an oxidizing potential on the metal or alloy surface. In most engineering situations the oxidizing species is oxygen, dissolved in the aqueous solution from air in contact with the solution. However, in many engineering applications, the oxidizing potential is supplemented by the addition of strong oxidizers, such as nitrates, molybdates, and tungstates. The function of the oxidizing species is to establish a thin, oxygen-rich protective film on the surface and to repair the film if it is chemically or mechanically damaged. When crevices are present on passive metal surfaces, the interior of the crevice becomes depleted in the

oxidizer, and the limited diffusion path for admitting more oxidizer establishes a differential oxidation cell. The differential oxidation cell establishes a large surface for reduction of the oxidizer on the passive surface outside of the crevice. The inside of the crevice, depleted of the oxidizer, becomes reducing, resulting in a large cathode (the area outside of the crevice) coupled to a small anode (the area inside of the crevice). Corrosion at the anode accelerates because of the large cathode/anode surface area ratio, which results in the rapid solubilizing of metal ions at the anode.

Initially, the solution in the crevice exhibits approximately the same pH as that outside of the crevice, but metal cations resulting from corrosion in the crevice combine readily with water, and hydrolysis takes place forming hydrated metal hydroxides and hydronium ions, which causes the solution in the crevice to become highly acidic. Thus, a gradient in charge concentration is established between the anode and the cathode. The charge imbalance can be accommodated by the diffusion of negative ions into the crevice. Anions in solution at relatively high concentrations will tend to migrate into the crevice because of conventional concentration gradient considerations. If the anions in the external solution are Cl^-, the solution in the crevice will become a concentrated HCl solution. It is well known that HCl is a strongly reducing acid that will dissolve passive films.

In nickel-based alloys, such as the Ni-Cr alloys, there is a further complication that the solutions in the crevice eventually become saturated in metal chlorides. At room temperature, the pH of a saturated $NiCl_2$ solution is 2.7 and that of a saturated $CrCl_3$ solution is -1.4. The crevice-corrosion process then is considered to be autocatalytic in that, while the large cathode-to-small anode couple may be maintained, the solution inside the crevice is sufficiently aggressive that it need not be maintained to support corrosion. The only limiting factor to crevice-corrosion crack growth becomes the continuous supply of Cl^- to maintain the reducing acid inside the crevice. Under laboratory conditions where the crevices are purposefully tightly clamped and times are relatively short, diffusion of chloride into the crevice may be curtailed as the crevice propagates, precipitation of solid corrosion products may occur near the mouth of the crevice where the solution attempts to return to neutrality, and the crevice may effectively be "stifled." In practice, however, the crevice-corrosion propagation rate may slow down until the interior of the crevice can be replenished in chloride, to form HCl and allow the reaction to continue. Crevice corrosion seldom is observed to be stifled under industrial conditions. If it were, crevice corrosion would not be a particular problem for practical applications.

Under repository conditions, where the times will be exceptionally long, it is doubtful that any crevice corrosion that might occur because of chlorides would be stifled because of diffusion considerations. Laboratory studies such as those conducted by He and by Scully [Scully/Bocher 2007][1] do not appropriately model a chloride-induced crevice condition since they are performed with concentrated chloride solutions, often with low pHs. Thus, no appreciable concentration gradients are established.

[1] See page 34 of Joe Payer and Rob Kelly's workshop presentation [Payer/Kelly 2006].

In general, crevice corrosion tests performed in a laboratory are highly useful in determining if crevice corrosion is likely to occur for an environment-alloy couple, assuming that the service environment can be reasonably simulated. Laboratory tests to determine propagation morphology or rates are less useful because of variabilities in crevice geometries, crevice-forming devices, and time constraints. For example, in tests performed specifically for the Yucca Mountain project, just changing the crevice former from a ceramic to PTFE had major consequences in the crevice-corrosion attack observed in simulated repository environments [Payer/Kelly 2006]. Accordingly, the use of laboratory experiments, or exposure tests, to screen out localized corrosion propagation — or even localized corrosion initiation — due to deliquescent salts is highly questionable.

On the other hand, a consideration of the environments likely to be present in the repository suggests that crevice corrosion due to deliquescent salts during the thermal pulse may allow the phenomenon to be screened out under the following circumstances :

1. Concentrated chloride/nitrate brines have been postulated to degas both HCl and HNO_3 in the open repository environment, and at least one laboratory test confirmed volatility of some acid species [Yang 2006].[2] Assuming degassing and subsequent volatilization, the questions become (a) the rates of degassing and volatilization and (b) which of the two acids degasses/volatilizes more rapidly. If EPRI is correct in that both acids are highly volatile, the salts in the repository may very well be dominated by sulfates and carbonates, and brines either would not form during the thermal pulse or would be essentially benign. If HNO_3 is more volatile, the result would be a concentration of acid chlorides on the waste package surfaces, which would be detrimental. However, if HCl is more volatile, waste package surfaces will become more concentrated in nitrates, and initiation and propagation of localized corrosion due to deliquescence at high temperatures likely would be mitigated.

2. Aqueous nitrates apparently have a higher transfer rate than chlorides [King 2006]. This is an important observation because the charge imbalance in the crevice must be neutralized by the migration of some ion into the crevice. If nitrate exists in concentrations in excess of 1:1, and if it in fact has a higher transference number, the charge neutrality will be achieved by nitrate migration, resulting in a passivating environment in the crevice. Proof of this concept must await an analysis of the crevice chemistry from corrosion tests performed in appropriate environments at appropriate temperatures.

3. It has been postulated that nitrates are effective inhibitors at $[NO_3^-]$:$[Cl^-]$ ratios as low as 0.5 at temperatures as high as 200°C [King 2006].

[2] The experiments presented at the workshop by Yang were not at Yucca Mountain conditions. For example, it appeared that the activity of water was higher than would be expected in deliquescent brines. Higher water activity could lead to increased degassing.

4. Individual dust particles may be too small to support crevices, or the dust layer may be permeable to oxygen [King 2006]. Crevices at manufacturing defects and mechanical design features are likely to function very differently than a layer of accumulated dust. At this time, however, no quantitative data have been presented to the Board on the size or shape of the dust particles or on the permeability of dust layers that would deposit on waste-package surfaces.

5. Insufficient liquid water may be present to provide a continuous water film under dust particles, because much of the water will reside in interstices between the dust particles [Bryan 2006].

6. For the environments postulated for the repository, with acid degassing, the evolution of the relative humidity in the repository is such that the package will not be wet until temperatures have declined to the vicinity of 100–120°C — when deliquescence-induced crevice corrosion may be unlikely [King 2006].

Conclusions

If any of the conditions cited in 1–6 are met, crevice corrosion due to deliquescence during the thermal pulse period could be screened out. Of each of these six scenarios, preferential charge neutralization by nitrate in the crevice is perhaps the most important, because the nitrate will be an effective inhibitor inside any crevices that are formed, at least for temperatures up to ~160°C.

The Board understands that the chemistry of the crevice environment is currently under study. Demonstrating an adequate technical basis for screening out deliquescence-based localized corrosion during the thermal pulse requires (a) determining the nitrate-to-chloride ratios that are inhibitive for the entire range of temperatures that deliquescent brines may occur on waste package surfaces and (b) confirming the hypothesis that the preferential migration of nitrate ions into the crevice is sufficient to maintain nitrate-to-chloride ratios that are inhibitive.

Although deliquescence can occur at any temperature below about 200ºC, our concern about deliquescence-induced localized corrosion is principally in the higher part of the temperature range, i.e., 150-200ºC. On the other hand, seepage-based corrosion may not occur above approximately 100ºC. Conceivably, deliquescence-based localized corrosion could occur on a waste package and then be followed by seepage-based localized corrosion at the same place on the package later during the thermal decline. Any damage caused by deliquescence-induced localized corrosion could result in earlier penetration by subsequent seepage-based corrosion than would occur in the absence of deliquescence-induced localized corrosion. Cumulative damage due to the combined effects of deliquescence-induced and seepage-based localized corrosion was not discussed at the workshop. However, the topic merits some analysis to determine its possible significance.

As things stand now, seepage-based localized corrosion is included in TSPA and deliquescence-induced localized corrosion is excluded. This always has struck us as incongruous because the processes are the same and particularly because the temperature range of concern about deliquescence-based localized corrosion is higher. We wonder whether the same degree of conservatism that is being applied to "screen out" deliquescence-induced localized corrosion is being applied to "screen in" seepage-based corrosion.

Additional Observations

The topic of general corrosion arose during the workshop in conjunction with experiments to obtain information about localized corrosion. Localized corrosion was observed in the LLNL autoclave experiments [Rebak 2006], so general corrosion would be expected to occur, also. However, no useful data on general corrosion could be obtained from those experiments. In contrast, localized corrosion seemed not to occur in CNWRA experimental results obtained under somewhat similar conditions [Yang 2006], but general corrosion was observed. The rates of general corrosion rates derived from that data were unexpectedly high and showed a maximum with respect to temperature, which also is unexpected. These anomalies require explanation. In any case, particularly since the proposed regulations for Yucca Mountain [70FR173, pp 53313-53320] require general corrosion to be modeled in TSPA, deliquescence-based general corrosion should be included in such modeling.

Mill-annealed and welded specimens prepared for the experiments discussed at the workshop generally were polished to a uniform surface finish before being placed in the experimental apparatus. The polishing step is useful for helping compare results within a laboratory or among laboratories. However, the actual waste packages emplaced in a repository will have been treated to remove the scale caused by heat treating by, e.g., blasting with abrasive particles or electropolishing, and will have scratches, dents, etc. from handling. Although some experimental investigation of the effects of surface condition on Alloy 22 corrosion has been undertaken, we are not sure that the effects have been investigated adequately. The discussion of the effect of surface condition on corrosion in the Alloy 22 corrosion AMR [BSC 2004], for example, is brief and is limited to the effect of surface condition on crevice corrosion.

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Department of Energy
Washington, DC 20585

QA: N/A

November 20, 2007

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

Dear Dr. Garrick:

In a letter dated January 12, 2007, the Nuclear Waste Technical Review Board (Board) provided a summary of its observations regarding the Workshop on Localized Corrosion of Alloy 22, held on September 25-26, 2006. The breadth of opinions and supporting data shared at the workshop and in the Board's letter are instrumental in assuring a thorough assessment of the likelihood of localized corrosion under deliquescent conditions. A follow-on letter regarding the effects of organic materials on nitrate/chloride ratios was transmitted on July 10, 2007.

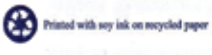
The enclosure to this letter provides discussion of five key areas identified by the Board, in its January letter, as issues associated with the treatment of localized corrosion under deliquescent conditions, and the issue of effects of organic materials as described in the July letter.

We look forward to continuing this dialogue with future technical exchanges. If you have any questions concerning this letter, please contact Claudia M. Newbury at (702) 794-1361.

Sincerely,

Edward F. Sproat, III, Director
Office of Civilian Radioactive
Waste Management

Enclosure



Enclosure

U.S. DEPARTMENT OF ENERGY RESPONSE TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD'S COMMENTS FROM THE SEPTEMBER 25-26, 2006 WORKSHOP

The following five topical discussions refer to comments received from the Nuclear Waste Technical Review Board (Board) on January 12, 2007:

(1) why seepage-induced localized corrosion and deliquescence-induced localized corrosion are treated differently,
(2) the U.S. Department of Energy (Department) perspectives on the study of the six circumstances identified by the Board for screening localized corrosion due to deliquescence,
(3) the impact of cumulative damage of deliquescence-induced and seepage-based localized corrosion,
(4) inclusion of deliquescence-based general corrosion in the modeling, and
(5) experimental investigation of the effects of surface condition on Alloy 22 corrosion.

The last topic of discussion, the effect of organics on nitrate to chloride ratios, is in response to additional comments received on July 10, 2007.

Why Localized Corrosion is Treated Differently under Seepage and Deliquescent Conditions

The Board points out that different approaches are used to address the potential for corrosion under seepage and deliquescent conditions. The Department concurs with this observation, but has determined that two separate analyses are warranted - and needed - due to the underlying differences presented by these two types of environments. These differences can be categorized as (1) differences in physical environment and (2) differences in the composition of the electrolyte and differences in uncertainty of the composition of the electrolyte.

Although the probability of seepage contacting a waste package is low during the period when the waste packages are still at elevated temperature, if dripping water does contact the waste package, the local environment may have characteristics of an inundated system. In such a case, a local corrosion site will be able to draw cathodic current from the surrounding material defined by the wetted area and conductivity of the electrolyte. Additionally, if dripping continues in the same location, a continuous supply of chloride and other ions is available to participate in electrochemical reactions. In the case of a deliquescent environment, the volume of electrolyte is predicted to be very small, thus communication between a corrosion site and the surrounding material will be severely limited in comparison to the seepage condition. The more critical difference, however, is the limited amount of reactants available in the deliquescent case. The makeup and quantity of solid components of the dust layer are nominally determined by the duration of the ventilation period and the composition of the repository air during this time. Once the waste package reaches a temperature-relative humidity condition where deliquescence is possible, the total available quantity of reactants (mass per unit area) is fixed and does not increase. Any corrosion process that results in consumption of aggressive species will be limited

by the initial quantity of reactants and brine volume. The deliquescent environment differs from the seepage environment as limitations on reactants are not as well defined in the seepage case. Consequently, the corrosion model under seepage conditions does not take credit for this damage-limiting mechanism.

A significant difference also exists in the range of possible compositions for seepage environments compared to deliquescent environments. The seepage environment can contain a wide range of dissolved salts; and the final composition will be determined by the initial seepage waters, the effect of salt separation, and the degassing behavior of the system. A high degree of uncertainty dominates the prediction of any particular environment for a specific time and location in the repository. The Department's analysis of the deliquescent environment concludes that this environment is comprised of $NaCl + KCl + NaNO_3 + KNO_3$ (Bryan 2006). The composition of deliquescent environments is bounded because for each temperature-humidity condition there is a minimum NO_3:Cl ratio required for deliquescence (Rebak 2006). Any liquid with a lower NO_3:Cl ratio will evaporate and concentrate to maintain the minimum ratio. In the case of salt degassing, either the Cl salts degas more rapidly resulting in a higher NO_3:Cl ratio or the NO_3 salts degas more rapidly resulting in evaporation and concentration. The implication is that the environments associated with deliquescent salt mixtures are constrained while those associated with seepage are much more uncertain. This difference in level of uncertainty justifies treating the two environmental conditions with different corrosion modeling approaches.

Study of Six Circumstances for Screening Localized Corrosion Due to Deliquescence

The Department appreciates the Board's suggestions for potential areas of discovery and analysis that can improve the confidence in the decision to screen out localized corrosion under deliquescent conditions. The Department recognizes that there are a number of approaches to reaching this goal and that an open discussion of the available alternatives will aid in building consensus within the scientific community. Although the Department may or may not pursue a particular line of investigation, the discussion of these strategies helps to identify and clarify the important issues.

1. Degassing of HCl and HNO_3 - The Board suggested two possible paths for the evolution of the deliquescent brine environment based on the relative rates of acid degassing. If HCl can be shown to degas more rapidly than HNO_3 then the brine composition will evolve to a high-pH, nitrate rich composition, and localized corrosion will be mitigated. The Board postulates that if HNO_3 degasses more rapidly then the resulting environment will contain a high concentration of acid chlorides, an aggressive condition.

The EQ3/6 calculations in the dust deliquescence feature, event, or process (FEP) screening report (BSC 2006) suggest that HCl degasses more readily than HNO_3. These calculations are based on thermodynamic data in the Yucca Mountain Project Pitzer database, from Barin and Platzki (Barin 1995), a widely used compilation of thermodynamic data. An examination of the log(K)-temperature grids shows that HCl is predicted to degas more readily than HNO_3 over the entire temperature range from 25°C-300°C. Experimental results have been observed that both agree and disagree with this analysis. The formation constants of HCl(g) and HNO_3(g) were measured at Oak Ridge National Laboratory (ORNL) with the results agreeing with the analysis

in the dust deliquescence FEP screening report (BSC 2006). This work yielded a relative ranking of volatility (decreasing) (Cole 2006):

$$HF >> HCL > HNO_3 >> H_2SO_4$$

However, other work at ORNL, which was conducted under the Office of Science and Technology and International Program, indicated that HNO_3 degassed more rapidly than HCl. This result was based on monitoring the gas composition that formed from heating a 0.4-mol/kg ionic strength solution of approximately equimolal nitrate, chloride, and sulfate.

Regardless of whether HCl or HNO_3 degasses more rapidly, the effect of degassing will be a beneficial rise in pH resulting in less corrosive brines. Additionally, it has been shown (Rebak 2006) that deliquescent brines have a minimum NO_3 to Cl ratio that is temperature-dependent. Brines that would have a more aggressive composition will evaporate and concentrate, leaving smaller volumes of brine that maintain the minimum NO_3 to Cl ratio. In the limiting case of complete loss of HNO_3 or HCl, the remaining brine is likely to dry out, leading to an environment on the waste package surface that cannot support electrochemical reactions.

While the Department agrees with the Board that an increased understanding of the absolute and relative degassing rates of HCl and HNO_3 would aid in improving confidence in screening out localized corrosion due to dust deliquescence, the current understanding is adequate for the analysis.

2. Transference Rate of Nitrate and Chloride - The Board references the Electric Power Research Institute (EPRI) presentation (King 2006) with respect to the relative transference rates within a brine of nitrates compared to chlorides. The postulate is that a higher transference rate for nitrate will result in an increase in nitrate to chloride ratio in a crevice. Such a process would result in maintenance of a passive environment. If it can be conclusively demonstrated, such a process could add confidence to the screening justification. However, the Department is not in possession of data that unequivocally support this mechanism. The mobility of Cl^- is slightly higher than that of NO_3^- at room temperature in dilute solutions, but they are close enough to be considered equivalent for a qualitative discussion. Taking the mobilities as equal, the transference numbers will be a function of the concentrations in solution. If the nitrate to chloride ratio is high in solution, it follows that the charge carried will be greater for nitrate than chloride and a high ratio will be maintained in the crevice chemistry. However, no data were presented at the September 2006 workshop that allows quantification of mobilities in concentrated, high temperature brines. In the absence of these data, the prediction of relative concentrations of species in the crevice remains speculative. For this reason, the Department does not rely on a relative transference number justification for supporting the decision to screen out localized corrosion due to dust deliquescence.

3. Inhibition by Nitrates at Elevated Temperature - The presentation from EPRI (King 2006) includes a plot of critical temperature versus nitrate to chloride ratio which shows the critical temperature to be in excess of 200°C for a nitrate to chloride ratio of 0.5. The Department's data from cyclic polarization experiments (Rebak 2006) show a beneficial effect from NO_3^- at temperatures up to 150°C. The Department concurs that validating the beneficial impact of NO_3^- at elevated temperatures could strengthen the screening justification.

4. Properties of the Dust Layer that Impede the Formation of Localized Corrosion Cells - The Board makes an important distinction that crevices due to dust accumulation will differ significantly from those from manufacturing defects or design features. The size of dust particles that will be transported into the drifts is analyzed in the dust deliquescence FEP screening report (BSC 2006), and the case is made that annular droplets of brine beneath such small particles cannot support the diffusive chemical gradients necessary to initiate or sustain localized corrosion. The porosity of the dust is very high (50% or higher), which is an indicator that the permeability will be very high as well. There is insufficient salt in the dust for deliquescent brines to cause saturation so the dust environment is unsaturated and the gas phase should exchange readily.

5. Insufficient Liquid Water to Form a Continuous Water Film Under the Dust Particles – The Department concurs with the Board's assessment that it is likely there will be insufficient water to form a continuous water film under the dust particles. As was noted in the September 2006 workshop, the Department conservatively estimates the quantity of deliquescent brine at 120°C and applies this volume to higher temperatures where the quantity will be even less than the bounding estimate of an 1.8 $\mu L/cm^2$ (an 18 µm thick layer). Furthermore, much of this solution will be bound within the dust layer itself and within the resulting corrosion products (if any).

6. Limited Temperature Range for Deliquescent Environments Due to Acid Degassing – The Department concurs with the Board's assessment that should degassing result in dry-out of brines at higher temperature; deliquescence leading to localized corrosion would only be an operative mechanism at lower temperatures. However, the data presented at the September 2006 workshop and discussed in this letter do not provide conclusive evidence that the rates or extent of brine degassing is known for the environments relevant to the repository. Should conclusive data become accessible, the Department will use this information to strengthen the justification for screening out localized corrosion under deliquescent conditions.

Impact of Cumulative Damage of Deliquescence-Induced and Seepage-Based Localized Corrosion

The Board raises the issue of the impact of coupling corrosion under deliquescent conditions with corrosion under seepage conditions. This is an important issue to consider irrespective of the result of the analysis. The three main concerns are (1) the possibility that deliquescence-induced corrosion lowers the barrier for localized corrosion under seepage conditions, (2) that a residual chemical effect results from the deliquescent environment, and (3) that the barrier capability for corrosion resistance has been reduced resulting in overestimation for the time until penetration under seepage conditions. The Department's position is that none of these concerns will impact the performance of the engineered barrier for the following reasons:

The most probable mechanism for corrosion under deliquescent conditions to lower the barrier for initiation of localized corrosion is by forming a repassivated oxide that has less resistant properties than the native oxide. However, although a repassivated oxide might be less resistant than an air-formed oxide, the model for localized corrosion initiation used in the Total System Performance Assessment (TSPA) is not linked to the oxide properties or to oxide breakdown. The parameter used for prediction of localized corrosion under seepage conditions is the crevice

repassivation potential -- a parameter which is evaluated under experimental conditions (active crevice) where there is no metal oxide present.

The environment on the surface of the waste package in the post-deliquescent period will be determined by the composition of the seepage water that contacts the package. The mass per unit area of salt available from dust decorating the package surface is insignificant in comparison to the quantity of salts in the seepage waters. As the corrosion models assume an excess of available aqueous environment (data for the model are collected under fully immersed conditions), any increase in reactants available from the dust layer will be insignificant compared to the experimental conditions used.

In order to determine how degradation under deliquescent conditions contributes to decrease in barrier capability it is necessary to review how failure occurs for both localized corrosion and general corrosion in the modeling. In the case of localized corrosion, the TSPA assumes that after initiation, localized corrosion continues at an extremely rapid rate until failure of the waste package occurs. Thus, any additional change in the thickness of the material, due to generalized corrosion, will have an unnoticeable impact on when a package fails. Additionally, the available quantity of reactants is extremely limited such that the extent of any localized corrosion damage during the deliquescence period would be very small in magnitude compared to the dimensions of the barrier.

Inclusion of Deliquescence-Based General Corrosion in the Modeling

The Board makes the observation that general corrosion processes may be relevant under conditions of dust deliquescence. The same reasoning for limiting localized corrosion can be used to propose limits on the total extent of general corrosion possible under dust deliquescence environments. In the absence of a source of reactants, the corrosion processes (localized and uniform) will be bounded by the initial surface concentration of contaminants. Although by this reasoning, uniform corrosion will not significantly degrade the waste package under deliquescent conditions, the model for general corrosion is invoked during the entire repository lifetime.

The only data presented at the September 2006 workshop that suggests high corrosion rates are those from the Center for Nuclear Waste Regulatory Analyses (CNWRA) (Yang 2006). The Department does not have confidence that those experiments accurately reflect the environment expected in the repository during the thermal pulse. The difference in quantity of available reactants – extremely low in the case of the dust layer vs. essentially infinite in the case of the CNWRA test – calls into question the applicability of CNWRA's results in predicting degradation under deliquescent conditions.

The Department's model for general corrosion accumulates damage throughout the repository lifetime based on the general corrosion model which is applied for all repository conditions, including the thermal pulse where the maximum modeled corrosion rate at 200°C is on the order of 10 μm/year. In order for the barrier capacity to be reduced by deliquescence-induced corrosion beyond the extent already captured in the TSPA, the uniform corrosion rate under deliquescent conditions would need to be higher than that predicted from inundated experiments. As the quantity of reactants is severely limited under deliquescent conditions and essentially

infinite under inundated experimental conditions, the Department maintains that the current model implementation adequately accounts for this damage process.

Investigation of the Effects of Surface Condition on Alloy 22 Corrosion

With regards to surface condition, the Department considers its current models to be conservative and appropriate. Most of the samples used for model development include welds, while only a small portion of the waste package is welded. Furthermore, by using the Alloy 22 crevice data for weight loss, the model overestimates the expected corrosion rates because these samples were not polished on the backside resulting in an overestimate of the corrosion rates as compared to samples that were polished on both sides. However, the Department agrees that the effects of surface condition should be further studied and plans are under development for future testing of surface condition effects.

Effect of Organics on Nitrate To Chloride Ratios

Dust samples from the Drift Scale Test (DST) heated drift have been analyzed by the U.S. Geological Survey (USGS) both for bulk dust compositions and for leachate compositions for soluble components. These compositions show some differences from the dust samples collected within the Exploratory Studies Facility (ESF) outside of the DST heated drift. The DST dust sample leachate compositions show higher chloride to nitrate ratios than the ESF samples (and than samples of ambient surface dust). The DST dust appears to have accumulated in an environment heavily influenced by the local materials and relatively isolated from ambient dust, which is introduced into the ESF via active ventilation. There are a number of possible sources of chloride in the materials, for example, the concrete liner cement, but no currently identified sources of nitrate. Both the DST bulk dust compositions and the leachate compositions show variations related directly to whether they were in the concrete lined section or not. Given this, and the discussion below, it does not appear that the DST dusts ever had higher nitrate content than measured currently, and it does not appear that the thermal evolution caused a change to that content.

It does not appear at this time that the observed variation in chloride/nitrate ratio for these DST dusts was due to evolution of the salts during heating. Rather the variation is more likely due to the relatively isolated nature of the heated drift from the ventilation system for the ESF. That is, there does not appear to be a large, if any, contribution of the outside natural ambient dust within the DST dust samples. What is clear, as indicated in the Marshall and Peterman (2007 USGS) Goldschmidt meeting abstract, is that the DST dust samples contain constituents derived from the concrete liner (occupying the last 10 meters of the heated drift), as well as from the steels within the heated drift. Preliminary evaluation of the DST liner concrete (and the cement in it) indicates that the DST dust compositions lie on a mixing trend between the rocks of the Topopah Spring Welded hydrogeologic unit, the ESF tunnel dust, and the concrete liner. The DST dust contains a larger fraction, based on calcium and silica content, of cement/concrete compared to the ESF dust. Even within the DST dust, the variation in the concrete liner contributions can be seen by comparing the bulk composition of the dust sample in the unlined section and the composition of the two samples that were within the concrete lined section. Although this does not directly account for the chloride and nitrate contents in the soluble fractions of the DST dust,

it does establish that this environment was sufficiently isolated from the ESF itself to develop a locally derived composition. This is not surprising given that the ESF tunnel dust itself shows location dependent compositional variation.

A number of other specific materials may have contributed to the chloride, bromide, and fluoride contents that appear to be enriched in the soluble fraction of the DST dust relative to the mean ESF dust leachate composition. These include (a) the LiBr traced construction water used in the excavation of the heated drift and emplacement of ground support and (b) volatiles released from packer/gasket materials in the rock close to wing heater boreholes that achieved higher temperatures than the drift heaters. Given the additional materials in the DST, it is not a direct representation of the expected material environment within the emplacement drifts at post-closure. Because much of the nitrate within the dust expected to be in the post-closure emplacement environment would come from atmospheric dust pulled into the active ventilation stream and deposited on the waste packages over the 50-year ventilation period, the starting dust composition is expected to be different from that collected in the DST.

The Department appreciates the thought that has gone into the Board's suggestions for potential areas of discovery and analysis that can improve the confidence in the decision to screen out localized corrosion under deliquescent conditions. The Department recognizes that there are a number of approaches to reaching this goal and that an open discussion of the available alternatives will aid in building consensus within the scientific community. Although the Department may or may not pursue a particular line of investigation, the discussion of these strategies helps to identify and clarify the important issues.

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

February 13, 2007

The Honorable Samuel W. Bodman
Secretary
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Secretary Bodman:

The U.S. Nuclear Waste Technical Review Board held its first public meeting of 2007 on January 24 in Las Vegas, Nevada. At the meeting, senior managers from the Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) presented a series of updates on the status of the Yucca Mountain repository program. The Director of OCRWM, Edward Sproat, led the presentations with an overview of his management objectives for the program. An important part of the meeting was a presentation on newly configured surface facilities that take into account the potential implementation of the transportation, aging, and disposal canister concept.

On the basis of information presented at the meeting and the Board's ongoing technical and scientific review, the Board believes that the new OCRWM leadership is moving the technical aspects of the program positively toward achieving DOE's mission of safely disposing of spent nuclear fuel and high-level radioactive waste in a deep geological repository. We are encouraged by the greater responsiveness recently shown by OCRWM management to Board suggestions for ways to enhance the technical basis for DOE's repository performance estimates. The Board sees such enhancements as important in establishing a credible safety analysis and in engendering public confidence in DOE's technical work.

The Board also views sustained support of a viable science and technology (S&T) program as critical to strengthening basic knowledge associated with the safety analyses of repository design and operations. Thus, we are disappointed that DOE's fiscal year 2008 budget request for OCRWM proposes to eliminate funding for the S&T program and postpones activities carried out under the auspices of the program until FY 2009. Although the principal goals of the S&T program are long term in nature, information derived from S&T investigations already has increased confidence in the technical bases for aspects of the license application that OCRWM intends to submit in June 2008. The Board is concerned that large funding variations for the S&T program may make it difficult to attract and retain high-quality scientific and technical investigators.

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The Board urges DOE to continue assigning high priority to work on the repository. We realize that DOE must consider and perhaps accommodate new options for reducing the volume of spent fuel that will require disposal. However, any such option would still require a repository for disposing of nuclear waste. Delays in progress toward achieving the goal of developing a safe repository would be counterproductive, especially now that there are strong indications that OCRWM is working toward resolving outstanding issues in a focused way.

The Board looks forward to continuing its ongoing review of DOE's technical activities related to managing and disposing of spent nuclear fuel and high-level radioactive waste. We are pleased that Mr. Sproat has indicated his willingness to engage with the Board on key issues to ensure that DOE's technical basis for estimating repository performance is sound.

Sincerely,

{Signed by}

B. John Garrick
Chairman

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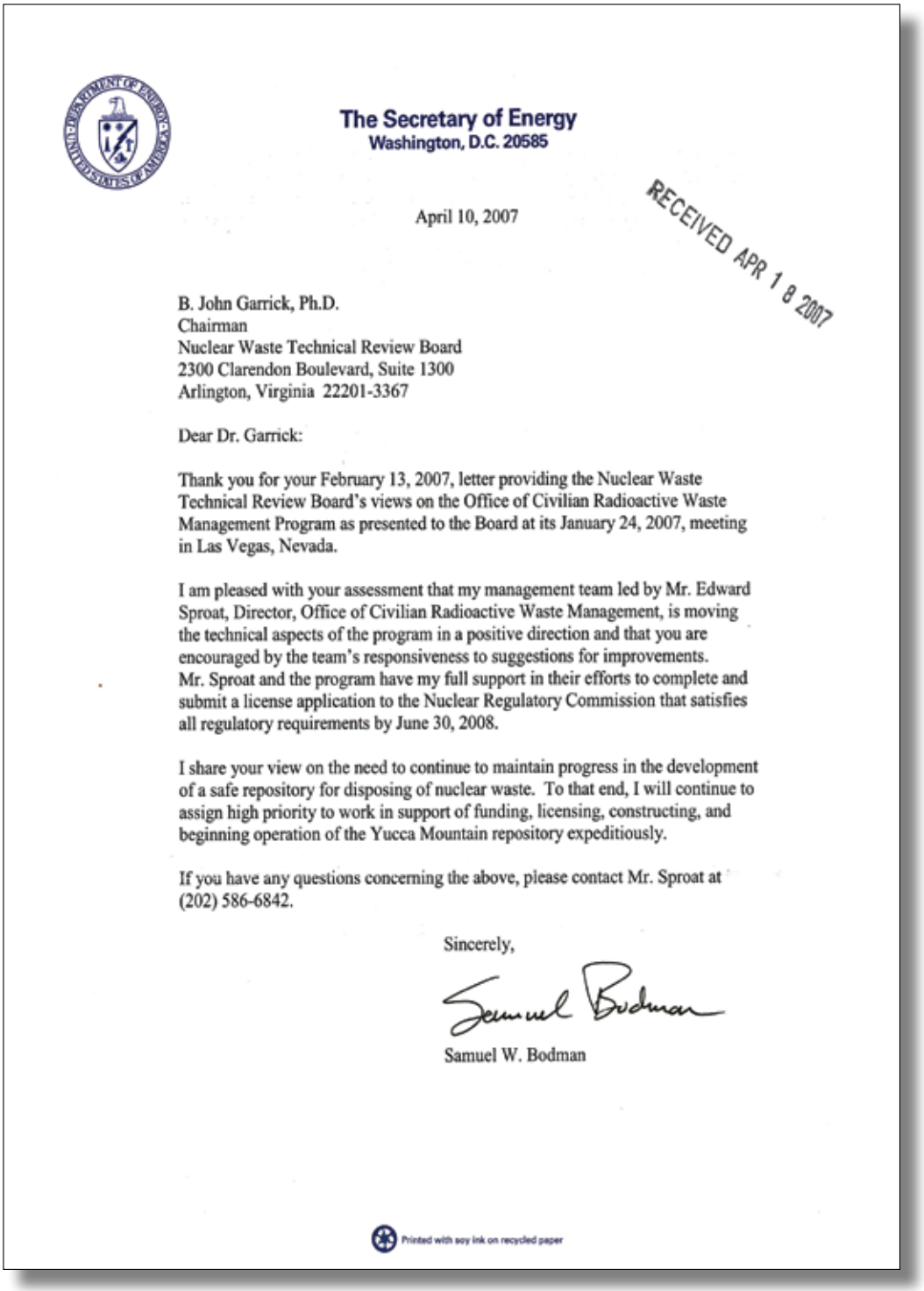

The Secretary of Energy
Washington, D.C. 20585

April 10, 2007

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B. John Garrick, Ph.D.
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, Virginia 22201-3367

Dear Dr. Garrick:

Thank you for your February 13, 2007, letter providing the Nuclear Waste Technical Review Board's views on the Office of Civilian Radioactive Waste Management Program as presented to the Board at its January 24, 2007, meeting in Las Vegas, Nevada.

I am pleased with your assessment that my management team led by Mr. Edward Sproat, Director, Office of Civilian Radioactive Waste Management, is moving the technical aspects of the program in a positive direction and that you are encouraged by the team's responsiveness to suggestions for improvements. Mr. Sproat and the program have my full support in their efforts to complete and submit a license application to the Nuclear Regulatory Commission that satisfies all regulatory requirements by June 30, 2008.

I share your view on the need to continue to maintain progress in the development of a safe repository for disposing of nuclear waste. To that end, I will continue to assign high priority to work in support of funding, licensing, constructing, and beginning operation of the Yucca Mountain repository expeditiously.

If you have any questions concerning the above, please contact Mr. Sproat at (202) 586-6842.

Sincerely,

Samuel W. Bodman

Printed with soy ink on recycled paper

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

April 19, 2007

Mr. Edward F. Sproat III
Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Sproat:

Thank you very much for participating in the U.S. Nuclear Waste Technical Review Board's meeting in Las Vegas, Nevada, on January 24, 2007. The Board appreciates the efforts of Office of Civilian Radioactive Waste Management (OCRWM) senior managers in presenting an overview of the Yucca Mountain Project. The Board believes that the Department of Energy's (DOE) proposed management initiatives — establishing a nuclear culture, initiating effective integration of preclosure and postclosure safety, and integrating the science and engineering programs — will enhance the technical basis of DOE's work at Yucca Mountain.

Your presentation made it clear that the Project's key milestones and issues are tied to the goal of submitting a license application (LA) by June 30, 2008. The Board recognizes your commitment to implementing initiatives that will help meet that objective and supports the Project's long-term emphasis on fostering intellectual continuity from repository licensing to closure. The Board also believes that the appointment of a director for the Office of Quality Assurance is a positive step. We look forward to hearing more about the Project's strategic licensing decisions and how those decisions will influence the repository design.

Waste Management System

It is clear from the waste management system (WMS) presentation that considerable progress has been made in designing repository surface facilities. The Board looks forward to continuing its review of the surface facility conceptual design. We are particularly interested in obtaining information on how the design will conform to preclosure safety requirements (i.e., the event sequences that require analysis and the implications for dose from those events).

The Board continues to believe that a "systems" analysis is needed to evaluate the interrelationships among diverse components of the WMS. The Total System Model can play a valuable role in analyzing the operational interdependencies of the WMS and the utility of the transportation, aging, and disposal (TAD) canister. Improvement is needed in developing a well-thought-out and clearly articulated thermal management strategy that forms the basis for integrating waste management activities. It is not clear, for example, how the Initial Handling Facility (IHF), used solely to handle canisterized high level waste and naval spent fuel fits into the Project's thermal-management strategy. In general, the role of the IHF needs to be explained

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more fully. The Board also believes that lessons learned from associated activities can be used to assess the interactions of WMS components. Accordingly, the Board is interested in hearing how experience gained from safety and facility maintenance in the Exploratory Studies Facility could be applied to subsurface repository design and operations.

The Board encourages DOE to evaluate surface-facility designs and operational concepts for opportunities to reduce the number of times waste is handled. For example, DOE should assess the need for and, to the extent practicable, limit the size of large aging pads called for in the current surface facilities design. An issue not covered at the meeting that may affect the number of times that waste is handled is disposal of spent fuel currently stored in dual-purpose canisters (DPC's). The Board urges DOE to evaluate the safety, operational, and economic issues related to opening, unloading, and disposing of empty DPC's in comparison to possible direct disposal of DPC's in Yucca Mountain. DOE's position on the related issues of criticality and burn-up credit should be clarified in the LA as part of an assessment of the feasibility of direct disposal of DPC's. In addition, the Board requests an explanation of the technical basis for the selection of borated stainless steel as a neutron absorber in TAD canisters.

The Board notes with some concern the following: First, while technical interaction between DOE and the nuclear utilities is ongoing, it is not apparent to the Board that this dialogue includes all key issues warranting coordination within a successful waste management system. Second, DOE has assigned postclosure planning responsibility to the Office of the Chief Scientist, while preclosure planning responsibility has been assigned to the Office of the Chief Engineer. The Board has not observed a systematic or comprehensive linking of these two components or recognition by DOE of the interdependencies of important repository design and operating elements (e.g., thermal management). Finally, the Board notes that DOE preclosure safety analysis starts with shipment receipt at the surface facility and does not take into consideration safety factors related to waste transportation or waste acceptance sites. Consequently, DOE waste-management strategies that might reduce risk at surface facilities but increase risk during waste acceptance would be viewed as a reduction of risk rather than a transfer of risk.

The Board is encouraged by the Project's efforts in developing a strategic transportation plan and will follow with interest the evolution of the national and Nevada transportation systems. DOE should monitor the upcoming Department of Homeland Security and Pipeline and Hazardous Materials Safety Administration rulemakings on routing criteria and route risk assessments involving radioactive material shipments by rail. DOE should also monitor the anticipated changes being made by the Federal Motor Carrier Safety Administration concerning security route risk assessments for motor carrier transport of radioactive materials to ensure that DOE's approach is consistent with this legislation and guidance.

Office of the Chief Scientist

The Board found interesting the presentation on science investigations supporting the LA and believes that maintaining a core scientific effort is very important. The technical and scientific activities assigned to the Office of the Chief Scientist are numerous but necessary in supporting performance and operational concepts.

New estimates of infiltration of precipitation into the hydrogeologic unsaturated zone are higher than previously estimated. For example, the mean present-day infiltration rate was reported to be 13.4 mm/year—approximately 3 times higher than previously estimated. Because the rate of infiltration is a factor in controlling radionuclide transport and dose, the Board wants to understand thoroughly, the technical basis of DOE's new infiltration estimates. The Board's panel meeting on infiltration on March 14, 2007, in Berkeley, California, provided an excellent forum for addressing and discussing these issues.

The engineering update highlighted the importance of understanding the long-term cumulative effects of seismicity on the geologic environment. The Board realizes that seismic risks are generally of low probability but that such events could diminish waste isolation during the postclosure period, especially if the repository compliance period is extended to 1 million years. Estimates of seismic ground motion during the period of repository operation significantly affect the engineering design of surface facilities. For example, for meeting current preclosure safety requirements, the current surface facility design includes structural walls made of steel-reinforced concrete that are more than 4 feet thick. The Board long has encouraged DOE to develop more-realistic estimates of ground motion for both preclosure and postclosure periods and supports DOE scientific and engineering activities aimed at developing such realistic estimates.

The Project is to be commended for the sustained support of the Probabilistic Volcanic Hazard Assessment Update (PVHA-U). That long-term effort benefits from a rigorous, well-defined, and state-of-the-art methodology and from careful examination of a number of potential buried basaltic volcanic deposits (or "anomalies") that were delineated through a high-resolution aeromagnetic survey. Many of those anomalies have been investigated by drilling into them, and the preliminary conceptual and numerical models have been updated to reflect the results of the investigation. This investigation is proceeding on its own schedule, independent of the LA, but may be completed in 2008. When the PVHA-U becomes available, it will aid in a realistic assessment of the significance of low-probability volcanic hazards at Yucca Mountain.

The Project has continued to evaluate the ^{36}Cl problem. The most recent studies have not determined conclusively the origin of sporadic measurements of ^{36}Cl in samples collected from within Yucca Mountain. This remains an outstanding issue whose resolution could greatly enhance confidence in understanding fluid flow within Yucca Mountain.

Science and Technology (S&T) program

The Board strongly supports scientific activities currently performed under the S&T program. The Board is concerned, however, that budget constraints in fiscal year (FY) 2007 and the elimination of funding for this purpose in OCRWM's budget request for FY 2008 will negatively affect the continuation of these activities that otherwise might support the technical basis of important elements of the LA. Of particular importance is work on the source term, natural barriers, and materials performance. Scientific efforts in other areas also are potentially important. DOE appears to be making progress on waste package corrosion, potential use of cementitious materials in the repository, and understanding how heat and water vapor will move in three dimensions through the mountain for hundreds to thousands of years after the waste is

emplaced in the drift tunnels. The Board also is interested in recent results from the backfill thermal conductivity test, which seem to point to a potential means of mitigating both seismic and igneous consequences by using backfill.

In general, in reviewing the information presented at the January meeting, the Board is encouraged by project management initiatives and progress made in addressing technical and scientific issues.

Sincerely,

{Signed By}

B. John Garrick
Chairman

bjg068vF 4

Department of Energy
Washington, DC 20585

QA: N/A

November 6, 2007

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

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Dear Dr. Garrick:

Thank you for your April 19, 2007, letter providing the Nuclear Waste Technical Review Board's (Board) views on the Office of Civilian Radioactive Waste Management (OCRWM) Program, as presented to the Board at its January 24, 2007, meeting in Las Vegas, Nevada. As always, I appreciate the opportunity to interact with the Board.

The Program remains on track to complete the key milestones and meet its strategic objectives, as I outlined in my presentation.

In your letter, the Board raised some additional questions and asked for clarification of some of our plans. The enclosure to this letter provides detailed responses to the Board's inquiries.

If you have any questions concerning this letter, please contact Claudia M. Newbury at (702) 794-1361.

Sincerely,

Edward F. Sproat, III, Director
Office of Civilian Radioactive
Waste Management

Enclosure

ENCLOSURE

Response to Nuclear Waste Technical Review Board Comments from January 24, 2007, Board Meeting

1) **The Nuclear Waste Technical Review Board (Board) noted that it was "interested in obtaining information on how the design will conform to preclosure safety requirements (i.e., the event sequences that require analysis and the implications for dose from those events)."** The following discussion provides information on level of design detail and implementation of the Preclosure Safety Analysis (PCSA).

The U.S. Department of Energy (Department) is developing the design for its License Application (LA) to the level of detail necessary to assure the availability of structures, systems and components (SSCs) as modeled in the PCSA. The level of design information will conform to the U.S. Nuclear Regulatory Commission (NRC) staff guidance including HLWRS-ISG-02 PCSA – Level of Information and Reliability Estimation. This approach will include a greater level of design detail for Important to Safety (ITS)/Important to Waste Isolation (ITWI) components than there will be for Non-ITS/Non-ITWI components. For example, Piping and Instrumentation Diagrams, Ventilation and Instrumentation Diagrams, electrical single line diagrams, and logic diagrams for ITS/ITWI SSCs will include sufficient component information to allow modeling for reliability assessment. Another example is that structural design for the Canister Receipt and Closure Facility (CRCF), the Receipt Facility (RF), and Wet Handling Facility (WHF) will include design details such as lumped mass, multi-stick model with soil springs; peak accelerations at mass nodes; typical thicknesses and rebar patterns for shear walls, floor and roof slabs; typical details for penetrations; foundation (basemat) thickness and rebar patterns; assessment of building stability for sliding and overturning effects; and sizing of principal structural steel members. The results of the analyses will be included in the LA submittal scheduled for June 30, 2008. Schematics with sufficient mechanical handling equipment component detail to support reliability assessment of speed control, brakes, travel limits, and the ability to hold load on loss of power will be included. The PCSA will include reliability assessment, including human reliability, for such items as ITS Heating, Ventilation and Air Conditioning (HVAC), ITS electrical power, WHF pool and support systems, and movable shield doors in addition to the mechanical handling equipment. Design calculations and drawings will be sufficient to allow the NRC to verify that the PCSA is adequate.

10 CFR 63.111(c) requires performance of a PCSA of the geologic repository operations area. The PCSA calculations and analyses are developed, reviewed, and approved in accordance with the overall design control and configuration management procedures Coordination and integration between the PCSA analysts and design engineering is accomplished as an integral part of daily routine activities similar to the interface between the separate engineering disciplines within an engineering, project and construction organization.

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The PCSA process is iterative and includes analysis of evolving design information, site characteristics, and operational features to evaluate the potential hazards, potential event sequences, and calculate the radiological consequences for operations of the geologic repository operations area. As the design and the PCSA progress, there is continuous feedback from PCSA analysts to designers regarding the safety functions of SSCs and target reliabilities being modeled in the PCSA. PCSA analyses are revised, as necessary, to maintain consistency with repository design. When the LA is submitted, the design and PCSA will be based on the same design information.

Interface activities are coordinated to ensure the design of the repository is consistent with the PCSA. This includes inputs from designers that are necessary to perform the preclosure safety calculations and analyses. The products developed by design engineering (e.g., project design criteria, system description documents, and drawings) and by the PCSA analysts (e.g., radiological hazards analyses and event sequence categorization) are closely coordinated between the respective organizations, and are subjected to procedurally required interface and interdisciplinary review before their issue.

The technical interface requirements between PCSA and design engineering are formally documented in the Preclosure Nuclear Safety Design Bases. This quality-affecting document provides the classification of systems, structures, and components ITS or not important to safety along with the associated safety function based on the results of completed event sequence analysis for each nuclear structure, and for subsurface areas and intra-site operations.

Overview of PCSA Process

In the PCSA required by 10 CFR 63.21(c)(5) and 10 CFR 63.112, an assessment of the safety of the geologic repository operations area is made and the ITS SSCs that are required to ensure that the credited safety functions can meet the performance objectives of 10 CFR 63.111 are identified. The four major portions of the analysis are (1) initiating events identification and event sequence development, (2) event sequence analysis and categorization, (3) radiological consequence, and (4) identification of SSCs ITS and specification of the nuclear safety design bases and procedural safety controls. The nuclear safety design bases for ITS SSCs and the procedural safety controls provide means to (1) prevent or reduce the likelihood of event sequences and (2) mitigate or reduce the consequences of event sequences.

Initiating events are considered only if they are reasonable (i.e., based on the characteristics of the geologic setting and human environment, and consistent with precedents adopted for nuclear facilities with comparable or higher risks to workers and the public (10 CFR 63.102(f)).

Initiating Events Identification and Event Sequence Development

To assess potential external and internal hazards, PCSA evaluates the site and uses descriptions of the repository facilities (surface and subsurface), SSCs, operational process activities, and characteristics of the waste stream to identify applicable hazards that may result in reasonable, credible, initiating events to be considered in further analyses. Examples of the internal hazard categories analyzed include, but are not limited to, collisions, drops, system failures (e.g., HVAC), floods, and fires. Master logic diagrams and process flow diagrams are being used to identify internal hazards and initiating events. Examples of external hazard categories analyzed include, but are not limited to, natural phenomena such as tornadoes and seismic events, and human activity such as aircraft crashes that could impart sufficient energy to be hazardous to a waste form.

Event Sequence Identification and Categorization

Potential event sequences are developed by safety analysis and evaluated based on the identification of credible potential external and internal initiating events. The event sequence analyses process quantifies (determines the overall probability or frequency) the sequences of events that lead to a potential radiological release or criticality. Event sequences are categorized in accordance with definitions of Category 1 and Category 2 event sequences in 10 CFR 63.2. Event sequences that have less than one chance in 10,000 of occurring during the preclosure period are screened out and categorized as beyond Category 2 event sequences.

Radiological Consequence Analyses

Analyses of radiological consequences of potential radionuclide releases and direct exposures from normal operations of repository surface and subsurface facilities, Category 1 event sequences, and Category 2 event sequences are performed as required by 10 CFR 63.111(c). Radiological consequences are calculated for workers and members of the public during normal operations and are added to the radiological consequences from the Category 1 event sequences to demonstrate compliance with 10 CFR 63.111(a) and (b).

For Category 2 event sequences, offsite public radiological consequences are evaluated for each Category 2 event sequence, individually. No worker radiological consequences are required to be calculated for Category 2 event sequences to demonstrate compliance with 10 CFR 63.111(b)(2).

Identification of SSCs ITS and Specification of the Nuclear Safety Design Bases and Procedural Safety Controls

The SSCs that perform safety functions credited in event sequence analyses and radiological consequence analyses are classified as ITS. The credited safety functions are documented in preclosure nuclear safety design bases.

For certain ITS SSCs, the PCSA specifies required reliability values for equipment or operator performance (or both) to ensure that event sequences involving those SSCs are prevented, the likelihood of occurrence is reduced, or the consequences are mitigated. The reliability specified by PCSA analyses is an engineering design requirement that is included in the preclosure nuclear safety design bases.

SSCs credited with preventing or ensuring that an event sequence is beyond a Category 2 event sequence are also identified as ITS with specific safety function design requirements.

2) The Board stated that improvements should be made in the thermal management strategy that forms the basis for integrating waste management activities and requested clarification of how the Initial Handling Facility (IHF) fits into the Department's thermal-management strategy and the role of the IHF in general. The following discussion provides additional information on the thermal management strategy and the role of the IHF.

With the change to the primarily canister-based approach relying on the use of Transport, Aging and Disposal (TAD) canisters, the Department plans on receiving up to 90% of the Commercial Spent Nuclear Fuel (CSNF) in TAD canisters loaded by the utilities. The Standard Contract (10 CFR Part 961) requires that the CSNF assemblies be a minimum of five years time out of reactor for classification as Standard Fuel; however, the Standard Contract does not impose any thermal limit on the CSNF to be accepted by Office of Civilian of Civilian Radioactive Waste Management (OCRWM). Selection of the CSNF assemblies to be delivered rests with the utilities.

Further, the Department's draft performance-based specification for the TAD canisters imposes temperature limits for protection of cladding at the utility sites, during transportation, and for the preclosure and postclosure periods at the repository. The performance-based specification imposes heat flux vs. canister-wall temperature limitations for the TAD canister at the time of emplacement. Other than these temperature limits, the thermal limits on CSNF that the Department must accept from the utilities are the NRC-approved individual assembly and total canister thermal limits from 10 CFR Part 71 Certificates of Compliance (CofC) for the TAD-based transportation systems (consisting of a TAD canister and its transportation overpack) that are determined by the TAD vendors.

Accordingly, with no set upper thermal basis and a lack of certainty of the specific thermal power of the TAD canisters, the Department is developing a thermal management strategy. It includes establishing thermal limits for handling of the TAD canisters and includes considerations for the design to allow for flexibility in the handling of the TAD waste stream to achieve thermal emplacement requirements.

There are several operational approaches, as part of the thermal management strategy, that are being planned for use at the repository. They include:

- Establishing a broad envelope for the emplacement process, that satisfies the TSPA constraints
- Allowing for the aging of TAD canisters to allow decay heat of the TAD canisters to achieve the thermal limits for emplacement
- Using low thermal power naval Spent Nuclear Fuel (SNF) and U.S. Department of Energy (DOE) High-Level Waste (HLW)/ SNF codisposal packages to blend the average thermal power in the emplacement drift to meet emplacement constraints
- Accounting for the decay of waste from its date of actual emplacement and the effects of ventilation during the preclosure period

As part of this strategy, the capability of the surface facilities is considered with respect to:

- Designing facilities that can meet potential thermal limits for receipt and handling of the TAD canister
- Accepting CSNF to meet DOE receipt rates
- Evaluating the capabilities of the facilities for the rates associated with closure of the waste package and subsequent emplacement in the proper thermal arrangement
- Evaluating the size of the aging facilities with respect to various waste streams

Each of the facilities has specific roles in the thermal strategy with respect to receipt of the TAD canisters, performing waste package closure, transporting TAD canisters to the aging facilities, and then returning them for handling and emplacement.

The IHF, in particular, receives and places the naval SNF canister into a waste package with subsequent closure, and has the capability to handle and close waste packages containing HLW, thus reducing the complexity of the Canister Receipt and Closure Facility. Waste packages are then placed into the transport and emplacement vehicle for emplacement in accordance with the thermal limits.

A thermal management study, using the above concepts to establish appropriate thermal emplacement limits, is currently underway to demonstrate the viability of a range of waste streams to meet the receipt and emplacement thermal limits for the repository.

A preliminary evaluation of proposed site operations, with these thermal constraints, has shown that there is considerable flexibility in the thermal limits for the waste packages and the thermal line load. Accordingly, there is considerable flexibility to receive waste streams of varying thermal characteristics while still meeting the preclosure and postclosure temperature and thermal limits used in the repository design and the 100-year preclosure operations period. Similarly, the Aging Facility has been shown to be of adequate size for a range of thermal powers associated with different waste streams. Since the thermal characteristics of the as-received waste stream is uncertain, the Department plans to perform a drift-by-drift analysis of the thermal loading to demonstrate preclosure and postclosure performance based on the as-received waste once the facility begins operations. This is similar to the nuclear industry's approach to conduct a core reload analysis of a reactor following refueling.

One of the results of the adoption of the TAD canister concept for simplifying repository waste handling operations was the segregation of functions to different waste handling facilities. The WHF is designed to receive CSNF and repackage it into TAD canisters. The CRCF are designed to receive disposable canisters (TAD, DOE SNF, and HLW) and transfer them into waste packages. The RF is designed to receive TAD canisters and dual-purpose canisters (DPC) and transfer them to aging overpacks to de-couple CSNF receipt from emplacement. The Initial Handling Facility is designed to receive disposable canisters (naval SNF and HLW) and transfer them into waste packages. The IHF reduces the operating load, complexity, and cost of the CRCF by processing all of the naval SNF. The IHF can process all 400 Naval Spent Nuclear Fuel Canisters in 17 years. The IHF also has the ability to process HLW canisters. There is a 300 ton crane in the IHF that is required to handle the transportation cask in which the naval SNF will be shipped. The CRCF design only requires a 200 ton crane with a lower maximum hook height than the IHF to handle the waste that it will receive, which has resulted in a less expensive and less complex design for the three CRCF. Also, since processing naval SNF in the CRCF would require removal of other waste forms from staging areas to ensure criticality safety, elimination of the naval SNF from the CRCF mitigates the resultant operational delays associated with clearing the CRCF of other waste forms prior to handling naval SNF, allowing increased throughput for the CRCF.

In the IHF, the radiation source terms from naval SNF and high-level radioactive waste are sufficiently low that mitigation is not required to meet site boundary dose limits. All other waste forms to be handled at the repository require mitigation to meet site boundary dose limits. Consequently, the IHF does not require the confinement function of the other waste handling facilities and can be constructed primarily from structural steel. This allows the IHF to be constructed considerably faster than the other waste handling facilities which are primarily built of reinforced concrete. The current schedule is for the IHF to be completed a year before CRCF 1. This period will be used to demonstrate equipment operations and refine operating procedures for cask handling, canister transfer, and waste package loading, closure and loadout. Lessons learned in the year will be applied to the other handling facilities. The IHF provides for an improved throughput of Naval SNF, while simplifying operations in the CRCF.

Therefore, throughput is improved for Naval Spent Nuclear Fuel and for waste going through the CRCF.

3) The Board requested information on experience gained from safety and facility maintenance in the Exploratory Studies Facilities (ESF) could be applied to subsurface repository design and operations. The following information may be helpful in this regard.

In the summer and fall of 2006 the Department conducted two workshops with outside experts in underground construction and environmental safety and health. A hazard analysis of current ESF operations and construction practices was also completed, and the result of these two efforts was the development of an Underground Safety and Health Requirements Document (DOE/RW-0586), issued in January 2007. This document was intended to be applied to continued site operations until construction authorization. Some specific experience gained from safety and facility maintenance in the ESF includes the following:

- Nominal excavation airflow design volumes are based on the 150 ft/min velocity established during ESF construction
- Drift orientation (azimuth 252) based on post excavation ESF information
- Measurements of steel set loads indicate no evidence of long-term time-dependent effects. The rock at the repository host horizon demonstrates a good self-supporting capacity, rock bolts with wire mesh are an adequate ground support system, and steel sets with lagging are a very conservative ground support system
- The two ground support systems, namely: the friction-type expandable rock bolts and cast-in-place concrete liner installed in the heated drift, performed very well while subjected to up to 200 degree C temperatures, supporting the use of that type of rock bolt in the ground support system proposed for emplacement drifts
- Lithophysal rock exposure in the ESF, particularly in the ECRB cross drift, revealed all the challenging rock mechanical aspects of testing the lithophysal rock, and the importance of integrating field activities such as mapping, in situ measurements, and field observations in the process of characterizing the lithophysal rock mass thermo-mechanical performance
- Use of a blowing system to deliver fresh air directly to the TBM face, so workers at the face will be in cleaner air. (An Exhaust system was used during ESF operation, intake air went to the working face through the TBM tunnel, where the airflow picked up a lot of dust in the tunnel)

- Use of 1,000-ft flexible tube segments for minimizing air leakage. (Compared with 20-ft steel duct segments used in ESF, this eliminates majority of the vent-line joints that are potential source of air leakage)

- Covered muck cars (instead of conveyer used in ESF, which was a major source of dust).

4) The Board encouraged the DOE to evaluate surface-facility designs and operational concepts for opportunities to reduce the number of times waste is handled. The Board suggested that DOE should, for example, assess the need for and, to the extent practicable, limit the size of large aging pads called for in the current surface facilities design. The current status of the repository design as modified to accommodate the TAD is described below.

The current design of the surface facilities has resulted in a significant reduction in the number of times the waste is required to be lifted and handled as compared to the previous repository design. As an example, in the former Dry Transfer Facility a loaded waste package was lifted by a crane a minimum of three times, and as many as six times, during handling. In the current design of the surface facilities, all crane lifts of a loaded waste package have been eliminated.

The current 21,000 MTHM capacity of the aging pads uses Total System Model delivery predictions that are based on a waste package thermal limit at emplacement of 11.8 kW. Evaluations are currently underway to determine the effect of increasing the thermal limit at emplacement on the postclosure analyses. If the Department chose to increase the waste package thermal limit at emplacement, more TAD canisters could be directly loaded into waste packages, thereby reducing the required capacity of the aging pads. Any such change would necessitate discussion with the NRC.

As discussed above, as part of the thermal strategy, the aging pads are a part of the overall program to handle the wide variability of the potential waste streams to be received. Evaluations of waste stream in the past with different waste package designs and thermal emplacement constraints identified that the 21,000 MTHM capacity (approximately 2500 "spots" for TAD canisters or dual-purpose canisters (should DOE accept them) may be needed to allow for thermal decay. Current evaluations suggest that the needed capacity of the aging facilities could possibly be reduced by as much as 50%, depending on the thermal characteristics of the waste stream and the emplacement strategy employed, even if emplacement of the lower thermal waste is deferred until the end of the emplacement period. Included in this consideration for this sizing is queuing of waste based on the throughput capability of the facilities. The uncertainty of the waste stream thermal characteristics and the thermal capability of the TAD canister causes the repository to retain the facilities' capacity of 21,000 MTHM as part of the current design. As the design matures, with respect to the throughput capability of the facilities, the TAD thermal capabilities as identified by the vendors, emplacement strategies during preclosure for postclosure acceptance are accepted by the NRC, and

the characteristics of the waste stream become more certain, the Department will re-evaluate the need for the capacity of the aging facilities and adjust their capacity as necessary to support operations. Aging capacity will be developed in phases.

5) While not directly discussed at the January meeting, the Board urged the DOE to evaluate the possible direct disposal of DPCs in Yucca Mountain (YM). The Board suggested that the DOE should clarify its position regarding criticality and burn-up credit as part of an assessment of the feasibility of direct disposal of DPCs. DOE's plans with respect to DPCs are described below.

Should the Department accept DPCs, the direct disposal of existing DPCs is not planned and disposal of DPCs is not included in the LA. DOE does not currently plan that DPC disposal would be included in any amendments to the LA until the DPCs have been analyzed for postclosure criticality and other considerations. Several existing DPC designs rely on internal geometry and flux traps as well as neutron absorbers. During the postclosure period, internal geometry is lost due to material degradation, therefore credit is not taken for geometric controls. Also, any neutron absorber currently in DPCs may not have the same high level of corrosion resistance as the neutron absorber being specified for the TADs (borated stainless steel). If future analyses determine that direct disposal of DPCs is feasible, then the Department could propose an amendment to the license. However, currently the plan is to cut open DPCs in the WHF and transfer the fuel assemblies from DPCs to TADs. DOE intends to include burn-up credit in its evaluation of postclosure criticality and would expect burn-up credit to be considered in any direct disposal DPC analysis performed in the future.

6) The Board also requested an explanation of the technical basis for the selection of borated stainless steel as a neutron absorber in TAD canisters. The technical basis is described below.

The Department completed a comprehensive sensitivity study as documented in the calculation, "Evaluation of Neutron Absorber Materials Used for Criticality Control in Waste Packages" (CAL-DS)-NU-000007). This calculation looked at a range of absorber specifications, concentrations and geometric arrangements. The final recommended neutron absorber material for the TAD was borated stainless steel with a boron loading of 1.16 wt % at a minimum thickness over 10,000 years of 0.6 cm. The basis for the recommendation, as taken directly from the calculation, is as follows:

- Commercial experience with fabricability, commercial availability, and neutronics experience of absorber materials containing boron is much broader than with the Ni-Gd alloy. Also, ceramic based materials (B4C) would need special cladding and welding to ensure that they remain in place over long time periods of corrosion

- There are a relatively large number of criticality benchmark experiments with boron absorber in geometries representative of the TAD than with Gd absorber

- Expected corrosion rates for the Ni-Gd alloy and the borated stainless steel using powder metallurgy are expected to be relatively similar for the in-package pH ranges expected in the repository provided with boron loading is kept a relatively low levels

- A minimum absorber plate thickness of 0.6 cm with a credited boron loading of 0.87 wt% with natural boron provides a loading curve that is nearly identical to the proxy TAD configuration loading curve. This is the minimum thickness required after being subjected to 10,000 years of corrosion

- Further, additional corrosion testing of borated stainless steel have corroborated the expected corrosion rates.

7) The Board expressed concern that, while technical interaction between DOE and the nuclear utilities is ongoing, it is not apparent to the Board that this dialogue includes all key issues warranting coordination within a successful waste management system.

The Department believes that its current level of dialogue with nuclear utilities has been both appropriate and constructive. For example, the Department's discussions with both utilities and cask vendors has led to the successful development of the Preliminary Performance Specification for the canister. The Department also has continuing interactions with utilities on numerous topics including of nuclear operations, licensing, emergency preparedness, training, and configuration management. Additionally, the Department, with the assistance of the Electric Power Research Institute and the Nuclear Energy Institute, is working with a group of utilities to obtain additional data on spent nuclear fuel characteristics that it believes will be helpful in efforts to obtain an NRC license for the construction and operation of repository at YM.

The Department intends to expand the ongoing dialogue with nuclear utilities on additional issues as the program progresses into the licensing phase of the repository and beyond.

8) The Board expressed concern that DOE has assigned postclosure planning responsibility to the Office of the Chief Scientist (OCS), while preclosure planning responsibility has been assigned to the Office of the Chief Engineer (OCE). The Board indicates that it has not observed a systematic or comprehensive linking of these two components or recognition by DOE of the interdependencies of important repository design and operating elements (e.g., thermal management).

The Environmental Protection Agency, in 40 CFR 197, and the NRC, in 10 CFR 63, provide different standards and expectations with regard to pre- and post-closure safety.

The Department's organizational structure is reflective of these differences in requirements and associated areas of expertise. However, the Department has long recognized that these topics are not totally divorced from each other and require close coordination of activities and clear definition of interfaces. The OCE has been given responsibility for the development and control of top-level requirements documents including management of the technical change control process. This ensures consistent assignment and integration of requirements throughout the program, establish single point accountability for managing changes within the program, and develop a clearinghouse for integration at the management level.

Currently, the interface between postclosure activities performed under the direction of the OCS by the Lead Laboratory (LL), and preclosure activities performed under direction of the OCE by Bechtel SAIC Company, LLC (BSC), is managed through several processes and management actions, including the following:

- The LL and BSC have established a formal process for information exchange. Interface Exchange Drawings (IEDs) have been issued to document and control the exchange of information across the organizational boundary between preclosure functions (e.g., repository engineering, design, operations, and preclosure safety and criticality analyses) and post-closure and scientific investigation functions (e.g., post-closure performance modeling and assessment, post-closure criticality analyses, and site-specific geotechnical, environmental, meteorological, and seismic investigations). Control of the exchange of information across this boundary is necessary to ensure compatibility between the design of systems, structures and components and interfacing processes and scientific analyses.

- An additional document that ensures consistency and integration between the LL and BSC design is the Postclosure Modeling and Analysis Design Parameter Report, which augments the IEDs by documenting a review of Analysis and Model Reports to identify parameters and constraints to design (e.g., design bases that must be met by the design). These constraints to design are included in the design requirements documents, thus assuring that postclosure modeling and performance analyses bases are being met.

- The contractors exchange review copies of in-process technical documents for inter-contractor review if there are impacts on either the content of an IED or the Post Closure Modeling and Analysis Design Parameter Report.

- A joint management review in the Technical Review and Management Board is performed by the LL and BSC on any proposed changes to the IEDs or the Post Closure Modeling and Analysis Design Parameters Report.

- A regularly scheduled Subsurface Integration Meeting is hosted by BSC engineering with Department and LL attendees. The purpose of the meeting is

to provide a means to discuss specific issues that affect both preclosure and postclosure work.

The need for integration between offices is not limited to just the OCS and the OCE, particularly with regard to the Board's example of thermal management. The OCS, OCE, and Office of Waste Acceptance and Management are jointly developing the Thermal Management Strategy discussed above. An integrated team evaluated potential waste streams and associated parameters, and set bounds for the thermal envelope in the facility preclosure operations while meeting the initial conditions for the TSPA for postclosure. This was a significant integration effort that is now being implemented. Those parameters, defined in the study are being included into the control documents described above, for implementation into the ongoing design and TSPA analyses.

9) The Board suggested that DOE monitor the upcoming rulemakings by the Department of Homeland Security and Pipeline and Hazardous Materials Safety Administration and the Federal Motor Carrier Safety Administration to ensure that DOE's approach is consistent with new regulations.

Current and proposed rulemakings and legislation related to hazardous materials transportation security may impact the Department's system planning, and will be closely monitored by DOE. Accordingly, the Department will continue to closely follow developments in this area.

10) The Board discussed the importance of developing more-realistic estimates of seismic ground motion for both preclosure and postclosure periods and noted its support for scientific and engineering activities aimed at developing such realistic estimates.

During the last year work has been ongoing to refine seismic analyses. To address the evolution of the area where surface facilities will be sited, ground motions for design and preclosure safety analyses have been updated. In updating these ground motions, an alternate approach to incorporating site response has been implemented that results directly in a site-specific seismic hazard curve. In addition, reasonable limits to extreme (very low probability) ground motions at YM are directly incorporated. Limits are assessed both on the basis of geologic evidence that indicates a level of ground motion that has not been experienced at the site and on an evaluation of earthquake source parameters that are consistent with the geologic setting of the site.

Analyses and modeling of seismic consequences during the postclosure period are being updated to take into account the transportation, aging, and disposal canister concept and to evaluate performance for the period after 10,000 years. As part of this work, response to seismic loading is being assessed for additional states of degradation and failure of the engineered barrier system and for the effects of multiple seismic events.

11) The Board considers the question of ^{36}Cl measurements an outstanding issue whose resolution could greatly enhance confidence in understanding fluid flow within YM.

The Cl-36 studies can be viewed as consistent in one important aspect which is that the studies conducted to date consistently indicate that fast pathways, as indicated by bomb-pulse Cl-36 are either rare or non-existent. This is consistent with the way the unsaturated zone is modeled in process models and the TSPA, in which a small percentage of fast pathways are included in the models for unsaturated zone flow. Links to the completed reports on the work conducted by DOE investigators, including conflicting results and interpretations, were provided in a presentation at the January 24, 2007 Nuclear Waste Technical Review Board meeting.

12) The Board expressed concern that budget constraints in fiscal year (FY) 2007 and the elimination of funding for this purpose in OCRWM's budget request for FY 2008 will negatively affect the continuation of the Science and Technology (S&T) program.

Funding constraints will cause the Department to reduce or eliminate funding for the independent S&T program. The Department is investigating other avenues, such as the DOE Office of Science and cooperative research programs, to maintain the capability to investigate new and unproven techniques and technologies.

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

July 10, 2007

Mr. Edward F. Sproat III
Director, Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Sproat:

The U.S. Nuclear Waste Technical Review Board held a public workshop on localized corrosion of Alloy 22 on September 25-26, 2006, in Las Vegas, Nevada. Following the workshop, the Board conveyed its comments and conclusions on screening out deliquescence-based localized corrosion in a letter to you dated January 12, 2007. The Board stated in that letter that "demonstrating an adequate technical basis for screening out deliquescence-based localized corrosion during the thermal pulse requires (a) determining the nitrate-to-chloride ratios that are inhibitive for the entire range of temperatures that deliquescent brines may occur on waste package surfaces and (b) confirming the hypothesis that the preferential migration of nitrate ions into the crevices is sufficient to maintain nitrate-to-chloride ratios that are inhibitive." The following extends and supplements the Board's January 2007 letter.

In addition to (a) and (b) above, the Board believes that the technical basis for screening out deliquescence-induced localized corrosion would be strengthened by showing that inhibitive nitrate-to-chloride ratios would persist during the thermal pulse under expected repository conditions. The importance of establishing the continued presence of inhibitive nitrate-to-chloride ratios was reinforced by the results of recent analyses of dust collected from the cool-down phase of the drift-scale thermal test, which show that nitrate may have been depleted under the testing conditions. The Board believes that factors and processes that contribute to a decline in nitrates under potential repository conditions should be analyzed and understood.

An example of such factors is the composition of dusts that will be present in the repository. Most of the nitrate in deliquescent brines comes from inorganic salts contained in dust that deposits on waste package surfaces, primarily during the ventilation period. However, the dust also contains organic materials and carbon that have not been included in DOE's representation of dust likely to be present in repository tunnels. DOE should evaluate the potential effects of the depletion of nitrate that would occur from a reaction with organic material under repository conditions during the thermal pulse.

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As discussed in the Board's January letter, screening out localized corrosion requires determining the nitrate-to-chloride ratios that would exist in brines on waste package surfaces under varying repository conditions during the thermal pulse. Providing convincing evidence that inhibitive nitrate-to-chloride ratios will persist under repository conditions could strengthen the technical basis for screening out localized corrosion. Therefore, DOE should analyze the effects of the full range of factors that would affect such ratios (e.g., organics in dust, acid-gas devolatilization, radiolysis).

Sincerely,

{Signed by}

B. John Garrick
Chairman

bjg070v3 2

Department of Energy
Washington, DC 20585

August 13, 2007

QA: N/A

RECEIVED AUG 16 2007

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

Dear Dr. Garrick:

Your 2006 Report to the U.S. Congress and the Secretary of Energy describing the activities of the Nuclear Waste Technical Review Board (Board), as well as more recent correspondence, raised a number of technical issues to which the Office of Civilian Radioactive Waste Management has responded in the enclosed table. The table summarizes the issues raised, the U.S. Department of Energy (DOE) responses to the Board's concerns, and DOE's current work activities in these areas.

We appreciate this opportunity to communicate with the Board regarding issues of importance to the Yucca Mountain Project and look forward to future exchanges. If you have any questions concerning the enclosed table, please contact me or Russ Dyer, Director, Office of the Chief Scientist, at 702-794-1408.

Sincerely,

Edward F. Sproat, III, Director
Office of Civilian Radioactive
Waste Management

Enclosure

NUCLEAR WASTE TECHNICAL REVIEW BOARD ISSUES RAISED IN 2006 REPORT TO CONGRESS AND IN RECENT CORRESPONDENCE WITH DOE, AND DOE RESPONSES TO THESE ISSUES

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
The Capability of Natural Barriers to Isolate Radionuclides	
The Board believes…that additional work on radionuclide transport is needed – in particular, research on secondary mineralization. This area of investigation relates to what is more generally referred to as the radionuclide source term, the understanding of which is critical to assessing the overall performance of the repository. If these investigations determine that the neptunium and plutonium leaving the EBS are captured in the secondary mineral phases, the possibility exists that the natural system's capability to isolate the dose-contributing radionuclides (^{237}Np and ^{242}Pu) could be greatly increased. Further work investigating matrix diffusion, colloid-facilitated transport, or other processes that might significantly affect the rate at which dose significant radionuclides are transported also could yield important insights. In addition, the Peña Blanca analogue site in Mexico provides an opportunity to test models and methods for predicting radionuclide migration and retention processes at Yucca Mountain. The Board encourages the Project to continue studies at that location.	The DOE Office of the Chief Scientist, Science, Technology and Management (OCS/STM) funds independent work in a number of "Thrust Areas". The Source-Term Thrust Area is dedicated to scientific studies relevant to spent nuclear fuel (SNF) and nuclear waste glass and the critical processes within the waste package and drifts that affect potential radionuclide release from the waste forms and from the engineered barrier system. Source Term research studies include: 1) actinide thermodynamics at elevated temperatures; 2) impact of uranyl alteration phases of spent fuel on mobility of neptunium and plutonium; 3) effect of deliquescence and decay heat on source term degradation; 4) spent fuel dissolution mechanisms and rates; 5) in-package sequestration of radionuclides; and 6) long-term corrosion of spent nuclear fuel; 7) natural sequestration of radionuclides in volcanic tuff and secondary phases; 8) in-situ spectroelectrochemical study of Np redox, dissolution, and precipitation behavior at corroding commercial spent nuclear fuel (CSNF)/Alteration phase interface; 9) migration of the release of I-129 from SNF via uptake by uranyl alteration phases; 10) actinide adsorption to U(VI) silicates; 11) direct determination of the thermo-dynamic properties of uranyl minerals important to repository performance; 12) surface charge and radionuclide adsorption characteristics of U(IV/VI) and metal corrosion oxides at 25°-150°C under repository chemical environments. OCS/STM work also includes work at the Peña Blanca natural analogue site. OCS/STM activities have been reduced in FY 2007 and will not be funded in FY 2008, due to budget constraints.

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
	The Office of the Chief Scientist, Repository Science and Integration (OCS/RSI) directs the scientific program that supports the DOE's licensing case. OCS/RSI work includes incorporation of kinetics of filtration of irreversible colloids in the unsaturated and saturated zones through the "colloid diversity model". The approach (1) recognizes variability (diversity) in the attachment/detachment rate constants resulting from differences in colloid size, mineralogy, surface charge, and characteristics of sorption sites, (2) treats these variations with a distribution of retardation factors for colloids, and (3) develops the distribution of retardation factors as a function of transport time through the UZ and SZ. This work involves an abstraction of kinetic colloid filtration into the FEHM software to replace the current equilibrium approach. New data related to the performance of the natural barrier system are evaluated on an ongoing basis. For example, results from Alcove 8/Niche 3 tests are being utilized to more realistically take into account matrix diffusion in UZ flow and transport using an enhancement factor to the matrix diffusion coefficient estimated with the dual permeability model and possibly employing the MINC (multiple interacting continua) method. More realistic accounting of the role of matrix diffusion in radionuclide transport through the unsaturated zone will be evaluated and documented in the *Particle Tracking Model and Abstraction of Transport Processes* (MDL-NBS-HS-000020) AMR.
The Board is skeptical about the Project's claim to have found evidence of a "reducing curtain" in the saturated zone.	The evidence behind the notion that there may be areas of 'reducing ground waters' in the saturated zone is discussed in the BSC 2005 report: *Impact of Solubility and Other Geochemical Processes on Radionuclide Retardation in the Natural System.* A sensitivity study is planned for this year to evaluate the impact of potential 'reducing conditions' on radionuclide transport in the saturated zone through Monte Carlo simulations using the SZ flow and transport abstraction model for a range of reducing conditions.

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
The Board remains puzzled by the Project's inability to put to rest the issues related to the bomb-pulse chlorine-36 (^{36}Cl) observed in the proposed repository horizon and to the water found behind the bulkhead in the sealed section of cross-drift. Inconsistencies in past studies of ^{36}Cl raise questions about the technical basis of model predictions of water flow and radionuclide transport. In the case of the water found in the cross-drift, the Project has not developed and tested a hypothesis that explains all of the physical and chemical data collected. The Board recommends that work be expedited to resolve both of these issues to enhance confidence in both the quality and the conclusions of the Project's technical analyses.	Work performed as part of the ^{36}Cl validation activities by the Lawrence Livermore National Laboratory, the U.S.Geological Survey, and the Los Alamos National Laboratory have been documented in a report which is available on the OCRWM web site at http://www.ocrwm.doe.gov/documents/design/35641/index.htm. An independent study of ^{36}Cl issues has been conducted under a cooperative agreement between the Department and the Nevada System of Higher Education (NSHE) Scientists have collected samples from the Exploratory Studies Facility, evaluated experimental techniques, and tested rock samples in 2006. NSHE has submitted the results of their independent study of ^{36}Cl. The results were inconclusive and the report recommended additional work. DOE has not planned additional work on the ^{36}Cl issue. The report is available on the NSHE web site.
Thermal-Management Strategy	
The Board has concerns about the technical basis behind the Project's thermal management strategy…. First, the technical basis for the Project's choice of thermal criteria to limit temperature is not well-defined. For example, the 11.8 kW/waste package limit appears to have been based arbitrarily on the average power of a PWR SNF assembly plus 20 percent. A more technically valid approach might be to derive the maximum waste package-surface temperature limit from limits on drift wall temperature. The Board believes that the Project should articulate in a transparent way the basis for its thermal criteria.	The Department agrees that the thermal management strategy must be clearly defined to provide the technical basis for waste acceptance, transportation, waste handling, and waste emplacement. Postclosure near-field and in-drift conditions affecting performance of the engineered and natural barriers are being addressed in the postclosure elements of the thermal management strategy. This includes the thermal decay characteristics of the waste and temperature limits at key locations such as the waste package wall and drift wall. The FY 2007 work scope is addressing these thermal management issues.
Second, the implications for thermal management of the Project's provisional decision to implement the TAD concept do not seem to have been evaluated fully. In particular, the Board is concerned about the ability of the utilities to blend the spent nuclear fuel to the required thermal loading, given the spent nuclear fuel available in spent-fuel pools, the increasing volume of spent nuclear fuel in dry storage at reactors, and the trend towards higher burn-up fuel…. Moreover, the Board is	The performance specification is being developed taking into account all the system requirements from waste acceptance to final disposal. Accordingly, it has been the Department's intent to incorporate requirements that, while ensuring that the thermal performance of the TAD canister system would be consistent with the current postclosure thermal management approach, would provide sufficient flexibility to accommodate alternative thermal management strategies. If, as a result of further analyses, the current postclosure thermal management approach is

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
concerned that the constraints imposed by line-load during emplacement have not been fully represented or understood in terms of surface facility design and operation.	altered, the Department believes that such changes can be accommodated by altering the manner in which the TAD canister system is operated, (i.e. by decreased surface aging), rather than by requiring changes to the TAD canister design. The Department is developing an updated thermal management strategy to reflect commercial spent nuclear fuel (CSNF) forecast at somewhat higher burnup and earlier time out of the reactor than previously considered. This strategy is intended to maximize operational flexibility and minimize the related need for canister thermal limits. Using postclosure process models and parameters from alternative waste streams, sensitivity analyses will be performed to evaluate effects of a broader range of variables affecting thermal performance.
Third, the Board is not persuaded that the thermal-hydrologic models being used to predict postclosure temperature, relative humidity, and vapor transport within the drifts have a strong technical basis. For example, the thermal conductivity of the rock at Yucca Mountain is important for predicting thermohydrologic conditions in the proposed repository. Uncertainty in the thermohydrologic conditions, especially during the thermal pulse that last about 1500 years, arises in part from the scarcity of *in situ* measurements of thermal conductivity in the lower lithophysal rocks where approximately three-quarters of the repository might be constructed. More data on thermal conductivity could reduce this uncertainty…In addition, further analysis of data obtained from the Drift-Scale Heater test might be helpful in reducing the uncertainty in thermohydrologic conditions during the thermal pulse.	The geostatistical model used to calculate the thermal conductivity of the repository horizon rocks has been developed based on site-specific data including well logs and measurements of physical properties and thermal conductivity on rock cores from boreholes. Because a sequential Gaussian simulation is used, the model provides an appropriate representation of the spatial variability and uncertainty of the underlying data, especially the key input parameters (i.e., matrix thermal conductivity and lithophysal porosity). Both parameters contribute to the spatial variability and uncertainty in the model results, although the dominant influence is from matrix thermal conductivity. Whereas, *in situ* tests are useful in evaluating the effects of discontinuties such as lithophysal cavities, laboratory tests are used to measure matrix thermal conductivity, the dominant contributor to spatial variability and uncertainty. The *in situ* test results are not part of the basis for spatial variability and uncertainty in the model results. The reason is that *in situ* tests by their nature (and cost) cannot be performed over nearly as broad a range of spatial distribution and stratigraphic facies as can be performed using geophysical well logs and core samples. Thus, additional *in situ* tests would not be a practical way to improve the model treatment of spatial variability and uncertainty.

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
	The in situ thermal conductivity test results are point measurements that corroborate the geostatistical model. All test results are within the range of values derived from the model. One of the test results is slightly over 1.5 standard deviations from the model-derived mean and the others are within one standard deviation. Additional confidence in the model is gained by the methods and models used to estimate matrix thermal conductivity, lithophysal porosity, matrix porosity, and bulk density. The latter two are used to estimate the former two, which are used to obtain bulk thermal conductivity. For the Drift-Scale Heater Test, activities such as re-entry, retrieval of sample materials, collection of additional samples, and photography have been deferred for budgetary reasons. Longer term activities will include coring, rock-bolt pull tests, and investigation of spalling at the drift crown. The objectives of these activities include obtaining a better understanding of the thermal-hydrologic-chemical-mechanical effects on repository performance. The thermal-hydrologic model to predict postclosure temperature, relative humidity, and vapor transport in the emplacement drifts is being revised, to support the license application. No additional *in situ* thermal conductivity tests are planned. The Department believes than an acceptable level of model validation has been achieved. While potentially useful, further *in situ* thermal conductivity tests are not necessary for this purpose.

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
[T]he Project is conducting three-dimensional analyses to complement its two-dimensional multi-scale model of water and vapor flow. The Board plans to review those analyses to determine what impact, if any, they might have on the safety case. In particular, the Board would like to see how energy and mass balances are achieved and how these results are integrated into performance assessment. Due to the importance of the multiscale model, the Board also recommends that it be reviewed by independent experts.	DOE does not plan to conduct an external review of the multiscale model. The OCS/STM Program has funded an integrated in-drift/near field flow and transport model with reactive chemistry. This includes an integrated thermal hydrologic chemical model with a rigorous mass balance.
Range of Possible Near-Field Environments that Might Occur and the Effect of Those Environments on the Integrity of the Engineered Barrier System	
The Project maintains that potential localized corrosion of Alloy-22 at elevated temperatures can be excluded from its performance-assessment calculations. The Board believes that the technical basis for the exclusion is not compelling, partly because only very limited corrosion data have been collected at temperatures above 150°C, and partly because data showing cessation (stifling) of localized corrosion at lower temperatures may or may not be relevant to all conditions under which localized corrosion could occur in the proposed repository. The Board strongly urges the Project to continue collecting data that might justify its assumption that localized corrosion will not occur at temperatures as high as 200°C.	Further work on the role of stifling has been planned for FY 2007, and will be included in planning for the long-term corrosion test facility. Collection of dust samples and studies of the role of dust deliquescence on localized corrosion are also expected to continue.
Some previous performance assessment models have assumed that general corrosion of Alloy-22 *does not occur above 120°C*, presumably based on the assumption that aqueous conditions do not exist above this temperature. Because aqueous conditions *can* exist at elevated temperatures-as Project researchers have demonstrated- future performance assessments should not exclude general corrosion at elevated temperatures when aqueous conditions are predicted to be present. The Board strongly urges the Project to continue to collect data to resolve the issue of whether general corrosion occurs at temperatures as high as 200°C.	In the current TSPA simulations, general corrosion of both waste package and drip shield materials is assumed to occur at all temperatures. The Alloy 22 general corrosion model is temperature-dependent and the temperature dependency is represented by an Arrhenius relationship. The titanium alloy general corrosion rate is taken to be independent of temperature in agreement with the experimental results of Smailos and Köster (1986 IAEA-TECDOC-421). General corrosion data for Ti Grades 7 and 29 (as well as some analogue alloys) has been collected at 150°C. These data were found to be consistent with the Project's existing models for Ti Grade 7. The data indicated that the Project's model for Ti Grade 29 was somewhat

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
	conservative. The Project will continue to collect general corrosion data in high temperature environments.
[F]or Yucca Mountain environments above 160°C, only limited SCC data exist for Alloy-22. Given that the susceptibility of metals to SCC generally increases with temperature, the Project will have to obtain relevant data under higher-temperature conditions, assume that SCC will occur, or use a different approach.	SCC requires 1) a susceptible material; 2) a critical environment; and 3) a source of stress. The Project's SCC models assume that waste package and drip shield materials are susceptible to SCC and that a critical environment exists at all temperatures. SCC initiation is subject to a threshold stress and SCC propagation is subject to a threshold stress intensity factor. Current models use SCC initiation data acquired in solutions at temperatures up to 165°C in aggressive SCW solution. Limited crack growth rate data collected in SCW solutions at 175°C agree with more extensive data collected at 150°C. In FY 2007, testing of Alloy 22 specimens containing simulated weld flaws will be continued. These tests are used to evaluate whether SCC will initiate at defect sites. During FY 2007, Alloy 22 U-Bend specimens, exposed for times up to ~9 ½ years, will be evaluated for evidence of SCC initiation and growth.
The Board continues to believe that SCC in titanium alloys cannot be dismissed.	SCC is not expected for the as-emplaced drip shields as they have undergone stress relief treatments (no source of stress is available to drive crack growth). SCC of the drip shield materials can occur under seismic loadings. After seismically-induced cracks penetrate, only limited water flow is expected because cracks in passive materials are tight and tortuous, water would be flowing against a thermal gradient, and there is potential for crack plugging by mineral precipitation and/or corrosion products. During FY 2006/2007, Ti Grades 7 and 29 specimens continue to be tested at General Electric. These data will produce information useful in understanding titanium alloy SCC (e.g., stress and stress intensity thresholds and crack growth rates). During FY 2007, titanium alloy U-Bend specimens, exposed for times up to ~9 ½ years, will be evaluated for evidence of SCC initiation and growth.

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
	Testing of titanium alloy specimens containing simulated weld flaws will be continued. These tests are used to evaluate whether SCC will initiate at defect sites.
[T]here is considerable uncertainty about the source term incorporated into the TSPA. To address this uncertainty or lack of detailed analysis, the Project has made simplifying assumptions that need to be reviewed carefully for their effects on the fuel degradation and radionuclide migration processes.	DOE agrees. Although the simplifying assumptions are conservative, they will be examined in light of the best available data. The OCS/STM has a number of research studies in the areas of source term, spent fuel degradation, and radionuclide migration.
The Postclosure Risk Associated with the Proposed Repository	
The Board appreciates the fact that the Project is in the midst of preparing a license application for its repository system. Not surprisingly, the Project is motivated to advance a licensing case whose main–and possibly sole–objective is to demonstrate compliance with the applicable regulations via an intense legalistic process. Consequently, when faced with gaps in understanding, "bounding" conservative approaches are often adopted. What is difficult to assess is the degree of total conservatism that exists when scientists add their own conservatism in the chain of integrated analyses that form the performance assessment. For that reason, the Board remains concerned that by adopting a conservative compliance-focused approach, the Project discounts the importance of letting policy-makers, the public, and the broader technical and scientific community know what the Project's experts believe are the intrinsic capabilities of the proposed repository at Yucca Mountain. Having a more-definitive information on the adequacy of the natural system and the levels of conservatism involved, for example, may well provide all interested and affected parties with important and relevant information. Thus, the Board believes that the DOE should carry out a realistic performance assessment in parallel with its efforts to develop a compliance case. Such a realistic performance	The Department's approach to the TSPA reflects international experience and Nuclear Regulatory Commission (NRC) staff perspectives, and the unique challenge of modeling transport in partially saturated fractured rock. The Department believes that the performance assessment supporting the postclosure compliance analyses is reasonable for this application and has been developed cautiously. However, Department recognizes the Board's perspective that some aspects of the model might be considered unrealistic. Because the approach that the Department is using for postclosure performance assessment has evolved over many years through interaction with NRC staff and is reflected in the Yucca Mountain Review Plan, it is an integral part of our approach to development of the license application. The Department is currently undertaking development of a performance margin analysis of system performance. This would be used (1) as a management and communication tool, (2) to build confidence in the estimate of repository performance in the compliance-based analysis, and (3) to quantify and help understand the degree of overall conservatism in the TSPA. The Department plans to complete performance margin analyses that will use available data to evaluate the extent of conservatism and/or non-conservatism in the conservative compliance-focused analyses. These analyses will complement the TSPA for compliance.

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
assessment would establish a "baseline" for measuring how "conservative" or "non-conservative" DOE's licensing case might be. Although some assumptions still may be required, they, too, will need to be well justified if this realistic assessment is to be carried out credibly. Thus the Board reiterates its view that fundamental understanding is important and encourages the Project to fill in areas where significant gaps in such understanding occur. Further, to address what now appear to be the critical radionuclides contributing to peak dose, the Board recommends that the DOE prepare full and realistic process models that account for the transport of the two radionuclides in question, neptunium-237 and plutonium-242. Such an effort should trace the radionuclides from when they leave the degraded fuel pellet until they are taken up by the "reasonably maximally exposed individual". These analyses should be consistent with the thermal hydraulic analyses used in the thermal management strategy with the calculations extending until the time of peak dose or 1,000,000 years.	
Design and Operation of Surface and Subsurface Facilities	
[The] Board remains concerned that the Project has not fully evaluated the range of consequences associated with implementation of the TAD concept, especially with respect to thermal management. Thus, the Board recommends that the Project carry out a formal analysis that addresses, among other things, the following areas: What are the performance specifications of the TAD? How were they derived? How does the introduction of the TAD affect logistic capabilities and limits?	The Department will continue the integrated system engineering and analyses approach to gain a greater understanding of the interrelationships between the subsystem components: waste acceptance, transportation, and repository operations. These continuing analyses are expected to provide additional insights as design details are further refined and operational scenarios are more fully defined, but will be sequenced to occur as details and scenarios are deemed mature for consideration to ensure that realistic representations of the waste management system are examined. The Department accepted the preliminary TAD performance specifications submitted by BSC. The Department is currently tailoring those specifications to support a procurement action for a TAD conceptual design which, when completed, will address the Board's questions.

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
What constraints on SNF blending does the TAD create? How does the TAD affect surface facility design and operation? How does the TAD affect the sequencing of waste emplacement necessary to maintain the specified line load of 1.45 kW/meter? ….Such an analysis should take into consideration a full complement of scenarios that can evaluate various design and operational assumptions associated with waste acceptance, transport, receipt, and processing at the surface facilities, and emplacement.	The Department has completed its Critical Decision-1 (CD-1) process which included a description of surface facility design and operation effects from the TAD. The Department has approved introduction of a canister-based system into the baseline. CD-1 authorized the preliminary TAD design which is underway.
The Board believes the Project needs to refine its drip shield design and implementation approach….Although the Project has produced some analytical results that it believes show that the drip shield interlocks will withstand seismic events, it is hard to believe that the drip shields will maintain their "as-installed" configuration even as those same events cause the waste packages to fail. Further, the Board believes that the Project needs to address issues related to in-drift operational envelopes and installation tolerances that could potentially increase the difficulty of installing the drip shields remotely. Finally, because the drip shields will not be installed until just before repository closure,…the Project should evaluate now what factors will effect the final design of this EBS component and explain how, when, and by whom decisions about installing drip shields will be made, including whether to install them at all.	The Department agrees that it is important to evaluate factors that will influence the final drip shield design well in advance of repository closure. The Department plans to fabricate prototype drip shields to evaluate operational envelopes and design and installation tolerances in the performance confirmation drifts. In addition, a revision to the *Seismic Consequences Abstraction*, MDL-WIS-PA-000003, is planned to account for drip shield damage as a function of thinning due to corrosion and response to seismic events in intact and collapsed drifts.
Plans for the Waste-Management System	
The Board considers the Total System Model (TSM) being developed by the DOE to have significant potential as a tool for understanding the performance of the coupled waste-management system. The TSM can be used to examine system	The results of TSM analyses were used to evaluate a primarily canister-based system using TADs for commercial spent nuclear fuel (CSNF). Insights from the TSM analysis included, but were not limited to, factors such as dose, thermal management, and waste handling. The Department

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
throughput, identify possible "choke points", and show where various design and operational elements are incompatible. To maximize the value of the TSM, however, the input data must be based on the most up-to date information; critical modeling assumptions must be confirmed; there should be an ability to represent off-normal conditions; and all components of the waste-management system, including emplacement, need to be incorporated in the model. Further, the Board recommends that the Project enhance the TSM in the following ways to increase the model's utility in evaluating the waste-management system: • Add a system optimization module • Allow for stochastic processing times • Incorporate the effects of contingent events, such as major storms, bridge collapses, and delays in the construction of key facilities and system components. The Board recommends that that the TSM be used by designers of surface facilities and all other components of the waste-management system to determine needs and capabilities and to eliminate problems or constraints in the future.	recognizes that information obtained from the utilities is important to the quality of the TSM analyses and success of the canister-based approach. The Department has provided information on the new canister-based approach to cask vendors and nuclear utilities and is evaluating technical issues raised by them regarding developing and licensing of TADs. The Department is committed to continuing the close coordination with cask vendor and nuclear utility representatives, not only in the development of the performance-based specification for TADs, but also in the subsequent design of the TADs. The Department will continue the integrated system engineering and analyses approach to gain a greater understanding of the interrelationships between the subsystem components: waste acceptance, transportation, and repository operations. This will be done in close cooperation with the utilities and cask vendors.
[T]he Board believes that the DOE should move expeditiously to perform a comparative risk analysis of alternate rail corridors that might be used to move spent nuclear fuel and high-level radioactive waste to Yucca Mountain. Once that risk analysis has been completed, the DOE should inform all interested and affected parties what route(s) it prefers. In addition, the DOE should develop a contingency plan for greater use of legal-weight and heavy-haul trucking.	In a Record of Decision published in April 2004, the Department selected "mostly rail" as the mode of transport, both nationally and in the State of Nevada. The "mostly rail" option includes an expectation that some truck shipments will be made. In a Supplement Analysis to the *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-0250F), the Department considered the potential environmental impacts of shipping legal-weight truck casks on railcars. This scenario involved shipments from generator sites to an intermodal transfer station that would be constructed and operated in Nevada and the subsequent transportation of those casks to a repository at the Yucca Mountain site by legal-weight trucks. In the event that the rail line is not completed when the repository begins operations,

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
	these truck transportation options would still be available for initial shipments to Yucca Mountain and will have been fully planned and ready for completion by that time. A full range of transportation contingencies is also being considered for shipment of TAD canisters in the event that the Nevada rail line is not available when the repository begins operations. However, the Department is currently planning the project, subject to available funding, to ensure that the rail line will be completed at least one year before the repository begins operation. Analyses completed for the Final Environmental Impact Statement (FEIS) considered alternative rail corridors with the contingency for some truck shipments.
Localized Corrosion	
Unlike deliquescence-induced localized corrosion, which the Project plans to screen out of the total system performance assessment (TSPA), seepage-induced localized corrosion is not screened out of TSPA. Why seepage-induced localized corrosion and deliquescence-induced localized corrosion are not treated consistently in TSPA remains puzzling to us. The important question is, "Does including deliquescence-induced localized corrosion significantly affect the dose received by the reasonably maximally exposed individual?" Even if the effect is not significant, including this phenomenon would add to the completeness, robustness, and credibility of TSPA. (Garrick, 2007)	The analysis performed by the Project to date concludes that Na-K-Cl-NO_3 (plus other dust components) will define the starting composition of the deliquescent brines that form during the thermal pulse. Any deliquescent brine will contain a temperature-dependent minimum value of NO_3:Cl. The effects of degassing will be to reduce the volume of deliquescent brine and in the limit cause dry-out, or increase NO_3:Cl and the electrolyte pH. Results from experiments conducted at temperatures up to 150°C (Reebak 2006) support the conclusion that localized corrosion will not initiate under deliquescent conditions due to the high NO_3:Cl. Localized corrosion initiation and propagation under deliquescent conditions is further inhibited by the small cathode-to-anode ratio, the lack of oxygen diffusion gradients in the dust layer, the limited quantity of reactants (namely chloride) and the absence of a physical crevice (except in the case of the waste package contacting the pallet). As identified by the Board, the conditions for which data are most limited are for temperatures between 150°C and the maximum predicted waste package temperature of approximately 205°C. Strengthening the Project's position for screening out localized corrosion during the thermal pulse can be achieved by testing under these conditions.

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
	To meet this goal the Project is pursuing a collaborative testing strategy that is being implemented at Lawrence Livermore National Lab (LLNL) and Sandia National Lab (SNL). The driver for this testing is to obtain additional crevice corrosion data under conditions that are representative of the repository during cool down. Thin-film experiments being performed at LLNL are designed to assess the crevice corrosion behavior of Alloy 22 and analogue material at temperatures up to 180°C while maintaining ambient pressure. The strategy is to put representative (or bounding) salt assemblages on the samples, and then expose the samples to RH levels sufficient to allow deliquescence at temperatures up to 180°C. Post-test examination will be used to determine if localized (or uniform) corrosion has occurred on these samples. A complementary effort at SNL involves conducting tests in repository-relevant environments at temperatures up to and exceeding 200°C. Importantly, the environmental chamber is capable of maintaining these conditions at ambient pressure and in an open flow-through system (thus preventing artifacts due to uncontrolled evolution of the test environment). Another aspect of the SNL experiments is the option to monitor initiation and propagation in-situ through the use of a direct-current potential-drop (DCPD). DCPD may be applied to both creviced and uncreviced samples of Alloy 22 and less-resistant analogues in an effort to understand the parameters that control initiation and stifling. Instrumentation may also be included that enables monitoring of deliquescence in parallel with monitoring the damage state of exposed materials.

BOARD FINDINGS AND RECOMMENDATIONS	DOE RESPONSE
Prototype testing	
As mentioned at the meeting, the efficacy of engineering designs—including operational processes—can be tested using prototyping. This is especially important in the case of the Yucca Mountain repository because many of the engineered elements are first-of-a-kind designs. Examples of specific elements that could benefit from engineering prototyping include waste package fabrication, loading, sealing, and emplacement; robotics; and drip-shield emplacement. Experience gained from engineering prototyping will enable OCRWM to identify potentially high-consequence design and operational flaws in an orderly and efficient manner. For example, contemporary industrial experience has shown that metal fabrication defects can be susceptible to localized corrosion. This has important implications for performance of the repository waste packages. Many engineering design specifications are important to TSPA calculations. Consequently, engineering prototyping can serve as an integrating mechanism and a cross-check for TSPA. Finally, engineering prototyping can be helpful as the repository program moves its focus from research and analysis to implementation.	The DOE agrees with the NWTRB recommendations on engineering prototyping and is currently prototyping various equipment. The objective of this work is to gather information to supplement the design, ensure safety requirements are met and to reduce risk for development of unique first-of-a-kind items. In the near term, prototyping is focused on waste package closure equipment and prototyping the waste package, pallet, and drip shield. Note that most spent fuel will be shipped in transportation, aging, and disposal containers (TADs); however, some fuel is expected to arrive in dual purpose containers (DPCs). These DPCs will need to be opened for transfer of contents into TADs. Existing technology for opening DPC's and for opening a sealed waste package needs to be more fully developed; therefore, DPC and waste package opening are planned for prototyping in the future. A waste package closure system (WPCS) is being prototyped. This system performs the operations required to complete closure of the waste package after it has been loaded with TAD canisters, navy canisters, DOE Spent Nuclear Fuel (SNF) canisters, or High Level Waste (HLW) canisters containing SNF or HLW. The objective of prototyping the WPCS is to design, develop, and construct the complete system required to successfully close a loaded waste package. An iterative process of revising and modifying the WPCS design will be part of the prototype process. When construction is finalized, a demonstration of closure operations will be performed on a full-scale mock-up of the waste package. The mock-up will be full diameter but not full height of a waste package. This mock-up will not contain nuclear waste but will be heated to simulate the calculated, loaded waste package temperatures. The purpose of the demonstration is to verify that the individual subsystems and the integrated system function in accordance with the design requirements and to establish closure operations procedures. This program is in progress and is also closely coordinated with the waste package design and prototype program.

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Appendix F

Nuclear Waste Technical Review Board Strategic Plan FY 2008-2013

Nuclear Waste Technical Review Board Strategic Plan FY 2008–2013

Summary Statement of the Board

The Nuclear Waste Policy Amendments Act (NWPAA) 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 commercial spent nuclear fuel and defense high-level radioactive waste. The NWPAA also established the U.S. Nuclear Waste Technical Review Board as an independent agency within the executive branch of the United States Government. The NWPAA requires 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) 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 DOE to comply with its recommendations.

Congress created the Board to perform ongoing independent technical and scientific evaluation—crucial for confidence in decisions related to disposing of spent nuclear fuel and high-level radioactive waste. The Board strives to provide Congress and the Secretary of Energy with unbiased, credible, and timely technical and scientific evaluations and recommendations achieved through peer review of the highest quality. 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.

This strategic plan includes the Board's goals and objectives for fiscal years (FY) 2008 through 2013. During that period, DOE plans to submit to the U.S. Nuclear Regulatory Commission (NRC) an application for authorization to construct a repository. Although the Board realizes that DOE's efforts will be focused on compliance activities, in conducting its evaluation, the Board will encourage DOE through its science and technology program to undertake research and analyses that will increase basic understanding of the potential performance of the entire waste-management system. The Board believes that improving basic understanding will increase confidence in DOE's performance estimates and make them more realistic.

The Board has organized its review of DOE activities into three technical areas: preclosure operations, including surface-facility design and operations and the transport of spent nuclear fuel and high-level radioactive waste from nuclear utility reactors or storage facilities to the repository site; postclosure repository performance issues, including the nature of the source term and the movement of the radionuclides most significant to dose through

the engineered and natural barriers; and integration of science and engineering and preclosure and postclosure activities, including the effects of temperature on repository performance and the effects of waste package designs on the temperatures in the repository. The Board's strategic goals and objectives have been organized around these three technical areas, and the Board's panels have been realigned to help facilitate and focus the Board's review.

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 disposing of high-level radioactive waste] undertaken by the Secretary after the date of the enactment of the Nuclear Waste Policy Amendments Act of 1987, including—

(1) site characterization activities; and

(2) activities relating to the packaging or transportation of high-level radioactive waste or spent nuclear fuel."

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 disposing of the nation's spent nuclear fuel and high-level radioactive waste. The Board provides vital technical and scepeat ientific information to decision-makers in Congress and at DOE and to the public on issues related to disposing of, packaging, and transporting spent nuclear fuel and high-level radioactive waste.

Values

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

- The Board strives to ensure that its members have no real or perceived conflicts of interest related to the outcome of the Secretary's efforts to implement the Nuclear Waste Policy Act (NWPA).
- Board members arrive at their conclusions on the basis of objective and unbiased evaluations of the technical and scientific validity of the Secretary's activities.
- The Board's deliberations are conducted in such a way 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 site-characterization and 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 Board's general goals were established in accordance with its statutory mandate and with congressional action in 2002 authorizing DOE to proceed with the preparation and submittal of an application to the Nuclear Regulatory Commission (NRC) for authorization to construct a repository at Yucca Mountain.

General Goals of the Board

The Board believes that the nuclear waste-management system includes all elements of waste management and disposal. To accomplish its congressional mandate, the Board has organized its review around three technical areas: preclosure operations, including surface-facility design and operations and the transport of spent nuclear fuel and high-level radioactive waste from nuclear utility reactors or storage facilities to the repository site; postclosure repository performance issues, including the nature of the source term and the movement of the radionuclides most significant to dose through the engineered and natural barriers; and integration of science and engineering and preclosure and postclosure activities, including the effects of temperatures on repository performance and the effects of waste package designs on the temperatures in the repository.

The Board's general goals for FY 2008–2013 reflect the importance of gaining a realistic understanding of the potential performance of the proposed repository and the interdependence and interactions of all elements of the nuclear waste management system. The Boards general goals for FY 2008–2013 are the following:

1. Evaluate the technical and scientific validity of activities undertaken by DOE related to preclosure operations.
2. Evaluate the technical and scientific validity of activities undertaken by DOE related to postclosure repository performance.
3. Evaluate the technical and scientific validity of activities undertaken by DOE related to integrating science and engineering and cross-cutting preclosure and postclosure issues.

Strategic Objectives of the Board

To achieve its general goals, the Board has established the following 5-year objectives.

1. Objectives Related to the Preclosure Period

1.1 Evaluate the technical and scientific validity of DOE efforts to implement its canister-based transportation, aging, and disposal (TAD) concept.

1.2. Evaluate DOE efforts to design and construct surface facilities and infrastructure at the proposed repository site.

1.3. Review DOE efforts to develop a plan for transporting waste from nuclear utility reactors or federal storage sites to the proposed repository.

2. Objectives Related to the Postclosure Period

2.1. Evaluate DOE studies and analyses related to determining the source term—the release of dose-contributing radionuclides as a function of time from the engineered-barrier system.

2.2. Encourage DOE to develop realistic performance models and review the technical and scientific validity of DOE efforts to gain a more realistic understanding of potential repository performance.

2.3. Evaluate the technical and scientific validity of DOE data and analyses related to infiltration, flow and transport through the natural system, and seepage into drifts.

2.4. Assess DOE efforts to increase understanding of repository tunnel environments and the potential for localized corrosion of waste packages in the proposed repository.

2.5. Review DOE activities related to predicting the potential effect on dose of disruptive events.

3. Objectives Related to System Integration

3.1. Evaluate DOE efforts to develop thermal criteria for the repository and a strategy for managing the effects of heat on preclosure operations and postclosure repository performance.

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

3.3. Review DOE integration of operational and performance models.

3.4. Review DOE analysis and integration of issues and designs related to receipt, processing, aging, and emplacement of spent nuclear fuel and high-level radioactive waste (e.g., TAD and Yucca Mountain surface facilities).

Achieving Board 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 the Board considers appropriate. At the request of the Board and subject to existing law, the NWPAA directs 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, Congress provided such access with the expectation that the Board will review and comment on DOE decisions, plans, and actions as they occur, not after the fact.

By law, no nominee to the Board may be an employee of 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.

Board Panels

To facilitate and focus the Board's review, the Board has established three panels. The respective focus of the panels corresponds to the Board's general goals.

1. Panel on Preclosure Operations

Panel Focus—Evaluate the technical and scientific validity of activities undertaken by DOE related to waste-management system activities and operations before repository closure.

2. Panel on Postclosure Repository Performance

Panel Focus—Evaluate the technical and scientific validity of activities undertaken by DOE related to understanding, analyzing, and modeling the performance of geologic and engineered components of a proposed Yucca Mountain repository after repository closure.

3. Panel on System Integration

Panel Focus—Evaluate the technical and scientific validity of activities undertaken by DOE related to integrating scientific and engineering activities, operational and performance issues, and preclosure and postclosure design and strategies.

Information Gathering

Much of the Board's information gathering occurs at open public meetings arranged by the Board. At each meeting, 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 meetings for comments from members of the public and interested parties. The full Board usually meets three times each year. The Board's panels and smaller Board cohorts meet as needed to investigate specific issue areas. Typically, two of the three full Board meetings are held in Nevada each year.

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 analogs.

Technical Analysis

Technical analysis is performed by Board members with assistance from the full-time technical staff. When necessary, the Board hires special expert consultants to perform in-depth reviews of specific technical and scientific topics.

Cross-Cutting Functions

As discussed in the following paragraphs, the Board's ongoing peer review complements the activities of other organizations involved in disposing of and managing spent nuclear fuel and high-level radioactive waste.

- *Congress and the Administration, including the Secretary of Energy,* make decisions on and establish national policies for nuclear waste disposal. They also determine how such decisions and policies 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 as context for their decision-making.
- *Other federal agencies* with roles in disposing of and managing spent nuclear fuel and high-level radioactive waste include DOE, the NRC, the Environmental Protection Agency (EPA), the Department of Transportation (DOT), and the United States Geological Survey. 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.
- *State and local governments* comment on and perform oversight of DOE activities, and other interest groups monitor DOE activities related to a Yucca Mountain repository. The Board's technical evaluation is at once different from and complementary to the activities of these groups 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 an independent federal agency with Board members who are nominated by the National Academy of Sciences and appointed by the President on the basis of their expertise in the various disciplines represented in the DOE program.

Key External Factors

Some factors are beyond the Board's control and 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 peer-review body that makes recommendations to DOE. According to the legislative history, Congress expected that DOE would accept the Board's recommendations or indicate why the recommendations could not or should not be implemented. However, DOE is not legally obligated to accept any of the Board's recommendations. If DOE does not accept a Board recommendation, the Board's recourse is to advise Congress or reiterate its recommendation to DOE, or both. The Board's recommendations and 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 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 enacted or how the Board might be affected by such legislation.

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 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 its 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 DOE's 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, 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 first 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, which were incorporated in an earlier revision. Comments on this revised strategic plan will be solicited on the Board's Web site: www.nwtrb.gov.

Appendix G

Nuclear Waste Technical Review Board
Fiscal Year (FY) 2007 Budget Request Submittal

Including Performance Evaluation for FY 2005 and Supplementary Information about the Board

Nuclear Waste Technical Review Board Fiscal Year (FY) 2007 Budget Request Submittal

Summary and Highlights

This is the U.S. Nuclear Waste Technical Review Board's performance-based budget request for fiscal year (FY) 2007. The request will support the Board efforts to achieve its performance goals for the year. The performance goals are listed in the budget document and have been established in accordance with the Board's congressional mandate: Conduct an independent evaluation of the technical and scientific validity of U.S. Department of Energy (DOE) activities related to disposing of commercial spent nuclear fuel and defense high-level radioactive waste. These activities include evaluating the proposed Yucca Mountain repository site in Nevada and packaging and transporting the waste. The Board's ongoing peer review is vital to the credibility of the DOE's technical and scientific activities.

In 2002, Congress approved the President's recommendation of Yucca Mountain and authorized the DOE to proceed with preparing an application that will be submitted to the U. S. Nuclear Regulatory Commission (NRC) for a license to construct a repository at Yucca Mountain. Throughout this process, the Board has evaluated the technical and scientific validity of DOE work and has reported its findings to Congress and the Secretary of Energy.

The Board's performance goals for FY 2007 have been updated to reflect expected DOE activities during that period. For example, the Board will review DOE activities related to increasing understanding of the natural system, developing a radionuclide risk profile derived from Total System Performance Assessment (TSPA), analyzing the implications of DOE plans for a transportation, aging, and disposal canister system, and assessing issues relevant to thermal loading and waste-package lifetime. The Board also will review DOE activities related to planning and implementing a waste management system and designing, planning, and developing repository surface facilities. The Board is requesting $3,670,000 to support these activities in FY 2007.

U.S. Nuclear Waste Technical Review Board

Salaries and Expenses (Including Transfer of Funds)

For necessary expenses of the Nuclear Waste Technical Review Board, as authorized by Public Law 100-203, section 5051, $3,670,000 to be transferred from the Nuclear Waste Fund and to remain available until expended.

(2006 Energy and Water Development Appropriations Act, P.L. 109-103)

Board Budget Request for FY 2007

Background

Approximately 2,000 metric tons of spent nuclear fuel are produced each year by nuclear reactors and are stored at more than 70 sites nationwide. By the time the presently operating reactors reach the end of their scheduled 40-year lifetimes (at some time in the 2030's), approximately 87,000 metric tons of spent fuel will have been produced. (This estimate does not include spent nuclear fuel from plants that may be granted license renewals by the NRC.) In addition, high-level radioactive waste (HLW) from defense activities has been stored at numerous federal facilities throughout the country. Disposal of the spent nuclear fuel and HLW in a deep geologic repository is the primary approach being pursued by the United States and other countries.

In early 2002, the Secretary of Energy recommended approval of the Yucca Mountain site to the President. The President then recommended the site to Congress. The State of Nevada later disapproved the recommendation. Both the U.S. House of Representatives and the U.S. Senate went on to approve the site recommendation. Since that time, the DOE has focused on preparing an application to be submitted to the NRC for authorization to construct a repository at the Yucca Mountain site. Throughout this process, the Board has evaluated the technical basis of the DOE's work and communicated Board views to Congress and the Secretary of Energy in letters, reports, and congressional testimony.

The Board's Continuing Role

The Board was established by Congress in the Nuclear Waste Policy Amendments Act of 1987 (NWPAA). The Board is charged with evaluating the technical and scientific validity of activities undertaken by the Secretary of Energy, including site-characterization activities and activities related to the packaging and transportation of HLW and spent nuclear fuel. Board technical and scientific findings and recommendations are included in reports that are submitted at least twice each year to Congress and the Secretary. In creating the Board, Congress realized that an ongoing independent and expert evaluation of the technical and scientific validity of the DOE's site-evaluation and other waste-management activities would be crucial to acceptance by the public and the scientific community of any approach for disposing of spent nuclear fuel and HLW.

The Board's Funding Requirement for FY 2007: $3,670,000

The Board's budget request of $3,670,000 for FY 2007 represents the funding needed to accomplish the Board's performance goals for the year. During FY 2007, the Board intends to continue its evaluation of the technical and scientific validity of DOE activities,

including those related to increasing understanding of the natural system, developing a radionuclide risk profile derived from TSPA, analyzing tradeoffs between preclosure and postclosure risks, assessing issues relevant to thermal loading and waste-package lifetime, and evaluating the implications of plans for a transportation, aging, and disposal canister system. The Board also will review DOE activities related to planning and implementing a waste management system and designing, planning, and developing repository surface facilities. The amount requested will support the work of the Board members who will conduct the comprehensive review described above, enable the Board to comply with extensive federal security requirements related to the Board's information systems, and allow the Board to undertake a financial audit in accordance with the Accountability of Tax Dollars Act (ATDA).

Performance-Based Budget for FY 2007

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

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 NWPAA. Such activities include characterizing the Yucca Mountain site and packaging and transporting spent nuclear fuel and HLW.

The Board's general goals and strategic objectives are set forth in its strategic plan for FY 2004–2009. They have been established in accordance with the Board's statutory mandate and with congressional action in 2002 authorizing the DOE to proceed with developing an application to the NRC for authorization to construct a repository at Yucca Mountain. The Board's performance goals for FY 2007 have been established in accordance with its general goals and objectives. The Board's performance-based budget for FY 2007 has been developed to enable the Board to meet its performance goals for the year.

The Board will accomplish its goals by doing the following:

- Holding up to three public meetings with the DOE and DOE contractor personnel involving the full Board and holding meetings of the Board panels, as needed.
- When appropriate, holding fact-finding sessions involving small groups of Board members who will focus in depth on specific technical topics.
- Reviewing critical documents provided by the DOE and its contractors, including TSPA, preclosure safety analyses (PCSA), contractor reports, analysis and modeling reports (AMR), and design drawings and specifications.
- When appropriate, visiting and observing ongoing investigations, including those conducted at the national laboratories or potential analog sites.
- Visiting programs in other countries and attending national and international symposia and conferences.

The Board's performance goals for FY 2007, which are described below, are divided into four topical areas that correlate with the purviews of the Board's panels. The numbering system has been simplified, and performance goals have been updated from previous years to reflect current activities. Amounts have been allocated preliminarily to each set of performance goals for FY 2007.

Performance Goals for FY 2007

1. Performance Goals Related to the Natural System

(Dollars in Thousands)		
FY 05	**FY 06**	**FY 07**
839	893	917

1.1. Review DOE activities related to natural-system performance, including tests of models and assumptions, and pursuit of independent lines of evidence.

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.

1.3. Review DOE efforts in addressing questions related to possible seismic and igneous events and consequences.

1.4. Evaluate data and test results obtained from testing in the enhanced characterization of the repository block (ECRB) and other facilities.

1.5. Evaluate DOE efforts to analyze the source term and to estimate what radionuclides will be mobilized and transported through the natural system at what time periods.

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

1.7. Recommend additional work needed to address uncertainties related to estimates of the rate and distribution of water seepage into repository tunnels, given anticipated infiltration rates.

1.8. Review DOE efforts in integrating results of scientific studies related to the behavior of the natural system into repository designs.

1.9. Review plans and studies undertaken by the Office of Science & Technology and International (OSTI) related to the natural system.

2. Performance Goals Related to the Engineered System

(Dollars in Thousands)		
FY 05	**FY 06**	**FY 07**
1,006	1,071	1,101

2.1. Review DOE activities related to the engineered system in response to changes in the regulatory compliance period.

2.2. Review thermal-mechanical and rock-stability testing on potential conditions in repository tunnels.

2.3. 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.

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

2.5. Review DOE analyses of facilities, systems, and component designs, including the transportation, aging, and disposal canister.

2.6. Evaluate the accuracy and completeness of the technical bases for repository and waste package designs.

2.7. Evaluate the integration of subsurface and repository designs, layout, and operational plans into an overall thermal management strategy.

2.8. Assess the integration of scientific studies into engineering designs for the repository and the waste package.

2.9. Evaluate the plans and activities of the OSTI related to the engineered system.

3. Performance Goals Related to Repository System Performance and Integration.

(Dollars in Thousands)		
FY 05	**FY 06**	**FY 07**
671	714	735

3.1. Identify technical and scientific activities that are on the critical path to reconciling uncertainties related to DOE performance estimates in light of changes in the regulatory compliance period.

3.2. Evaluate strengths and weaknesses of TSPA.

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

3.4. Evaluate activities undertaken by the DOE to develop a risk profile for specific radionuclides.

3.5. Evaluate DOE efforts to develop a realistic analysis of repository performance.

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

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

3.8. Evaluate DOE efforts to develop a feedback loop among performance-confirmation activities and TSPA models and data.

3.9. Monitor the DOE's proposed performance-confirmation plans to help ensure that uncertainties are addressed.

3.10. Review plans and studies undertaken by the OSTI related to overall performance of the repository.

4. Performance Goals Related to the Waste Management System

(Dollars in Thousands)		
FY 05	**FY 06**	**FY 07**
839	894	917

4.1. Evaluate the integration of the repository facility, including the surface and subsurface components.

4.2. Evaluate the design of surface facilities, including the fuel handling and aging facilities, and how the design affects and is affected by the thermal management of the repository.

4.3. Review DOE procedures for ensuring that waste accepted for disposal has been suitably characterized.

4.4. Monitor DOE efforts to implement Section 180 (c) of the NWPA.

4.5. Monitor the DOE's progress in developing and implementing a transportation plan for shipping spent nuclear fuel and HLW to a Yucca Mountain repository.

4.6. Review DOE efforts to develop criteria for routing decisions.

4.7. Evaluate logistics capabilities of the transportation system.

4.8. Monitor progress in implementing new technologies for improving transportation safety for spent nuclear fuel, including transportation, aging, and disposal canisters and casks.

4.9. Evaluate DOE plans for enhancing safety capabilities along transportation corridors, and review DOE planning and coordination activities, accident prevention activities, and emergency response activities.

4.10. Review the potential and limits of the total system model.

Budget Request by Object Class

Object Class 11.1, Full-Time Staff: $1,724,000

The amount requested for full-time permanent staff is based on the requirement to fund a total of 15 positions. Because the Board's technical and scientific evaluations are conducted by Board members supported by professional staff, the Board's enabling legislation authorizes the Board chairman to appoint and fix the compensation of not more than 10 senior professional staff members. This request assumes the use of all 10 positions under this authority. In addition, the chairman is authorized to appoint such clerical and administrative staff as may be necessary to discharge the responsibilities of the Board. The other 5 positions funded under this object class are support staff engaged in clerical, secretarial, and administrative activities; development and dissemination of Board publications; information technology, including maintenance of the Board's Web site; public affairs; and meeting logistics for the Board. The small administrative staff supports the very active part-time Board members and full-time professional staff.

The estimate assumes a 1.022 percent combined cost-of-living adjustment and locality raise in January 2007 for both General Schedule and Executive Schedule employees.

Object Class 11.3, Other than Full-Time Permanent Staff: $376,000

The amount requested for this category includes compensation for Board members. Each Board member will be compensated at the rate of pay for Level III of the Executive Schedule for each day that the member is engaged in work for the Board. The 11 Board members serve on a part-time basis equaling 2 full-time equivalent positions. The budget assumes that each member will attend 3 full Board meetings, 2 panel meetings, and an average of 2 additional meetings or field trips during the year. This estimate represents an average of 57 workdays per member in

FY 2007. This estimate also assumes a 1.022 percent increase in Executive Schedule compensation for employees in this category for FY 2007 (effective January 2007).

Object Class 11.5, Other Personnel Compensation: $47,000

The amount requested for this category covers approximately 80 hours of staff overtime and performance awards under the Performance Management System approved by the Office of Personnel Management (OPM). Most Board and panel meetings require considerable overtime for on-site meeting logistics and other preparations.

Object Class 12.1, Civilian Personnel Benefits: $441,000

The estimate for this category represents the government's contribution for employee benefits at the rate of 25.75 percent for staff and 7.65 percent for members.

Object Class 21.0, Travel: $298,000

The amount requested for this object class includes travel costs for Board members, staff, and consultants traveling to Board and panel meetings, to other meetings (including professional meetings, conferences, and orientation activities) and sites to acquire technical and scientific data, and to Yucca Mountain in Nevada to review site activities within the scope of the Board's mission. The request is based on 11 Board members attending 3 Board and 2 panel meetings and making an average of 2 other trips during the year at an average length of 3 days each, including travel time. In addition, the 10 professional staff members will travel on similar activities an average of 8 trips during the year at an average of 3 days per trip. In FY 2007, the expectation is that the DOE may increase its activities related to planning for transportation and packaging of the waste and designing the repository surface and subsurface facilities. The Board's meetings will increase commensurately and will be held in parts of the country affected by the DOE action.

Object Class 23.1, Rental Payments to the General Services Administration (GSA): $197,000

The estimate for this object class represents the amount that the Board will pay to the GSA for rental of office space totaling 6,288 sq. ft. at an annual rate of $31.34 per sq. ft.

Object Class 23.3, Communications, Utilities, Miscellaneous: $24,000

The requested amount represents estimates for telephone service, postage, local courier services, video teleconferencing, FTS long-distance telephone service, the Internet, and mailing services related to management and use of the Board's mailing list.

Object Class 24.0, Printing and Reproduction: $22,000

The major items in this object class are the publication of reports to the U.S. Congress and the Secretary of Energy, publication of meeting notices in the Federal Register, production of press releases announcing meetings and report publication, and production of other informational materials for Board members and the public. All Board meeting are open to the public, and copies of meeting materials are provided. Members of the public who live in rural areas and who do not have Web access may be interested in obtaining printed copies of Board documents.

Object Class 25.1, Consulting Services: $103,000

Consultants will be hired when necessary to support and supplement Board and staff analysis of specific technical and scientific issues. This will enable the Board to conduct the kind of comprehensive technical and scientific review mandated by Congress.

Object Class 25.2, Other Services: $177,000

This category includes court-reporting services for an estimated five Board or panel meetings, meeting-room rental and related services, maintenance agreements for equipment, professional development, and services from commercial sources. In addition, the Board will contract with part-time technical consultants to supplement and support in-house operations in systems management, Web site management, report production, and editing. Costs of a financial audit to comply with the Accountability of Tax Dollars Act also are included in this category.

Object Class 25.3, Services from Other Government Agencies: $108,000

This category includes GSA administrative support services (payroll, accounting, personnel, etc.), legal advice from GSA, security clearances through OPM, and other miscellaneous interagency agreements.

Object Class 26.0, Supplies and Materials: $62,000

Anticipated expenses include routine office supplies, subscriptions and library materials, and off-the-shelf technical reports and studies.

Object Class 31.0, Equipment: $91,000

This estimate is for miscellaneous equipment costs, including audiovisual equipment and computer hardware, and computer-network software maintenance. In addition, funds are included to support the Federal Information Security Act, which requires federal agencies to periodically test and evaluate the effectiveness of their information security policies, procedures, and practices. The category also includes continued upgrades to IT security and continuity of operations (COOP) availability, support to E-Gov telecommuting efforts, and technical support of the management of electronic records and e-mails.

Nuclear Waste Technical Review Board
Projected 2007 Expenditures

Object Classifications

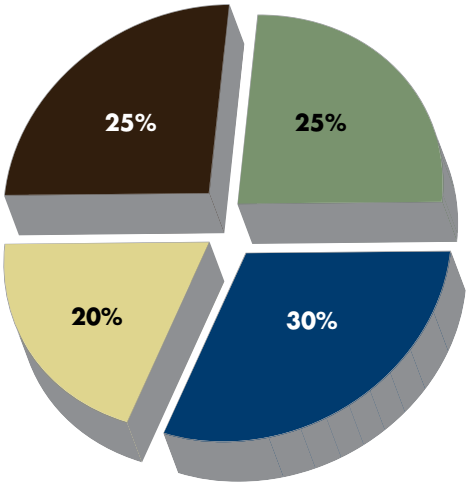
(in thousands of dollars)

Identification Code 48-0500-0-1-271		FY05 ACT	FY06 EST	FY07 REQ
Expenditures				
11.1	Full-Time Permanent	$1,605	$1,686	$1,724
11.3	Other than Full-Time Permanent	364	366	376
11.5	Other Personnel Compensation	30	47	47
12.1	Civilian Personnel Benefits	401	430	441
21.0	Travel and Transportation	328	312	298
23.1	Rental Payments to GSA	185	184	197
23.3	Communication, Utilities, Miscellaneous	24	26	24
24.0	Printing and Reproduction	16	20	22
25.1	Consulting Services	101	103	103
25.2	Other Services	169	148	177
25.3	Services from Government Accounts	59	69	108
26.0	Supplies and Materials	42	61	62
31.0	Equipment	31	120	91
99.9	Total Obligations	$3,355	$3,572	$3,670

Nuclear Waste Technical Review Board Salaries and Expenses

Personnel Summary

Identification Code 48-0500-0-1-271	05 ACT	06 EST	07 REQ
Total Number of Full-Time Permanent Positions	17	17	17
Total Compensable Work-Years: Full-Time Equivalents	17	17	17



Natural System (natural barriers at Yucca Mt.)	25%
Engineered System (engineered barriers at Yucca Mt.)	30%
Repository System Performance and Integration	20%
Waste Management System (including transportation)	25%

ADDENDUM A

Nuclear Waste Technical Review Board Performance Evaluation

Fiscal Year 2005

The U.S. Nuclear Waste Technical Review 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 commercial spent nuclear fuel and defense high-level radioactive waste. The Act also established the U.S. Nuclear Waste Technical Review Board (Board) as an independent agency within the executive branch of the United States Government. The Act directs the Board to evaluate continually the technical and scientific validity of activities undertaken by the Secretary of Energy related to disposing of, transporting, and packaging the waste and to report its findings and recommendations to Congress and the Secretary of Energy at least twice yearly. The Board only can make recommendations; it cannot compel the DOE to comply. 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.

Board Performance Criteria and Method of Evaluation

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, the Board has developed the following criteria to measure its annual performance in achieving individual performance goals.

1. Did the Board undertake the reviews, analyses, or other activities needed to evaluate the technical and scientific validity of the DOE activity identified in the performance goal?

2. Were the results of the Board's evaluation communicated in a timely, understandable, and appropriate way to Congress, the Secretary of Energy, the Office of Civilian Radioactive Waste Management (OCRWM), or the public?

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 or outdated, it will be noted in the evaluation.

The Board will use this evaluation of its own performance from fiscal year (FY) 2005, together with its assessment of current or potential key technical issues of concern related to the DOE program, to develop its annual performance objectives and to inform spending allocations in its performance-based budget for subsequent years.

Performance Evaluation for FY 2005

The Board's performance goals for FY 2005 were developed to achieve the general goals and strategic objectives in the Board's strategic plan for fiscal years 2004–2009. The goals also were 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 U. S. 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.

This evaluation will be submitted to the Office of Management and Budget (OMB), attached to the Board's budget request to Congress for FY 2007, included in the Board's summary report for 2005, and posted on the Board's Web site (www.nwtrb.gov). The reliability and completeness of the performance data used to evaluate the Board's performance relative to its annual performance goals are high and can be verified by accessing the referenced documents on the Board's Web site.

Strategy for Achieving Performance Goals

To evaluate DOE activities and achieve its performance goals, the Board engages in the following activities in any given year:

- Holding public meetings of the full Board and of Board panels.
- Reviewing the common DOE database, including scientific literature and laboratory and field data, contractor reports, analysis and model reports, and total system performance assessment (TSPA).
- Meeting with DOE contractor principal investigators on technical issues, observing ongoing tests and laboratory and field investigations, and visiting potential analog sites.
- Visiting nuclear waste disposal programs in other countries and attending national and international symposia and conferences.

In addition, in FY 2005, small contingents of Board members and staff held fact-finding meetings with the DOE, its contractors, and key stakeholders (e.g., representatives of the rail and trucking industries, the nuclear utilities, and logistics service providers). The fact-finding meetings enabled the Board to engage in concentrated discussions of important technical issues and to understand better how the DOE applies fundamental methods of analysis. Those meetings facilitated and enhanced the Board's evaluation of current issues of importance to the DOE program and helped identify additional technical issues that will be the focus of the Board's evaluation of DOE activities in coming years. In the following evaluation of the Board's performance for FY 2005, the meetings are referenced by date and the topics discussed.

For this evaluation, the Board's performance goals for FY 2005 have been organized and numbered to correlate with appropriate strategic objectives in the Board's strategic plan for FY 2004–2009.

FY 2005 Board Performance Goals and Evaluation

1. The Natural System

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

Evaluation of 1.1.1: Effective. *Explanation: During FY 2005, the Board engaged in several fact-finding meetings at which activities of the Office of Science & Technology and International (OSTI) were discussed. In its letter dated November 30, 2004, to OCRWM director, Dr Margaret Chu, the Board commented on the importance of the science and technology program. In its December 30, 2004, letter report to Congress and the Secretary of Energy, the Board again commented on the importance of the science and technology effort.*

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

Evaluation of 1.1.2: Effective. *Explanation: The Board held a fact-finding meeting on SZ flow and transport on September 7-8, 2005. The DOE's work related to understanding SZ flow and transport was discussed in some detail at the meeting. The Board's December 2004 report to Congress and the Secretary described studies and analyses under way indicating that the natural system might be an effective barrier against radionuclide migration and identifying a better understanding of the waste-isolation characteristics and behavior of the natural system as an area requiring more attention.*

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

Evaluation of 1.1.3: Effective. *Explanation: The Board commented on DOE efforts to increase fundamental understanding of the Yucca Mountain site in its November 2004 letter to Dr. Chu. The Board's December 2004 report to Congress and the Secretary described studies and analyses under way indicating that the natural system might be an effective barrier against radionuclide migration and identifying a better understanding of the waste-isolation characteristics and*

behavior of the natural system as an area requiring more attention. In the same letter report, the Board stated that estimates of the performance of the natural barriers should be based on multiple lines of evidence. The Board held two fact-finding meetings during FY 2005, at which the SZ and the unsaturated zone (UZ) were discussed in detail.

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

Evaluation of 1.2.1: Effective. *Explanation: The Board commented on the DOE's progress in developing realistic ground-motion estimates in its November 2004 letter to Dr. Chu and noted that OSTI was undertaking work in this area. The Board included its comments on realistic ground-motion estimates in its December 2004 letter report to Congress and the Secretary. In the same report, the Board noted the completion of an aeromagnetic survey that could shed light on igneous activity at Yucca Mountain and commented on the need to improve modeling of volcanic consequences.*

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

Evaluation of 1.3.1: Effective. *Explanation: The Board commented on the importance of maintaining access to the ECRB in its November 2004 letter to Dr. Chu. The Board held a fact-finding meeting on June 27-28, 2005, at which issues relevant to testing in the ECRB were discussed. The Board will comment on the need to complete studies in the ECRB in its December 2005 report to Congress and the Secretary.*

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

Evaluation of 1.3.2: Effective. *Explanation: The Board commented on the importance of completing the drift-scale heater test in its November 2004 letter to Dr. Chu. The Board held a fact-finding meeting on the UZ in June 2005 at which issues relevant to the drift-scale heater test were discussed. The Board will comment on the need to complete the drift-scale test in its December 2005 report to Congress and the Secretary.*

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

Evaluation of 1.3.3: Minimally effective/deferred. *Explanation: The DOE did not report on its activities in this area during FY 2005. The Board will comment on the need to continue testing at the Peña Blanca analog site in its December 2005 letter report to Congress and the Secretary.*

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: Effective. *Explanation: The Board discussed with the OCRWM ways to reduce technical and scientific uncertainty and make performance estimates more realistic at several fact-finding meetings held in 2005. The Board commented on the need for a clear explanation and understanding of repository conditions after closure in its December 2004 letter report to Congress and the Secretary. In the same*

report, the Board cited the need to address uncertainties related to the pervasiveness of capillary and thermal barriers, which will affect seepage into repository tunnels. The Board commented on the DOE's climate studies using opal dating in its April 19, 2005, letter to OCRWM director, Theodore Garrish.

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

Evaluation of 1.4.1: Minimally Effective/deferred. *Explanation: The Board discussed tunnel stability at its fact-finding meeting with the DOE on surface/subsurface facility design and operations held on September 19-20, 2005. Plans are under way for a small fact-finding meeting with the OCRWM in early 2006 to discuss research results from OSTI work.*

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

Evaluation of 1.5.1: Effective. *Explanation: The Board discussed these issues with the OCRWM at a fact-finding meeting on surface/subsurface facility design on Sept. 19-20, 2005. The Board commented on the need for such integration in its November 2004 letter to Dr. Chu. Integration of TSPA and repository design was discussed at a meeting of the full Board held on February 9–10, 2005.*

2. The Engineered System

2.1.1. Monitor the DOE's performance allocation studies.

Evaluation of 2.1.1: Outdated goal. *Explanation: No such DOE studies were performed in FY 2005 or are expected. This goal will be eliminated in FY 2006.*

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

Evaluation of 2.2.1: Effective. *Explanation: The DOE's thermal management strategy was discussed at a meeting of the full Board in February 2004. The Board held fact-finding meetings with the OCRWM on thermal management on September 20–21, 2005, and on surface/subsurface facility design on September 19-20, 2005, at which these issues were discussed.*

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: Effective. *Explanation: Several Board members participated in three fact-finding meetings with the OCRWM at which these issues were discussed. The Board commented on the corrosion resistance of Alloy-22 in magmas and the potential for stress-corrosion cracking in its November 2004 letter to Dr. Chu. In its December 2004 letter report to Congress and the Secretary, the Board noted that a major issue involving deliquescence-induced localized corrosion had been addressed by the DOE. In the same report, the Board raised several other corrosion issues that require continued attention, including the presence of ammonium ion in repository tunnels and potential stress-corrosion cracking of the drip shield.*

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: Effective. *Explanation: See evaluation of 2.2.2.*

2.3.2. Evaluate DOE efforts in identifying natural and engineered analogs for corrosion processes.

Evaluation of 2.3.2: Deferred. *Explanation: The DOE did not engage in such activities during FY 2005.*

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

Evaluation of 2.4.1: Effective. *Explanation: At the Board's February 2004 meeting, the DOE presented information related to the integration of TSPA results into repository design efforts. Several members of the Board participated in a September 2005 fact-finding meeting with the DOE on surface and subsurface facility design at which these issues were discussed.*

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: Effective. *Explanation: At the Board's February 2004 meeting, the DOE presented information related to the integration of TSPA results with repository design efforts. Several members of the Board participated in a September 2005 fact-finding meeting on surface and subsurface facility design at which these issues were discussed. In its November 2004 letter to Dr. Chu, the Board commented on the need to analyze engineering design using TSPA.*

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

Evaluation of 2.4.3: Effective. *Explanation: See evaluation of 2.4.2.*

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

Evaluation of 2.5.1: Effective. *Explanation: Several members of the Board participated in a September 2005 fact-finding meeting with the OCRWM on surface and subsurface facility design at which these issues were discussed. The Board commented on the need to analyze and integrate engineering design using TSPA in its November 2004 letter to Dr. Chu.*

3. Repository System Performance and Integration

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

Evaluation of 3.1.1: Effective. *Explanation: During 2005, Board members participated in fact-finding meetings with the DOE designed to provide detailed information on technical and scientific issues currently important to the DOE repository program. The Board's December 2004 letter report to Congress and the Secretary provided an overview of the Board's views on areas of progress and issues requiring additional attention.*

3.1.2. Determine the strengths and weaknesses of TSPA.

Evaluation of 3.1.2: Effective. *Explanation: Several Board members participated in a fact-finding meeting with the OCRWM on TSPA in August 2005 at which*

these issues were discussed at length. The Board commented on issues related to integration and model validation in its November 2004 letter to Dr. Chu. The Board commented further on these issues in its December 2004 report to Congress and the Secretary. In its April 2005 letter to Mr. Garrish, the Board noted that TSPA will need to address relevant hydrologic processes that may be significant beyond 10,000 years and that technical and scientific elements of TSPA might change if the standard is modified.

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

Evaluation of 3.1.3: Effective. *Explanation: Several Board members participated in a fact-finding meeting with the DOE on TSPA in August 2005 at which these issues were discussed. In its November 2004 letter to Dr. Chu, the Board pointed out that engineering design and operations should be analyzed using TSPA to determine the potential significance of changes on the overall repository system. The Board used as an example that if the repository is modified to mitigate the effects of igneous activity, the modifications should be evaluated for their effects on repository performance. The Board also commented on the DOE's progress in making its ground-motion estimates more realistic. The same issues were raised in the Board's December 2004 letter report to Congress and the Secretary.*

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

Evaluation of 3.2.1: Minimally Effective. *Explanation: Several Board members participated in a fact-finding meeting with the DOE on TSPA in August 2005 at which these issues were discussed.*

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: Effective. *Explanation: Several Board members participated in a fact-finding meeting with the DOE on TSPA in August 2005 at which these issues were discussed. In its April 2005 letter to Mr. Garrish, the Board noted that TSPA will need to address relevant hydrologic processes that may be significant beyond 10,000 years and that technical and scientific elements of TSPA might change if the standard is modified.*

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

Evaluation of 3.3.1: Effective. *Explanation: Several Board members participated in a fact-finding meeting on TSPA in August 2005 at which these issues were discussed. The Board will comment in its year-end report in December 2005 that the DOE should prepare a parallel analysis that can be used by policy-makers, the public, and the technical and scientific community to understand how the natural and engineered components of a repository would work together to isolate waste and to gauge the degree of conservatism of TSPA assumptions and estimates.*

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

Evaluation of 3.3.2: Effective. *Explanation: See Evaluation of 3.3.1.*

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

Evaluation of 3.3.3: Deferred. *Explanation: The DOE did not present any information to the Board on this topic in FY 2005.*

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: Effective. *Explanation: In its December 2004 letter report to Congress and the Secretary, the Board encouraged the DOE to continue studies that will lead to a better understanding of the contribution of the natural system. The Board will comment in its year-end report in 2005 that the DOE should prepare a parallel analysis that can be used by policy-makers, the public, and the technical and scientific community to understand how the natural and engineered components of a repository would work together to isolate waste and to gauge the degree of conservatism of TSPA assumptions and estimates.*

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.

Evaluation of 3.5.1: Minimally effective. *Explanation: In September 2005, several Board members participated in a fact-finding meeting with the DOE on surface and subsurface facility design at which these issues were discussed. This performance goal will be modified in FY 2006.*

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

Evaluation of 3.6.1: Effective. *Explanation: In its April 2005 letter to Mr. Garrish, the Board stated that program integration is of continuing Board interest and could affect the DOE's safety case. The Board will comment in its year-end report in December 2005 that the DOE should prepare a parallel analysis that can be used by policy-makers, the public, and the technical and scientific community to understand how the natural and engineered components of a repository would work together to isolate waste and to gauge the degree of conservatism of TSPA assumptions and estimates.*

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

Evaluation of 3.7.1: Effective. *Explanation: The DOE updated the Board on its performance-confirmation (PC) plans at the Board's February 2004 meeting. In the Board's April 2005 letter to Mr. Garrish, the Board observed that many activities identified to be undertaken as part of PC can be used for validating modeling assumptions that form the basis of TSPA. The Board noted that rather than being integrated, PC is operating independently of TSPA and of the ongoing work on repository design.*

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

Evaluation of 3.7.2: Effective. *Explanation: See evaluation of 3.7.1.*

4. 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: Effective. *Explanation: Several Board members participated in a fact-finding meeting with the DOE in September 2005 on surface and subsurface facility design and operations at which these issues were discussed in detail. In a November 2004 letter to Dr. Chu, the Board discussed integration of the total waste management system. The Board commented on integration of the waste management system in its December 2004 letter report to Congress and the Secretary, indicating that planning and design of an integrated waste management system would remain a top priority for the Board. The DOE presented an overview of waste management-system integration at the Board's February 2005 meeting. The Board commented again on these issues in its April 2005 letter to Mr. Garrish.*

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: Effective. *Explanation: See evaluation of 4.1.1.*

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.

Evaluation of 4.1.3: Effective. *Explanation: See evaluation of 4.1.1.*

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: Effective. *Explanation: See evaluation of 4.1.1.*

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

Evaluation of 4.1.5: Minimally effective/deferred. *Explanation: Some discussion of these issues took place at a fact-finding meeting with stakeholders in October 2005. The Board will review whatever activities the DOE undertakes in this area in FY 2006.*

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

Evaluation of 4.2.1: Effective. *Explanation: The Board's Panel on the Waste Management System held a meeting in October 2004 at which the DOE's development of Section 180(c) programs was discussed, including reactions to the DOE efforts by state and regional stakeholders. In a follow-up letter to Dr. Chu, the Board observed that emergency planning through the 180(c) program appeared to be based on funding formulas and not enough on ensuring that adequate emergency response capacity exists along all selected routes. The issue was raised again at a fact-finding meeting with stakeholders in October 2005.*

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: Effective. *Explanation: The Board's panel on the Waste Management System met with the DOE and stakeholders in October 2004. The*

meeting agenda was devoted entirely to this topic. The Board sent a letter to Dr. Chu in December 2004 following up on issues identified at the October panel meeting. Some issues discussed in the letter included transportation planning—the Board recommended a systematic approach; security and emergency response planning; transportation risk assessment—the Board suggested a more risk-based approach; route selection; and program integration. The Board's December 2004 letter to Congress and the Secretary acknowledged transportation as an area where the DOE had made progress. Development of the waste management system was identified as a top priority for future Board review. In February 2005, the Board held a panel meeting on transportation—specifically, the Nevada branch line—in Caliente, Nevada. The Board sent a letter to Mr. Garrish on these subjects in April 2004.

4.3.2. Review DOE efforts to develop criteria for transportation mode and routing decisions.

Evaluation of 4.3.2: Effective. *Explanation: This topic was discussed at the Board's October 2004 panel meeting and in the December 2004 follow-up letter to the DOE. The Board indicated that it was advisable to involve state regional and tribal groups in developing the criteria. The Board noted that of particular importance was that technical issues are identified and that sound methods for addressing them are developed and applied.*

4.3.3. Evaluate logistics capabilities of the transportation system.

Evaluation of 4.3.3: Effective. *Explanation: In the Board's April 2005 letter to the DOE, the total system model was mentioned as having potential for planning and integrating the waste management system. In its December 2004 letter, the Board suggested that the DOE work with utilities in designing the waste management system. This topic was discussed at a fact-finding meeting with transportation service providers in October 2005. In the Board's December 2005 letter to Congress and the Secretary, the Board suggested that the DOE should determine first-hand the logistics capabilities at the reactor sites.*

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

Evaluation of 4.3.4: Effective. *Explanation: In the Board's April 2005 letter to the DOE, the total system model was mentioned as having potential for planning and integrating the waste management system. This topic also was discussed at a fact-finding meeting with transportation service providers in October 2005.*

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.: ***Effective.*** *Explanation: See evaluation of 4.3.4.*

ADDENDUM B

Supplementary Information on the Nuclear Waste Technical Review Board

The U.S. Nuclear Waste Technical Review Board was established on December 22, 1987, in the Nuclear Waste Policy Amendments Act (NWPAA) as an independent agency in the executive branch of the federal government. The Board is charged with evaluating the technical and scientific validity of activities undertaken by the Secretary of Energy, including the following:

- site characterization
- activities related to packaging and transporting high-level radioactive waste and spent nuclear fuel.

The Board was given broad latitude to review activities undertaken by the Secretary of Energy in implementing the Nuclear Waste Policy Act. However, the Board was not given authority to require the DOE to implement Board recommendations.[1]

Board Members

The NWPAA authorized a Board of 11 members who serve on a part-time basis; are eminent in a field of science or engineering, including environmental sciences; and are selected solely on the basis of distinguished professional service. The law stipulates that the Board shall represent a broad range of scientific and engineering disciplines relevant to nuclear waste management. Board members are appointed by the President from a list of candidates recommended by the National Academy of Sciences. To prevent gaps in the Board's comprehensive technical review, Board members whose terms have expired continue serving until they are reappointed or their replacements assume office. The first members were appointed to the Board on January 18, 1989. Current members were appointed by President George W. Bush.

The names and affiliations of the current 10 Board members are listed below.

[1] Taken from Legislative History of the Nuclear Waste Policy Amendments Act of 1987, February 26, 1998.

- B. John Garrick, Ph.D., P.E., is chairman of the Board. A founder of PLG, Inc., he retired from the firm in 1997 and is a private consultant. His areas of expertise include probabilistic risk assessment and application of the risk sciences to technology-based industries.
- Mark Abkowitz, Ph.D., is a professor in the Department of Civil & Environmental Engineering and director of the Vanderbilt Center for Environmental Management studies at Vanderbilt University. His areas of expertise include risk management, transportation of hazardous materials, emergency preparedness, and applications of advanced information technology.
- William Howard Arnold, Ph.D., P.E., a private consultant, retired from Louisiana Energy Services in 1996. He holds a doctorate in experimental physics and has special expertise in nuclear project development.
- Thure Cerling, Ph.D., is a professor in the Department of Geology and Geophysics at the University of Utah. His areas of expertise include terrestrial geochemistry.
- David Duquette, Ph.D., is professor and head of the Department of Materials Science and Engineering at Rensselaer Polytechnic Institute in New York. His areas of expertise include the physical, chemical, and mechanical properties of metals and alloys.
- George M. Hornberger, Ph.D., is Ernest H. Ern Professor of Environmental Sciences in the Department of Environmental Sciences at the University of Virginia. His areas of expertise include catchment hydrology and hydrochemistry and transport of colloids in geologic media.
- Andrew C. Kadak, Ph.D., is a Professor of the Practice in the Nuclear Engineering Department of the Massachusetts Institute of Technology. His areas of expertise include nuclear engineering and the development of advanced reactors.
- Ron Latanision, Ph.D., is a professor at the Massachusetts Institute of Technology with joint appointments in the Department of Materials Science and Engineering and the Department of Nuclear Engineering. His areas of expertise include materials processing and corrosion of metals and other materials in aqueous environments.
- Ali Mosleh, Ph. D., is professor of reliability engineering at the University of Maryland. His areas of expertise include risk and safety assessment reliability analysis and decision analysis.
- Henry R. Petroski, Ph.D., P.E., is professor of civil engineering and professor of history at Duke University. His areas of expertise include failure analysis and design theory.

Board Staff

The NWPAA limits the Board's professional staff to 10 positions. An additional 5 full-time employees provide administrative support to Board members and the professional staff. Because of the comprehensive nature of the program, the diversity of Board member experience and expertise, and the part-time availability of Board members, the small, highly qualified staff is employed to its full capacity in supporting the Board's review of the DOE program. The Board's offices are in Arlington, Virginia.

Board Reporting Requirements

As required under the NWPAA, the Board reports to the U.S. Congress and the Secretary of Energy at least two times each year. The reports include Board recommendations related to improving the technical and scientific validity of activities undertaken by the Secretary of Energy under the civilian radioactive waste management program. The DOE's written responses to Board recommendations are published in the Board's annual summary reports.

Board Activities

The Board and its panels sponsor meetings and technical exchanges with program participants and interested parties, including representatives of the DOE and its contractors, the U.S. Nuclear Regulatory Commission, the U.S. Environmental Protection Agency, the U.S. Geological Survey, the U.S. Department of Transportation, the State of Nevada, affected units of local governments, Native American tribes, nuclear utilities, environmental groups, state utility regulators, and members of the public. Board members and staff attend relevant technical conferences, meetings, symposia, and workshops. They participate in field trips and occasionally visit foreign programs to gain insights from the experience of other countries' repository development efforts.

Board and panel meetings are open to the public and are announced in the Federal Register four to six weeks before each meeting. To facilitate access for program participants and the public, the Board holds the majority of its meetings in the State of Nevada, and time is set aside for public comment at each meeting. Transcripts of Board and panel meetings and all Board reports, correspondence, and congressional testimony are available to the public via telephone or written request or can be obtained from the Board's Web site: www.nwtrb.gov.

Appendix H

Nuclear Waste Technical Review Board
Fiscal Year (FY) 2008 Budget Request Submittal

Including Performance Evaluation for FY 2006 and Supplementary Information about the Board

Nuclear Waste Technical Review Board Fiscal Year (FY) 2008 Budget Request Submittal

Summary and Highlights

The U.S. Nuclear Waste Technical Review Board's performance-based budget request for fiscal year (FY) 2008 will support Board activities related to achieving its performance goals for the year. The Board's general goals, strategic objectives, and annual performance goals are listed in the budget document and have been established in accordance with the Board's congressional mandate to conduct an independent evaluation of the technical and scientific validity of U.S. Department of Energy (DOE) activities related to disposing of commercial spent nuclear fuel and defense high-level radioactive waste. Such activities include developing performance estimates for, designing, and potentially constructing a repository at Yucca Mountain in Nevada. The Board also is mandated to review DOE activities related to packaging and transporting the waste to the proposed repository site. The Board's ongoing peer review is vital to the credibility of DOE's technical and scientific activities.

In FY 2007, the Board organized its review of DOE activities into three technical areas: *preclosure operations*, including surface-facility design and operations and the transport of spent nuclear fuel and high-level radioactive waste from nuclear utility reactors or storage facilities to the repository site; *postclosure* repository performance issues, including the nature of the source term and the movement of the radionuclides most significant to dose through the engineered and natural barriers; and the *integration* of science and engineering and preclosure and postclosure activities, including the effects of temperatures on repository performance and the effects of waste package designs on the temperatures in the repository.

The Board's strategic goals and objectives have been organized around these three technical areas and the Board's panels have been realigned to help facilitate and focus the Board's review. In addition, the Board's performance goals for FY 2008 have been updated to reflect the reorganization of the Board's approach to evaluation and expected DOE activities during the period. For example, the Board will review DOE activities related to developing realistic models of repository performance; determining the source term—the release of dose-contributing radionuclides as a function of time from the engineered-barrier system; implementing the transportation, aging, and disposal (TAD) program; analyzing the potential for localized corrosion of waste packages; and developing a

technically-based and integrated thermal management strategy. The Board is requesting $3,621,000 to support its comprehensive technical review in FY 2008.

U.S. Nuclear Waste Technical Review Board

Salaries and Expenses (Including Transfer of Funds)

For necessary expenses of the Nuclear Waste Technical Review Board, as authorized by Public Law 100-203, section 5051, $3,621,000 to be transferred from the Nuclear Waste Fund and to remain available until expended.

Note. — The regular FY 2007 appropriation for this account had not been enacted at the time the budget was prepared; therefore, this account is operating under a Continuing Resolution (P.L. 109-289, Division B, as amended). The amounts included for FY 2007 in this budget reflect the levels provided by the Continuing Resolution.

(2006 Energy and Water Development Appropriations Act, P.L. 109-103)

Board Performance-Based Budget Request for FY 2008

Background

Approximately 2,000 metric tons of spent nuclear fuel are produced each year by nuclear reactors and are stored at more than 70 sites nationwide. By the time the presently operating reactors reach the end of their scheduled 40-year lifetimes (at some time in the 2030's), approximately 87,000 metric tons of spent fuel will have been produced. (This estimate does not include spent nuclear fuel from plants that may be granted license renewals by the NRC.) In addition, high-level radioactive waste (HLW) from defense activities has been stored at numerous federal facilities throughout the country. Disposal of the spent nuclear fuel and HLW in a deep geologic repository is the primary approach being pursued by the United States and other countries.

In early 2002, the Secretary of Energy recommended approval of the Yucca Mountain site to the President. The President then recommended the site to Congress. The State of Nevada later disapproved the recommendation. Later that same year, both the U.S. House of Representatives and the U.S. Senate formally approved the site recommendation. Since that time, DOE has focused on preparing an application to be submitted to NRC for authorization to construct a repository at the Yucca Mountain site. Throughout this process, the Board has evaluated the technical basis of DOE's work and communicated Board views to Congress and the Secretary of Energy in letters, reports, and congressional testimony.

The Board's Continuing Role

The Board was established by Congress in the Nuclear Waste Policy Amendments Act (NWPAA) of 1987. The Board is charged with evaluating the technical and scientific validity of activities undertaken by the Secretary of Energy, including site-characterization activities and activities related to the packaging and transportation of HLW and spent nuclear fuel.[1] Board technical and scientific findings and recommendations are included in reports that are submitted at least twice each year to Congress and the Secretary. In creat-

[1] 42 U.S.C. 10263

ing the Board, Congress realized that an ongoing independent and expert evaluation of the technical and scientific validity of DOE's site-evaluation and other waste-management activities would be crucial to acceptance by the public and the scientific community of any approach for disposing of spent nuclear fuel and HLW.

Board Funding Requirement for FY 2008: $3,621,000

The Board's budget request of $3,621,000 for FY 2008 represents the funding needed to accomplish the Board's performance goals for the year. During FY 2008, the Board will continue to review DOE activities, including those related to developing realistic models of repository performance; determining the source term—the release of dose-contributing radionuclides as a function of time from the engineered-barrier system; implementing the transportation, aging, and disposal (TAD) concept; analyzing the potential for localized corrosion of waste packages; and developing a technically-based and integrated thermal management strategy. The amount requested will support the work of the Board members who will conduct the comprehensive review described above and enable the Board to comply with extensive federal security requirements related to the Board's information systems.

Board General Goals and Strategic Objectives for FY 2007–2012

The Board's general goals and strategic objectives were revised in its strategic plan for FY 2007–2012. They have been established in accordance with the Board's statutory mandate and with anticipated DOE activities during the five-year period.

General Goals

The Board's general goals for FY 2007–2012 reflect the importance of gaining a realistic understanding of the potential performance of the proposed repository and the interdependence and interactions of all elements of the nuclear waste management system.

The following are the Board's general goals for FY 2007–2012.

1. Evaluate the technical and scientific validity of activities undertaken by DOE related to preclosure operations.
2. Evaluate the technical and scientific validity of activities undertaken by DOE related to postclosure repository performance.
3. Evaluate the technical and scientific validity of activities undertaken by DOE related to integrating science and engineering and cross-cutting preclosure and postclosure issues.

Strategic Objectives

To achieve its general goals, the Board has established the following 5-year objectives.

1. Objectives Related to the Preclosure Period

1.1 Evaluate the technical and scientific validity of DOE efforts to implement its TAD canister concept.

1.2. Evaluate DOE efforts to design and construct surface facilities and infrastructure at the proposed repository site.

1.3. Review DOE efforts to develop a plan for transporting waste from reactor or federal storage sites to the proposed repository.

2. Objectives Related to the Postclosure Period

2.1. Evaluate DOE studies and analyses related to determining the source term of the release of dose-contributing radionuclides as a function of time from the engineered-barrier system.

2.2. Encourage DOE to develop realistic performance models and review the technical and scientific validity of DOE efforts to gain a more realistic understanding of potential repository performance.

2.3. Evaluate the technical and scientific validity of DOE data and analyses related to infiltration, flow and transport through the natural system, and seepage into drifts.

2.4. Assess DOE efforts to increase understanding of repository tunnel environments and the potential of localized corrosion of waste packages in the proposed repository.

2.5. Review DOE activities related to predicting the potential effect on dose of disruptive events.

3. Objectives Related to System Integration

3.1. Evaluate DOE efforts to develop thermal criteria for the repository and a strategy for managing the effects of heat on preclosure operations and postclosure repository performance.

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

3.3. Review DOE integration of operational and performance models.

3.4. Review DOE analysis and integration of issues and designs related to receipt, processing, aging, and emplacement of spent nuclear fuel and high-level radioactive waste (e.g., TAD and Yucca Mountain surface facilities).

Board Performance Goals for FY 2008

The Board's performance goals for FY 2008 have been established in accordance with its general goals and strategic objectives. The Board's performance-based budget for FY 2008 has been developed to enable the Board to meet its performance goals for the year.

The Board will accomplish its goals by doing the following:

- Holding up to three public meetings with DOE and DOE contractor personnel involving the full Board and holding meetings of the Board panels and technical workshops, as needed.
- When appropriate, holding fact-finding sessions involving small groups of Board members who will focus in depth on specific technical topics.
- Reviewing critical documents provided by DOE and its contractors, including TSPA, preclosure safety analyses (PCSA), contractor reports, analysis and modeling reports (AMR), and design drawings and specifications.

- When appropriate, visiting and observing ongoing investigations, including those conducted at the national laboratories or potential analog sites.
- On occasion, visiting programs in other countries and attending national and international symposia and conferences.

The Board's performance goals for FY 2008, which are described below, are divided into three technical areas that correlate with the Board's recently reorganized panel structure. The numbered goals also correspond with the Board's strategic objectives. Funding allocations for fiscal years 2006, 2007, and 2008 are indicated for each set of performance goals.

1. Performance Goals Related to Preclosure Operations

(Dollars in Thousands)		
FY 06	**FY 07**	**FY 08**
898	**917**	**905**

1.1.1. Review DOE analyses of facilities, systems, and component designs related to implementation of the TAD.

1.1.2 Review DOE procedures for ensuring that waste accepted for disposal has been suitably characterized.

1.2.1 Evaluate the design of surface facilities, including the fuel handling and aging facilities, and how the design affects and is affected by the thermal management of the repository.

1.3.1 Evaluate DOE's analysis of the comparative risks of alternative transportation modes and routes.

1.3.2. Review DOE efforts to develop criteria for routing decisions.

1.3.3 Evaluate logistics capabilities of the transportation system.

1.3.4. Evaluate DOE plans for enhancing safety capabilities along transportation corridors, review DOE planning and coordination activities, accident prevention activities, and emergency response activities.

2. Performance Goals Related to Postclosure Repository Performance

(Dollars in Thousands)		
FY 06	**FY 07**	**FY 08**
1,796	**1,835**	**1,811**

2.1.1. Evaluate DOE efforts to analyze the source term and to estimate the length of time it will take for radionuclides to be mobilized and transported through the natural system.

2.1.2. Evaluate activities undertaken by DOE to develop a risk profile for specific radionuclides.

2.2.1. Review updates of Total System Performance Assessment (TSPA) models; identify models and data that should be updated.

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

2.2.3. Evaluate results of studies undertaken by the science and technology program related to reducing uncertainties about the performance of the natural and engineered components of the repository.

2.2.4. Evaluate information from the science and technology program on secondary mineral phases and neptunium and plutonium mobilization.

2.2.5. Review DOE efforts to develop and articulate a repository safety case.

2.3.1. 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.

2.3.2. Review new infiltration work undertaken in response to questions about QA procedures used to obtained previous infiltration estimates.

2.4.1. 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.

2.4.2. Review thermal-mechanical and rock-stability testing on potential conditions in repository tunnels.

2.5.1. Review DOE efforts in addressing questions related to possible seismic and igneous events and consequences.

3. Performance Goals Related to System Integration

(Dollars in Thousands)		
FY 06	**FY 07**	**FY 08**
897	**918**	**905**

3.1.1. Evaluate the accuracy and completeness of the technical bases for repository and waste package designs.

3.1.2. Evaluate the integration of subsurface and repository designs, layout, and operational plans into an overall thermal management strategy.

3.2.1. Assess the integration of scientific studies into engineering designs for the repository and the waste package.

3.2.2. Review DOE efforts in integrating results of scientific studies related to the behavior of the natural system into repository designs.

3.2.3. Evaluate the integration of the repository facility, including the surface and subsurface components.

3.3.1. Review the potential and limits of the Total System Model (TSM).

3.4.1. Review DOE analyses and integration of designs for facilities, systems, and repository components, including TAD.

3.4.2. Evaluate DOE efforts to assess and integrate information on surface facilities and infrastructure at nuclear utility reactor sites.

FY 2008 Budget Request by Object Class

Object Class 11.1, Full-Time Staff: $1,810,000

The amount requested for full-time permanent staff is based on the requirement to fund 15 total positions. Because the Board's technical and scientific evaluations are conducted by Board members supported by professional staff, the Board's enabling legislation authorizes the Board chairman to appoint and fix the compensation of not more than 10 senior professional staff members. This request assumes the use of all 10 positions under this authority. In addition, the chair is authorized to appoint such clerical and administrative staff as may be necessary to discharge the responsibilities of the Board. The other 5 positions funded under this object class are support staff engaged in clerical, secretarial, and administrative activities; development and dissemination of Board publications; information technology, including maintenance of the Board's Web site; public affairs; financial and meeting logistics for the Board. The small administrative staff supports the very active part-time Board members and full-time professional staff.

The estimate assumes a 1.031 percent combined cost-of-living adjustment and locality raise in January 2008 for both General Schedule and Executive Schedule employees.

Object Class 11.3, Other than Full-Time Permanent Staff: $361,000

The amount requested for this category includes compensation for Board members. Each Board member will be compensated at the rate of pay for Level III of the Executive Schedule for each day that the member is engaged in work for the Board. The 11 Board members serve on a part-time basis equaling 2 full-time equivalent positions. The budget assumes that each member will attend 3 full Board meetings, 1 panel meeting, and an average of 3 additional meetings or field trips during the year. This estimate represents an average of 54 workdays per member in FY 2008. This estimate also assumes a 1.031 percent increase in Executive Schedule compensation for employees in this category for FY 2008 (effective January 2008).

Object Class 11.5, Other Personnel Compensation: $36,000

The amount requested for this category covers performance awards under the Performance Management System approved by the Office of Personnel Management (OPM).

Object Class 12.1, Civilian Personnel Benefits: $468,000

The estimate for this category represents the government's contribution for employee benefits at the rate of 25.6 percent for staff and 7.65 percent for members.

Object Class 21.0, Travel: $283,000

The amount requested for this object class includes travel costs for Board members, staff, and consultants traveling to Board and panel meetings, to other meetings (including professional meetings, conferences, and orientation activities) and sites to acquire technical and scientific data, and to Yucca Mountain in Nevada to review site activities within the scope of the Board's mission. The request is based on 11 Board members attending 3 Board and 1 panel meeting and making an average of 3 other trips during the year at an average length of 3 days each, including travel time. In addition, the 10 professional staff members will travel on similar activities an average of 9 trips during the year at an average of 3 days per trip. In FY 2008, the expectation is that DOE may increase its activities

related to planning for transportation and packaging of the waste and designing the repository surface and subsurface facilities. The Board's meetings will increase commensurately and will be held in parts of the country affected by DOE action.

Object Class 23.1, Rental Payments to the General Services Administration (GSA): $202,000

The estimate for this object class represents the amount that the Board will pay to the GSA for 6,288 square feet of office space.

Object Class 23.3, Communications, Utilities, Miscellaneous: $21,000

The requested amount represents estimates for telephone service, postage, local courier, video teleconferencing, FTS long-distance telephone service, the Internet, and mailing services related to management and use of the Board's mailing list.

Object Class 24.0, Printing and Reproduction: $17,000

The major items in this object class are the publication of reports to the U.S. Congress and the Secretary of Energy, publication of meeting notices in the Federal Register, production of press releases announcing meetings and report publication, and production of other informational materials for Board members and the public. All Board meetings are open to the public, and copies of meeting materials are provided at the meetings. Members of the public who live in rural areas and who do not have Web access receive the Board's material upon request.

Object Class 25.1, Consulting Services: $41,000

Consultants will be hired to support and supplement Board and staff analysis of specific technical and scientific issues. This will enable the Board to conduct the kind of comprehensive technical and scientific review mandated by Congress.

Object Class 25.2, Other Services: $145,000

This category includes court-reporting services for an estimated four Board or panel meetings, meeting-room rental and related services, maintenance agreements for equipment, professional development, and services from commercial sources. In addition, the Board will contract with part-time technical consultants to supplement and support in-house operations in systems management, Web site management, report production, and editing. Costs of a financial audit to comply with the Accountability of Tax Dollars Act also are included in this category.

Object Class 25.3, Services from Other Government Agencies: $100,000

This category includes GSA administrative support services (payroll, accounting, personnel, etc.), legal advice from GSA, security clearances through OPM, and other miscellaneous interagency agreements.

Object Class 26.0, Supplies and Materials: $54,000

Anticipated expenses include routine office supplies, subscriptions and library materials, and off-the-shelf technical reports and studies.

Object Class 31.0, Equipment: $83,000

This estimate is for miscellaneous equipment costs, including computer hardware, and computer-network software maintenance. In addition, funds are included to support the Federal Information Security Act, which requires federal agencies to periodically test and evaluate the effectiveness of their information security policies, procedures, and practices. The category also includes continued upgrades to IT security and continuity of operations (COOP) availability, support to E-Gov telecommuting efforts, and technical support of the management of electronic records and e-mails.

Nuclear Waste Technical Review Board

Projected 2008 Expenditures

Object Classifications

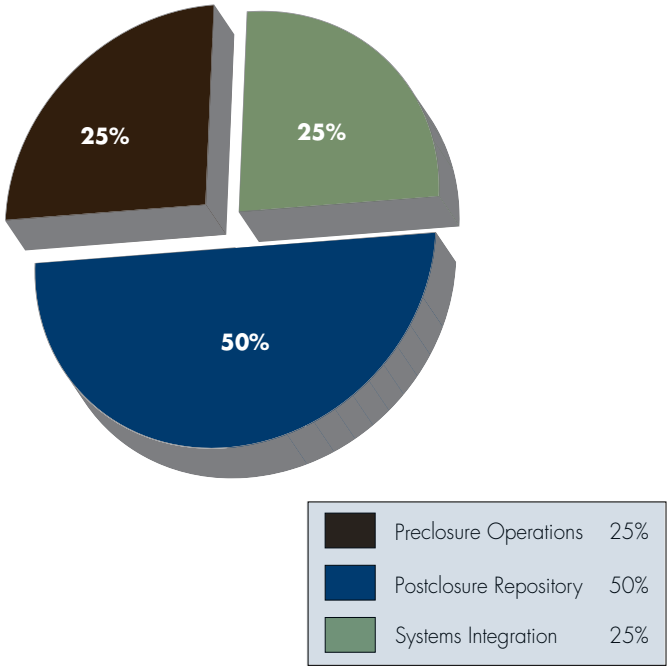
(in thousands of dollars; numbers are rounded)

Identification code 48-0500-0-1-271	FY 06 ACT	FY 07 REQ	FY 07 CR	FY 08 REQ
Expenditures				
Full-time Permanent	$1,558	$1,724	$1,725	$1,810
Board Members	362	367	365	361
Other Personnel Compensation	46	56	41	36
Total Personnel Compensation	**$1,966**	**$2,147**	**$2,131**	**$2,207**
Civilian Personnel Benefits	392	441	446	468
Travel and Transportation	336	298	250	283
Rental Payments to GSA	190	197	197	202
Communication, Utilities, Miscellaneous	25	24	26	21
Printing and Reproduction	9	23	16	17
Consulting Specialists	93	103	83	41
Other Services	291	177	233	145
Services from Government Accounts	102	108	89	100
Supplies and Technical Publications	52	62	58	54
IT Equipment and upgrades	135	91	80	83
Total Obligations	**$3,591**	**$3,670**	**$3,608**	**$3,621**

NOTE: FY 07 CR - salaries based on 2007 pay raise according to government guidelines.

Identification Code 48-0500-0-1-271	06 ACT	07 REQ	08 REQ
Total Number of Full-Time Permanent Positions	16	17	17
Total Compensable Work-Years: Full-Time Equivalents	16	17	17

FY 2008 Budget Request Resource Allocation



ADDENDUM A

Nuclear Waste Technical Review Board

Performance Evaluation

Fiscal Year 2006

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 commercial spent nuclear fuel and defense 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 directs the Board to evaluate continually the technical and scientific validity of activities undertaken by the Secretary of Energy related to disposing of, transporting, and packaging the waste and to report its findings and recommendations to Congress and the Secretary of Energy at least twice yearly. The Board only can make recommendations; it cannot compel DOE to comply. 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.

Board Performance Criteria and Method of Evaluation

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 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, the Board has developed the following criteria to measure its annual performance in achieving individual performance goals.

1. Did the Board undertake the reviews, analyses, or other activities needed to evaluate the technical and scientific validity of DOE activity identified in the performance goal?
2. Were the results of the Board's evaluation communicated in a timely, understandable, and appropriate way to Congress, the Secretary of Energy, the Office of Civilian Radioactive Waste Management (OCRWM), or the public?

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 or outdated, it will be noted in the evaluation.

The Board uses its annual performance evaluations, together with its assessment of current or potential key technical issues of concern related to DOE program, to develop its annual performance objectives and to inform spending allocations in its performance-based budget for subsequent years. The Boards evaluation of its success in achieving its performance goals for FY 2006 will be submitted to the Office of Management and Budget (OMB), attached to the Board's budget request to Congress for FY 2008, included in the Board's summary report for 2006, and posted on the Board's Web site (www.nwtrb.gov).

Performance Evaluation for FY 2006

The Board accomplishes its goals by doing some or all of the following:

- Holding up to three public meetings with DOE and DOE contractor personnel involving the full Board and holding meetings of the Board panels, as needed.
- When appropriate, holding fact-finding sessions involving small groups of Board members who will focus in depth on specific technical topics.
- Reviewing critical technical documents provided by DOE and its contractors, including TSPA, preclosure safety analyses (PCSA), contractor reports, analysis and modeling reports (AMR), and design drawings and specifications.
- When appropriate, visiting and observing ongoing technical and scientific investigations, including those conducted at the national laboratories or potential analog sites.
- Visiting programs in other countries and attending national and international symposia and conferences.

The Board's performance goals for FY 2006 that are listed below are divided into four topical areas that correspond to the Board's panel structure as it was organized in FY 2006. The numbering of the performance goals also correlates with the Board's general goals and strategic objectives set forth in its strategic plan for FY 2004-2009. Each performance goal is followed by a bullet that contains an evaluation of the Board's performance in achieving the performance goal and an explanation of the basis for the evaluation.

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

1. Performance Goals and Evaluation Related to the Natural System

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

Evaluation of 1.1.1: Effective. *The Board commented on the importance of work undertaken by the S&T program in its December 19, 2005, letter to OCRWM acting director, Paul Golan. In the Board's December 30, 2005, letter report to*

Congress and the Secretary, the Board recommended that DOE integrate corrosion data from work undertaken by the S&T program into repository performance estimates. In the same report, the Board signaled its intention to review S&T work related to an enhanced technical basis for predictions of the behavior of water in the repository environment. Board Chairman John Garrick encouraged the continuation of S&T work on the source term in testimony before the Senate Energy and Natural Resources Committee on May 16, 2006.

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: Effective. *The Board expressed concern to DOE about chlorine-36 studies that affect the technical basis for predictions of water flow in its December 19, 2005, letter to Paul Golan, acting director of OCRWM. The Board reiterated the concern in its letter report to Congress and the Secretary dated December 30, 2005. The issues of water flow and radionuclide transport were discussed at the Board's February 1, 2006, meeting. In testimony before the Senate Energy and Natural Resources Committee on May 16, 2006, Dr. Garrick reported that the Board believes that DOE has made progress in obtaining information on groundwater flow in the unsaturated and saturated zones under ambient temperature conditions. However, Chairman Garrick pointed out that the Board continues to believe that additional information is needed on secondary minerals and on colloid-facilitated radionuclide transport. The Board commented extensively on these issues in its June 2006 report to Congress and the Secretary.*

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

Evaluation of 1.1.3: Effective. *The Board received a science update at its meeting on November 8, 2005, and commented on a number of issues in a follow-up letter to OCRWM acting director Paul Golan on December 19, 2005, including the conclusion of large-scale tests, work at the Piña Blanca analog site, and the need to develop a realistic analysis of potential repository performance in parallel with a compliance case. In its December 30, 2005, letter report to Congress and the Secretary, the Board commented on the importance of determining the nature of the source term for predications of repository performance, raised questions about the "multi-scale" water flow model; and reiterated the need for a realistic analysis of repository performance. These issues were discussed at the Board's February 1, 2006, meeting, and in a March 6, 2006, letter to Paul Golan following the meeting. They also were touched on in Dr. Garrick's May 16, 2006, testimony before the Senate Energy and Natural Resources Committee and in Board answers to follow-up questions from members of the Committee after the hearing. The issues were discussed extensively in the Board's June 2006 report to Congress and the Secretary.*

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

Evaluation of 1.2.1: Ineffective. *The Board did not review or comment on DOE's work in this area during the period covered by the evaluation.*

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

Evaluation of 1.3.1: Effective. *The Board commented on the conclusion of a number of major tests, including those conducted behind the bulkhead in the ECRB, in its letter to OCRWM acting director Paul Golan dated December 19, 2005. The Board recommended that DOE complete and fully assess post-test characterization. The Board reiterated its comments in a report to Congress and the Secretary of Energy on December 30, 2005.*

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

Evaluation of 1.3.2: Effective. *The Board commented on the conclusion of a number of major tests, including the drift-scale heater test in its letter to OCRWM acting director Paul Golan on December 19, 2005. The Board recommended that DOE complete and fully assess post-test characterization data and use the information to supplement understanding of thermal-chemical-hydrologic effects. The Board reiterated its comments in a report to Congress and the Secretary of Energy on December 30, 2005.*

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

Evaluation of 1.3.3: Effective. *The Board commented on DOE's efforts to assess natural analogs in its letter to Paul Golan dated December 19, 2005; in its December 30, 2005, report to Congress and the Secretary; and in its June 2006 report to Congress and the Secretary.*

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: Effective. *In a December 19, 2005, letter to Paul Golan, OCRWM acting director, the Board recommended testing in the unsaturated and saturated zones and a continuation of analog-site studies on the potential performance of natural barriers; testing on secondary minerals and colloid-facilitated radionuclide transport; and a resolution of discrepancies among chlorine-36 studies. Those recommendations were reiterated in the Board's December 30, 2005, letter report to Congress and the Secretary. The topic of water seepage into repository drifts was discussed at the Board's February 1, 2006, meeting. In its follow-up letter to OCRWM acting director Paul Golan, dated March 6, 2006, the Board recommended continuation of studies relating to the source term. Chairman Garrick commented on the need for more information on the source term in testimony before the Senate Energy and Natural Resources Committee on May 16, 2006. The Board also stated its recommendations in its report to Congress and the Secretary of Energy released in June 2006.*

1.4.1. Evaluate tunnel-stability studies undertaken by DOE.

Evaluation of 1.4.1: Deferred. *The Board did not review DOE efforts in this area but signaled its intention to do so in the future in its letter to Congress and the Secretary dated December 30, 2005.*

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

Evaluation of 1.5.1: Effective. *In a letter dated December 19, 2005, to Paul Golan, OCRWM acting director, the Board urged DOE to determine the factors that will affect drip-shield performance and incorporate them into designs and operational plans. The Board recommended that the implications of thermal constraints be considered in designing elements of the waste management system, including the waste package and repository surface and subsurface facilities in its December 30, 2005, letter report to Congress and the Secretary. In the same letter and report, the Board noted the importance of assessing the results of recently concluded tests that may increase understanding of how the natural barrier will affect the performance of the engineered barriers. Chairman Garrick mentioned the importance of considering the system-wide implications of DOE's thermal-management strategy in testimony before the Senate Energy and Natural Resources Committee on May 16, 2006. These issues also were discussed at-length in the Board's June 2006 report to Congress and the Secretary.*

2. Performance Goals and Evaluation Related to the Engineered System

2.1.1. Monitor DOE's performance-allocation studies.

Evaluation of 2.1.1: Eliminated. *DOE did not undertake such work in the timeframe being evaluated. There is no indication that such work will be undertaken in the future.*

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

Evaluation of 2.2.1: Effective. *In its December 19, 2005, letter to Paul Golan, OCRWM acting director, and in its December 30, 2005, letter report to Congress and the Secretary, the Board commented on the need to obtain additional data on thermal conductivity of repository rocks.*

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: Effective. *DOE presented information on corrosion testing at the Board's November 8, 2005, meeting. The Board commented in a December 19, 2005, follow-up letter to OCRWM acting director Paul Golan that the Board has continuing concerns about DOE's technical basis for screening out localized corrosion from Total System Performance Assessment for license application (TSPA-LA). The Board reiterated the concern in its letter report to Congress and the Secretary dated December 30, 2005, in testimony before the Senate Energy and Natural Resources Committee on May 16, 2006, and in its report to Congress and the Secretary of Energy released in June 2006. The Board held a workshop on*

these issues in September 2006 and will send its findings and recommendations to OCRWM and Congress and the Secretary in FY 2007.

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: Effective. *DOE presented information on corrosion testing at the Board's November 8, 2005, meeting. The Board commented in a December 19, 2005, follow-up letter to OCRWM acting director Paul Golan that the Board has continuing concerns about DOE's technical basis for screening out localized corrosion from TSPA-LA. The Board reiterated the concern in its letter report to Congress and the Secretary dated December 30, 2005, in testimony before the Senate Energy and Natural Resources Committee on May 16, 2006, and in its report to Congress and the Secretary of Energy released in June 2006. The Board held a workshop on these issues in September 2006 and will send its findings and recommendations to OCRWM and Congress and the Secretary in FY 2007.*

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

Evaluation of 2.3.2: Deferred. *DOE did not undertake such work during the period being evaluated.*

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

Evaluation of 2.4.1: Effective. *DOE assessed differences in repository surface facility designs using the Total System Model (TSM). The Board discussed the TSM at its November 8, 2005, meeting and commented on the use and potential of the model in its follow-up letter to OCRWM acting director Paul Golan on December 19, 2005, and its report to Congress and the Secretary dated December 30, 2005. The Board discussed repository surface-facility designs at its meeting on May 9, 2006, and commented on the use of TSM to help guide surface-facility design in its letter to Paul Golan dated June 14, 2006. The Board also discussed these issues in its report to Congress and the Secretary released in June 2006.*

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

Evaluation of 2.4.2: Effective. *As part of its review of DOE's transportation, aging, and disposal (TAD) canister concept, the Board commented on the need to integrate TAD into a waste-management system that effectively balances preclosure safety and long-term repository performance in its December 19, 2005, letter to Paul Golan, acting director of OCRWM. Similar points were made by the Board in its December 30, 2005, letter report to Congress and the Secretary, testimony before the Senate Energy and Natural Resources Committee on May 16, 2006, and in the Board's report to Congress and the Secretary released in June 2006. The focus of the Board's May 9, 2006, meeting was TAD, and in a follow-up letter to Paul Golan, the Board underscored its interest in the performance specification for the TAD canister and its relationship to the postclosure thermal-management strategy.*

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

Evaluation of 2.4.3: Effective. *In its December 19, 2005, letter to Paul Golan, acting director of OCRWM, the Board emphasized that the success of the TAD concept depended on the integration of the TAD into a waste-management system that effectively balances preclosure safety and long-term repository performance. Similar points were made by the Board in its December 30, 2005, letter report to Congress and the Secretary, in testimony before the Senate Energy and Natural Resources Committee on May 16, 2006, and in the Board's report to Congress and the Secretary released in June 2006. The focus of the Board's May 9, 2006, meeting was TAD, and in a June 14, 2006, follow-up letter to Paul Golan, the Board underscored its interest in the performance specification for the TAD canister and the relationship of the specification to the postclosure thermal-management strategy.*

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

Evaluation of 2.5.1: Effective. *The Board emphasized the importance of integrating the TAD concept into a waste-management system that effectively balances preclosure safety and long-term repository performance in its December 16, 2005, letter to Paul Golan, acting director of OCRWM. Similar points were made by the Board in its December 30, 2005, letter report to Congress and the Secretary, in testimony before the Senate Energy and Natural Resources Committee on May 16, 2006, and in the Board's report to Congress and the Secretary released in June 2006. The focus of the Board's May 9, 2006, meeting was TAD, and in a follow-up letter to Paul Golan on June 14, 2006, the Board underscored its interest in the TAD canister and its relationship to the postclosure thermal-management strategy.*

3. Performance Goals and Evaluation Related to Repository System Performance and Integration

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

Evaluation of 3.1.1: Effective. *In its December 19, 2005, letter to OCRWM acting director Paul Golan, the Board discussed a number of issues related to uncertainties in repository performance estimates, including in-drift environments following repository closure, thermal conductivity of the repository rock, understanding the source term, and the potential for localized corrosion of waste packages. The issues were reiterated in the Board's December 30, 2005, report to Congress and the Secretary along with the effects of climate change, and retardation and retention of radionuclide colloids in the alluvium. In a letter dated March 6, 2006, the Board commented on the importance of continuing research on the source term exiting the engineered system as a matter of time. These issues were presented in testimony by Dr. John Garrick on May 16, 2006, to the Senate Energy and Natural Resources Committee. A detailed discussion of the issues is included in the Board's Report to Congress and the Secretary released in June 2006.*

3.1.2. Determine the strengths and weaknesses of TSPA.

Evaluation of 3.1.2: Effective. *The Board discussed TSPA at its meeting on November 8, 2005. In its December 19, 2005, letter to Paul Golan, OCRWM acting director, the Board commented on DOE's use of multiple conservatisms in dealing with uncertainties in TSPA and recommended that in addition to its compliance case, DOE develop a realistic assessment of repository performance. The Board also expressed concerns about DOE's technical basis for screening out localized corrosion of the waste packages from TSPA-LA. Similar points were made in the Board's December 30, 2005, letter to Congress and the Secretary. At its February 1, 2006, meeting the Board discussed peak-dose sensitivity analysis. The Board commented in a March 6, 2006, letter to Paul Golan that some methods used by DOE produce results that are inconsistent or unrealistic. The Board recommended a more risk-informed analysis of repository performance. Chairman Garrick commented on the potential for unrealistic results of TSPA at a hearing before the Senate Energy and Natural Resources Committee on May 16, 2006. The Board discussed these issues at length in its report to Congress and the Secretary released in June 2006.*

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

Evaluation of 3.1.3: Ineffective. *The Board did not review or comment on these issues in the period covered by the evaluation.*

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

Evaluation of 3.2.1: Effective. *(See explanation of 3.1.2)*

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: Effective. *(See explanation of 3.1.2)*

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

Evaluation of 3.3.1: Effective. *The Board discussed TSPA at its meeting on November 8, 2005. In its December 19, 2005, letter to Paul Golan, acting OCRWM director, the Board commented on DOE's use of multiple conservatisms in dealing with uncertainties in TSPA and recommended that in addition to its compliance case, DOE develop a realistic assessment of repository performance so that decision makers and the public would have important information on how conservative DOE's performance estimates are. Similar points were made in the Board's December 30, 2005, letter to Congress and the Secretary. At its February 1, 2006, meeting the Board discussed peak-dose sensitivity analysis. The Board commented in a March 6, 2006, letter to Paul Golan that some methods used by DOE produce results that are inconsistent or unrealistic. The Board recommended a more risk-informed analysis of repository performance. Chairman Garrick commented on the potentially unrealistic results of TSPA at a hearing before the Senate Energy and Natural Resources Committee on May 16, 2006. The Board discussed these issues at length in its report to Congress and the Secretary released in June 2006.*

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

Evaluation of 3.3.2: E*ffective.* *(See explanation of 3.3.1)*

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

Evaluation of 3.3.3: ***Effective.*** *The Board commented on the importance of continuing work at the analog site at Peña Blanca, Mexico in its December 19, 2005, letter to Paul Golan, OCRWM acting director, and in its December 30, 2005, report to Congress and the Secretary.*

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

Evaluation of 3.4.1: Effective. *The Board reviewed DOE activities and commented on various DOE efforts related to the contribution of engineered and natural barriers in most of its letters and reports during FY 2006. The Board was especially interested in DOE work related to the source term exiting the engineered barriers over time and to water flow and radionuclide transport.*

3.5.1. Evaluate technical aspects of value engineering and performance-related tradeoff studies, including criteria, weighting factors and decision methodologies for such studies and how technical uncertainties are taken into account.

Evaluation of 3.5.1: Minimally effective. *The Board discussed the TSM model at its meetings on November 8, 2005, and May 9, 2006. The Board commented on the potential of the model for analyzing systems and tradeoffs in letters to Paul Golan, acting director of OCRWM, on December 19, 2005, and June 14, 2006. The Board also discussed the TSM model in its report to Congress and the Secretary released in June 2006.*

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

Evaluation of 3.6.1: Effective. *In its December 19, 2005, letter to Paul Golan, acting OCRWM director, the Board recommended that in addition to its compliance case, DOE develop a realistic assessment of repository performance. The Board also expressed concerns about DOE's technical basis for screening out localized corrosion of the waste packages from TSPA-LA. Similar points were made in the Board's December 30, 2005, letter to Congress and the Secretary. At its February 1, 2006, meeting the Board discussed peak-dose sensitivity analysis. The Board commented in a March 6, 2006, letter to Paul Golan that some methods used by DOE produce results that are inconsistent or unrealistic. The Board recommended a more risk-informed analysis of repository performance. Chairman Garrick commented on the potentially unrealistic results of TSPA at a hearing before the Senate Energy and Natural Resources Committee on May 16, 2006. The Board discussed these issues at length in its report to Congress and the Secretary released in June 2006. The Board held a meeting on this subject in September 2006, and provided its views on these issues in a letter to OCRQM dated December 14, 2006.*

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

Evaluation of 3.7.1: Effective. *The Board reviewed DOE's latest performance-confirmation plan at a meeting on safety case held in September 2006. The Board communicated its views on performance confirmation in a letter to OCRWM dated December 14, 2006.*

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

Evaluation of 3.7.2: Effective. *The Board reviewed DOE's latest performance-confirmation plan at a meeting on safety case held in September 2006. The Board communicated its views on performance confirmation in a letter to OCRWM dated December 14, 2006.*

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

[Note: Because of DOE budget constraints and the development of the transportation, aging, and disposal (TAD) canister concept, much of DOE's planning related to transporting spent nuclear fuel and high-level radioactive waste was deferred in FY 2006. Consequently, several of the Board's performance goals related to reviewing DOE transportation-planning activities were likewise deferred.]

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

Evaluation of 4.1.1: Effective. *The Board commented on the potential of the TAD canister concept in a letter to Paul Golan, OCRWM acting director, on December 16, 2005, and in a report to Congress and the Secretary on December 30, 2006. The Board focused on operations, specifically TAD, at its May 9, 2006, meeting. In its follow-up letter to DOE dated June 14, 2006, the Board identified a number of issues important to the successful implementation of TAD, including the timing and availability of TADs for storage at reactor sites, the inclusion of the TAD concept in the TSPA-LA, resolving DOE's policy of accepting only bare fuel for disposal, integrating TAD into a the postclosure thermal-management strategy, and constructing a Nevada rail line to the proposed repository site. Many of these issues also were discussed in the Board's report to Congress and the Secretary released in June 2006.*

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: Effective. *The Board discussed the TSM model at its meetings on November 8, 2005, and May 9, 2006. The Board commented on the potential of the model for analyzing the waste management system in letters to Paul Golan, acting director of OCRWM, on December 19, 2005, and June 14, 2006. The Board also discussed the TSM model in its report to Congress and the Secretary released in June 2006.*

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

Evaluation of 4.1.3: Effective. *The Board discussed the TSM model at its meetings on November 8, 2005, and May 9, 2006. The Board commented on the potential of the model for analyzing the waste management system in letters to Paul Golan, acting director of OCRWM, on December 19, 2005, and June 14, 2006. The*

Board also discussed the TSM model in its report to Congress and the Secretary released in June 2006.

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: Minimally effective. *The Board did not explicitly address this issue in FY 2006. However, the Board discussed the TSM model at its meetings on November 8, 2005, and May 9, 2006. The Board commented on the potential of the model for analyzing the waste management system in letters to Paul Golan, acting director of OCRWM, on December 19, 2005, and June 14, 2006. The Board also discussed the TSM model in its report to Congress and the Secretary released in June 2006.*

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

Evaluation of 4.1.5: Deferred. *Citing budget constraints, DOE limited its transportation-planning work in FY 2006.*

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

Evaluation of 4.2.1: Deferred. *Citing budget constraints, DOE limited its transportation-planning work in FY 2006.*

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

Evaluation of 4.3.1: Deferred. *Citing budget constraints, DOE limited its transportation-planning work in FY 2006.*

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

Evaluation of 4.3.2: Deferred. *Citing budget constraints, DOE limited its transportation-planning work in FY 2006.*

4.3.3. Evaluate logistics capabilities of the transportation system.

Evaluation of 4.3.3: Effective. *The Board commented on the potential of the TAD canister concept in a letter to Paul Golan, OCRWM acting director, on December 16, 2005, and in a report to Congress and the Secretary on December 30, 2005. The Board focused on operations, specifically TAD, at its May 9, 2006, meeting. In its follow-up letter to DOE dated June 14, 2006, the Board identified a number of issues important to the successful implementation of TAD, including the timing and availability of TADs for storage at reactor sites, the inclusion of TAD in the TSPA-LA, resolving DOE's policy of accepting only bare fuel for disposal, integrating TAD into a the postclosure thermal-management strategy, and constructing a Nevada rail line to the proposed repository site. Many of these issues also were discussed in the Board's report to Congress and the Secretary released in June 2006.*

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

Evaluation of 4.3.4: Deferred. *Citing budget constraints, DOE limited its transpiration-planning work in FY 2006.*

4.3.5. Evaluate DOE's plans for enhancing safety capabilities along transportation corridors, and review 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 4.3.4: Effective: *Related issues were included in the Board's comments on the potential of the TAD canister concept in a letter to Paul Golan, OCRWM acting director, on December 16, 2005, and in a report to Congress and the Secretary on December 30, 2006. The Board focused on operations, specifically TAD, at its May 9, 2006, meeting. In its follow-up letter to DOE dated June 14, 2006, the Board identified a number of issues important to the successful implementation of TAD. Similar issues also were discussed in the Board's report to Congress and the Secretary released in June 2006.*

ADDENDUM B

Supplementary Information on the Nuclear Waste Technical Review Board

The U.S. Nuclear Waste Technical Review Board was established on December 22, 1987, in the Nuclear Waste Policy Amendments Act (NWPAA) as an independent agency in the executive branch of the federal government. The Board is charged with evaluating the technical and scientific validity of activities undertaken by the Secretary of Energy, including the following:

- site characterization
- activities related to packaging and transporting high-level radioactive waste and spent nuclear fuel

The Board was given broad latitude to review activities undertaken by the Secretary of Energy in implementing the Nuclear Waste Policy Act. However, the Board was not given authority to require DOE to implement Board recommendations.[1]

Board Members

The NWPAA authorized a Board of 11 members who serve on a part-time basis; are eminent in a field of science or engineering, including environmental sciences; and are selected solely on the basis of distinguished professional service. The law stipulates that the Board shall represent a broad range of scientific and engineering disciplines relevant to nuclear waste management. Board members are appointed by the President from a list of candidates recommended by the National Academy of Sciences. To prevent gaps in the Board's comprehensive technical review, Board members whose terms have expired continue serving until they are reappointed or their replacements assume office. The first members were appointed to the Board on January 18, 1989. Current members were appointed by President George W. Bush.

The names and affiliations of the current 11 Board members are listed below.

[1] Taken from Legislative History of the Nuclear Waste Policy Amendments Act of 1987, February 26, 1998.

- **B. John Garrick, Ph.D., P.E.,** is chairman of the Board. A founder of PLG, Inc., he retired from the firm in 1997 and is a private consultant. His areas of expertise include probabilistic risk assessment and application of the risk sciences to technology-based industries.
- **Mark D. Abkowitz, Ph.D.,** is professor of civil and environmental engineering and director of the Vanderbilt Center for Environmental Management studies at Vanderbilt University. His areas of expertise include transportation safety and security, systems analysis, all-hazards risk management, and applications of advanced information technologies.
- **William Howard Arnold, Ph.D., P.E.,** a private consultant, retired from Louisiana Energy Services in 1996. He holds a doctorate in experimental physics and has special expertise in nuclear project management, organization, and operations.
- **Thure E. Cerling, Ph.D.,** is Distinguished Professor of Geology and Geophysics and professor of biology at the University of Utah. His areas of expertise include terrestrial geochemistry and geochemistry processes.
- **David J. Duquette, Ph.D.,** is department head and professor of materials engineering at Rensselaer Polytechnic Institute. His areas of expertise include the physical, chemical, and mechanical properties of metals and alloys.
- **George M. Hornberger, Ph.D.,** is Ernest H. Ern Professor of Environmental Sciences in the Department of Environmental Sciences at the University of Virginia. His areas of expertise include catchment hydrology and hydrochemistry and transport of colloids in geologic media.
- **Andrew C. Kadak, Ph.D.,** is Professor of the Practice in the Nuclear Science and Engineering Department at the Massachusetts Institute of Technology. His areas of expertise include nuclear engineering and the development of advanced reactors.
- **Ronald M. Latanision, Ph.D.,** is emeritus professor of materials science and engineering at the Massachusetts Institute of Technology and a principal in Exponent, a science and engineering firm. His areas of expertise include materials processing and corrosion of metals and other materials in aqueous environments.
- **Ali Mosleh, Ph.D.,** is Nicole J. Kim Professor of Engineering, director of the Reliability Engineering Program, and director of the Center for Risk and Reliability at the University of Maryland. His areas of expertise include methods for probabilistic risk analysis and reliability of complex systems.
- **William M. Murphy, Ph.D.,** is associate professor in the Department of Geological and Environmental Sciences at California State University, Chico. His research focuses on geochemistry, including the interactions of nuclear wastes and geologic media.
- **Henry Petroski, Ph.D., P.E.,** is Aleksandar S. Vesic Professor of Civil Engineering and professor of history at Duke University. His areas of expertise include the interrelationship between success and failure in engineering design. He also has a strong interest in invention and in the history of evolution of technology.

Board Staff

The NWPAA limits the Board's professional staff to 10 positions. An additional 5 full-time employees provide administrative support to Board members and the professional staff. Because of the comprehensive nature of the program, the diversity of Board member experience and expertise, and the part-time availability of Board members, the small, highly qualified staff is employed to its full capacity in supporting the Board's review of DOE program. The Board's offices are in Arlington, Virginia.

Board Reporting Requirements

As required under the NWPAA, the Board reports to the U.S. Congress and the Secretary of Energy at least two times each year. The reports include Board recommendations related to improving the technical and scientific validity of activities undertaken by the Secretary of Energy under the civilian radioactive waste management program. DOE's written responses to Board recommendations are published in the Board's annual summary reports.

Board Activities

The Board and its panels sponsor meetings and technical exchanges with program participants and interested parties, including representatives of DOE and its contractors, the U.S. Nuclear Regulatory Commission, the U.S. Environmental Protection Agency, the U.S. Geological Survey, the U.S. Department of Transportation, the State of Nevada, affected units of local governments, Native American tribes, nuclear utilities, environmental groups, state utility regulators, and members of the public. Board members and staff attend relevant technical conferences, meetings, symposia, workshops, participate in field trips, and occasionally visit foreign programs to gain insights from the experience of other countries' repository development efforts.

Board and panel meetings are open to the public and announced in the Federal Register four to six weeks before each meeting. To facilitate access for program participants and the public, the Board holds the majority of its meetings in the State of Nevada, and time is set aside for public comment at each meeting. Transcripts of Board and panel meetings and all Board reports, correspondence, and congressional testimony are available to the public via telephone or written request or from the Board's Web site: www.nwtrb.gov.

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