U.S. NUCLEAR WASTE TECHNICAL
REVIEW BOARD

Report to

The U.S. Congress

And

The Secretary of Energy

January to December 1998

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
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April 1999

The Honorable Dennis Hastert
Speaker of the House
United States House of Representatives
Washington, D.C. 20515

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

The Honorable Bill Richardson
Secretary
U.S. Department of Energy
Washington, D.C. 20585

Dear Speaker Hastert, Senator Thurmond, and Secretary Richardson:

The Nuclear Waste Technical Review Board (Board) submits this *Report to The U.S. Congress and The Secretary of Energy – 1998 Summary and Findings* in accordance with provisions of the Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203, which requires the Board to report its findings and recommendations to Congress and the Secretary of Energy two times each year.

Congress created the Board to evaluate the technical and scientific validity of activities undertaken by the Secretary of Energy in characterizing a site at Yucca Mountain, Nevada, for its suitability as the location of a permanent repository for disposing of spent nuclear fuel and high-level radioactive waste. The Board also reviews the Department of Energy's (DOE) work related to the design of the repository and to the packaging and transport of spent fuel and high-level radioactive waste. In this report, the Board summarizes its major activities during calendar year 1998.

In 1998, the Board closely reviewed the DOE's preparation of the recently issued viability assessment (VA) of the Yucca Mountain site. Overall, the Board agrees with the research needs identified by the DOE in its VA. In particular, the Board supports the DOE's 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, and the flow and transport properties of the groundwater that lies approximately 200 meters beneath the repository horizon. The Board also agrees with the DOE on the importance of continuing long-term corrosion tests on materials such as Alloy 22.

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In addition to reviewing the VA, the Board reviewed and reported on the hypothesis that there were hydrothermal upwellings at Yucca Mountain and that large earthquake-induced changes in the water table are likely. The Board also organized a workshop to understand better the range of expert opinion about waste package materials, and it reviewed drafts of the DOE's environmental impact statement for Yucca Mountain.

We believe that the information in this report will be useful to policy makers as well as to DOE managers and staff when they make important decisions on the status of the Yucca Mountain site and the research priorities of the civilian radioactive waste management program.

We thank you for this opportunity to present the Board's views. The Board looks forward to assisting the Secretary of Energy and Congress in furthering the goal of safe and cost-effective management of spent nuclear fuel and high-level radioactive waste.

Sincerely,

Jared L. Cohon
Chairman

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Executive Summary

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

This document describes Board activities undertaken in the 1998 calendar year. Chapter 1 presents the Board's views about the DOE's ongoing characterization of the Yucca Mountain site in Nevada as a potential location for a repository. Chapter 2 summarizes other Board activities.

During 1998, the Board closely reviewed the DOE's preparation of the congressionally mandated report, *Viability Assessment of a Repository at Yucca Mountain* (USDOE 1998). The viability assessment (VA) synthesizes information collected by the DOE over the last decade and provides policy-makers with a "snapshot" in time of the following issues:

- preliminary waste package and repository designs
- estimates of repository performance
- additional research that DOE needs to conduct before making a decision on whether to recommend the site for development
- costs of constructing and operating a repository.

Overall, the Board agrees with the research needs identified by the DOE in the VA. In particular, the Board supports the DOE's plans to gather information on the following issues:

- How much water seeps into repository drifts under ambient conditions as well as during the first 1,000 years after waste emplacement, when the rock surrounding the facility is heated?
- Can the zeolitic formations beneath the repository retard the migration of radionuclides to the environment?
- What are the long-term corrosion rates of waste package materials, such as Alloy 22?
- What are the flow-and-transport properties of the groundwater that lies approximately 200 meters beneath the repository horizon?

During 1998, the Board also performed several other activities. It reviewed materials relating to the hypothesis that hydrothermal upwellings are ongoing at Yucca Mountain and that large earthquake-induced changes in the water table are likely. It organized a workshop to understand better the range of expert opinion about highly corrosion-resistant waste package materials. The Board also reviewed drafts of the DOE's environmental impact statement for Yucca Mountain.

Introduction

The federal government formally took on the responsibility for the permanent disposal of high-level radioactive waste and spent nuclear fuel with the passage of the Nuclear Waste Policy Act (NWPA) (U.S. Congress 1982) in 1982. The NWPA designated the U.S. Department of Energy (DOE) the agency for carrying out the federal responsibility. In 1987, Congress passed the Nuclear Waste Policy Amendments Act (NWPAA) (U.S. Congress 1987). That legislation created the U.S. Nuclear Waste Technical Review Board (Board) as an independent federal agency charged with evaluating the technical and scientific validity of the DOE's activities under the NWPA. The Board consists of 11 members who are nominated by the National Academy of Sciences and appointed by the President.

Mined geologic disposal has been and continues to be U.S. policy and is a central tenet of the NWPA. Since the early 1980's, the DOE has directed site-specific studies of as many as nine potential locations for a deep geologic repository for disposing of civilian spent nuclear fuel and high-level radioactive waste. In 1987, the NWPAA restricted site-characterization studies to a single candidate site at Yucca Mountain in Nevada.

Predicting the ability of a repository, anywhere, to isolate radioactive materials for thousands of years is a major technical challenge. The DOE is trying to meet that challenge with detailed studies of the Yucca Mountain site. Of utmost importance is that the appropriate studies are carried out; the scientific work is of the highest quality; and a strategy for isolating the waste can be demonstrated in a technically credible manner—first, in a decision to select the Yucca Mountain site, and second, in an adversarial licensing process. The goal of the scientific and engineering program is to develop confidence among scientists, engineers, regulators, and the public—especially the citizens of Nevada—that a repository will safely isolate spent nuclear fuel and high-level radioactive waste.

During 1998, the DOE engaged in several significant activities. It completed construction of an exploratory tunnel across the proposed repository block and carried out extensive site characterization. Most significantly, information collected over the last decade was synthesized into a congressionally mandated report, *Viability Assessment of a Repository at Yucca Mountain* (VA) (USDOE 1998).[1] The VA, which was published in December 1998, consists of five volumes.

- Overview
- The preliminary design concepts for the critical elements of the repository and the waste package. The DOE calls them collectively its "reference design."
- A total system performance assessment (TSPA-VA) based on the reference design and analyses available as of September 1998 (USDOE 1998). The TSPA-VA describes the projected behavior of a repository in the Yucca Mountain geologic setting, based on the data and level of understanding available in mid-1998.

1. Congress required the DOE to prepare the VA in the Energy and Water Development Appropriations Act of 1997 (U.S. Congress 1996).

- A plan and a cost estimate for the remaining work required to complete an application for beginning construction of a repository using the reference design at Yucca Mountain.

- An estimate of the total cost of constructing and operating such a repository.

The Board will comment on the VA in a separate report, but it believes that two comments are in order at this time. First, the VA proved to be a useful management tool that helped the DOE integrate scientific and technical studies and set priorities for further research and design work. Second, as the Board has indicated several times in the past, the VA should not be viewed as a statement about the suitability of the Yucca Mountain site. Such a statement is premature and must await more site-specific and laboratory research.

This report summarizes the Board's views on activities undertaken in the DOE's radioactive waste management program during 1998. In Chapter 1, the Board presents its assessment of the DOE's site-characterization and engineering design efforts. In Chapter 2, the Board describes its other oversight activities. The appendices to this report contain additional information on the Board, its meetings, and its communications with the DOE.

Chapter 1
Board Oversight of the DOE’s Scientific and Technical Activities at Yucca Mountain

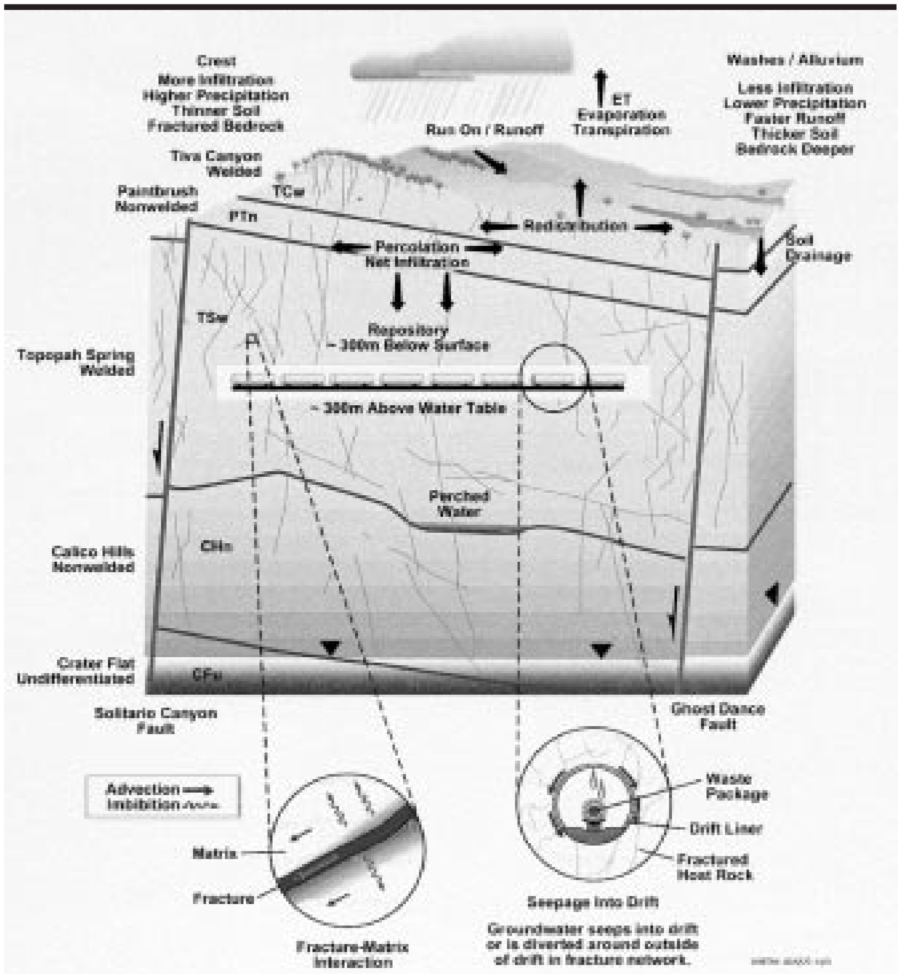
The DOE is characterizing Yucca Mountain in Nevada to evaluate the suitability of the site for constructing a mined geologic repository for the permanent disposal of spent nuclear fuel and high-level radioactive waste. It also is preparing designs for the packages in which the waste will be disposed of and the subsurface repository facilities. During 1998, the full Board reviewed those activities at its meetings. In addition, individual Board members attended DOE workshops and traveled to Yucca Mountain.

I. Characterization of the Unsaturated Zone

A. Overview

If the Nuclear Regulatory Commission (NRC) authorizes the repository, it will be constructed in the unsaturated zone (UZ) in welded tuff (volcanic rock) at a depth of at least 300 meters below the land surface and a distance of approximately 300 meters above the regional water table. (See Figure 1-1.) The UZ at Yucca Mountain is a critical natural feature of the repository system. Along with structural integrity, the UZ will provide the hydrologic and chemical environment for the waste canisters. The UZ will be the medium through which the radionuclides will be transported with the percolating water to the

Figure 1–1. Cross Section of Yucca Mountain (adapted from Andrews 1998)



saturated zone. The predicted repository performance is critically dependent on the volume and geochemistry of the water that may reach waste packages, mobilize the waste, and carry radionuclides to the water table. The potential repository block consists of a fault-bounded structural block composed of alternating welded and nonwelded tuffs of the mid-Miocene Age, about 10 to 13 million years old. The block is bounded by the Ghost Dance fault on the east and the Solitario Canyon fault on the west. Smaller faults not evident at land surface may be present within the block. Largely according to the degree of welding, the tuffs within the UZ at Yucca Mountain are grouped informally into hydrogeologic units that, from the surface down, are termed the Tiva Canyon welded (TCw) unit, the Paintbrush nonwelded (PTn) unit, the Topopah Springs welded (TSw) unit, the Calico Hills nonwelded (CHn) unit, and the Crater Flat undifferentiated (CFu) unit. The host rock at the level of the potential repository consists of densely welded ash-flow tuff within the TSw unit.

B. The DOE's Scientific and Technical Work

The DOE focused its scientific research in 1998 on addressing the following key UZ uncertainties: (1) the amount of water that potentially could seep into the emplacement drifts, (2) thermally induced flow in the UZ, and (3) transport of radionuclides through the UZ.

1. Seepage Flux

Of the natural characteristics of Yucca Mountain that are crucial for predicting repository performance, seepage flux—the magnitude and distribution of the percolating water that seeps (drips) into the emplacement drifts and, potentially, onto the waste packages—is the most important. This is because the amount, timing, and chemistry of water entering the tunnels can have a significant effect on the environment of the waste packages and other engineered barriers. Seepage flux also is an important determinant of the rate at which radionuclides can be mobilized from the waste form and released from the repository. Assessing the performance of the potential repository requires not only that the current level of seepage flux be estimated, but also that future levels be considered because the flux is expected to increase as the climate becomes wetter.

The estimates of this fraction for the present climate and for future climates are derived from model computations. The computations, although informative, are based on geologic and hydrologic parameters that cannot be estimated with certainty. During 1998, several experiments and tests were begun in the Exploratory Studies Facility (ESF) (e.g., alcove 1 and other locations) to measure the movement of water through the UZ under controlled flow conditions at multiple scales and to measure the seepage of water into excavated areas. In addition, experiments were designed to determine the movement of water from the cross drift to the ESF. The majority of these tests are in the initial scoping stages, and much of the key data are scheduled to be collected in calendar year 1999.

Results from monitoring ambient moisture conditions in the ESF and in various alcoves were obtained in 1998. One finding is the significant differences between the measurements of ambient water potential taken in the ESF tunnel and the values inferred from laboratory experiments on cores taken in the rocks from the horizon of the proposed repository (TSw). The TSw appears wetter than previously thought—that is, the pores, or voids, in the nonlithophysal TSw may be closer to 90 percent saturated than to 80 percent saturated.[2] These data could have as-yet-undetermined implications of matrix-fracture interactions and flow in the UZ and seepage rate into the repository drift.

2. Thermally Induced Flow in the UZ

A repository with a high thermal load (temperatures higher than about 100°C)[3] is designed to drive water away from waste packages for the first 3,000 years. However, research has shown that a high thermal load may result in additional water movement around, and perhaps into, the emplacement drifts

2. The differences are most likely due to an improvement in sampling techniques that minimizes the drying-out influence of forced-air drift ventilation. The problem associated with the previous sampling techniques was pointed out by Dr. Gaylon Campbell at the Board's June 1997 meeting.

during the early high-temperature regime. To understand this thermally induced flow better, the DOE has conducted single-heater and drift-scale heater experiments.

The single-heater test was completed in 1997 and has produced useful information on the movement of water and on the dryout region, which is formed around the heater. The drift-scale heater test, which began on December 6, 1997, is designed to provide a similar type of data but on a much larger spatial scale and for a longer time. The heating cycle is anticipated to last approximately 4 years. The cooling phase of the experiment also will take approximately 4 years so that there is sufficient time for chemical and mechanical processes that may alter near-field rock properties.

3. Transport of Radionuclides in the UZ

In 1998, the DOE began conducting experiments at Busted Butte to better characterize the flow and transport of radionuclides in the UZ after release of radionuclides from waste packages begins. These experiments are designed to investigate the transport properties of reactive and nonreactive tracers in the vitric tuffs in the Calico Hills Formation. Special emphasis will be on the retardation potential of the vitric tuffs and the likelihood of colloidal transport through this unit. The testing will be conducted in several phases and at several scales. The phases were designed for observing and measuring the movement of water and various tracers under controlled conditions through well-defined units. The tracers were chosen to represent various sorptive and diffusion properties that could be used in transport modeling.

The DOE continued its assessment of the solubility of neptunium (Np). The solubility of Np is important because the isotope ^{237}Np is a major contributor to the calculated radiation dose at 10,000 years and beyond. The initial volume of ^{237}Np (half life of 2.14×10^6 years) in spent nuclear fuel is approximately 0.03 percent of the initial inventory of radionuclides at the time of emplacement. The concentration increases with time as ^{237}Np is produced by the decay of americium-241 (half life of 432.7 years).

The DOE believed that the earlier (TSPA-95) solubility estimates (CRWMS 1995b) were too high (CRWMS 1998). The DOE concluded that its revised estimates of solubility represent a more realistic model of the situation that would exist in the proposed Yucca Mountain repository.[4]

As a result of the reassessment of experimental data, supported by thermodynamic calculations, the expected value for the solubility of Np in the VA is two orders of magnitude lower than the number used in TSPA-95. The new solubility values consequently lowers the calculated long-term potential dose that is due to Np by two orders of magnitude.

The DOE undertook field studies to better understand colloidal transport.[5] Strongly sorbing radionuclides, such as plutonium, may sorb on naturally occurring colloids in groundwater and migrate at velocities similar to the velocity of groundwater flow. This process can lead to travel times that are much shorter than those predicted by retardation factors measured in laboratory experiments. Recently, plutonium was measured in groundwater at the Nevada Test Site ER-20-5 wells (Kersting et al. 1999). The plutonium's origin was the 1968 nuclear test BENHAM on Pahute Mesa. All of the plutonium detected was associated with colloidal components, primarily clays and zeolites.

C. The Board's Review Activities

1. Seepage Flux

Most of the work on seepage flux that is being carried out in the ESF was reviewed by the Board during its visit to the tunnel on December 8, 1998. The

3. Throughout this chapter, the current design (reference design) of the underground facility is referred to as the "hot" repository design to distinguish it from a low-temperature alternative repository design.
4. The DOE initially reached this conclusion on the basis of experiments that used highly supersaturated solutions. The DOE's reassessment utilized experimental data for undersaturated systems, in which Np-bearing nuclear fuel was allowed to dissolve in water and to approach equilibrium from a state of undersaturation. As part of the reassessment, thermodynamic calculations of the solubility of Np also were performed.
5. A colloid is a particle that can be suspended easily or is a suspension of very fine particles.

Board was pleased to see the progress made and the magnitude of data that will be gathered on seepage flux in the next few years. In particular, the Board looks forward to reviewing the chlorine-36 (^{36}Cl) data that will be collected in the east-west drift as well as the data that will be collected on seepage between the east-west drift and the ESF.

The Board repeatedly has emphasized the importance of collecting data on ^{36}Cl and other environmental isotopes. Evidence of bomb-pulse ^{36}Cl has been well documented over the last few years and was reviewed by an outside panel at DOE's request in 1998.[6] The presence of bomb-pulse ^{36}Cl is the clearest evidence of rapid movement of water from the surface to depth at Yucca Mountain. Still, important questions remain about the significance of the data to overall flow and transport in the UZ. Quantitatively, how significant is this rapid-flow component? How is this flow distributed in time and space? Is this flow associated with major faults and fractures and thus can it be identified spatially? Although the Board has been given preliminary answers to these questions, they are not fully resolved.

2. Thermally Induced Flow in the UZ

If the repository is designed for a high thermal load, significant water movement may occur around the emplacement tunnels during the early, high-temperature, regime. As temperatures in the host rock rise above the boiling point, water will vaporize in the matrix and move through permeable fractures to cooler, lower-pressure areas. There, the vapor will condense and flow downward from the point of condensation, possibly into emplacement tunnels.

Because mathematical models sometimes smooth or average, they may have difficulty representing these complex, transient phenomena. Over a longer period of time, one type of model (a dual-permeability model) predicts that the mobilized water eventually will drain in bypass around an emplacement tunnel and that a local dryout will be achieved. This is what has been observed in the single-heater test. However, another type of model (a single effective continuum model) predicts accumulation of water above the tunnel and no draining around the tunnel. Neither model is capable of realistically predicting how much water could enter the tunnels when repository temperatures are high.

Currently, the question of how much water will be entering the tunnels during the thermal episode has not been answered by model computations or experiments. The single-heater test has provided useful information on the movement of water. The hope is that the drift-scale test will provide similar types of data on a much larger scale and for a different geometry in the next several years.

3. Transport of Radionuclides in the UZ

On several occasions in 1998, the Board visited the Busted Butte facility, where the flow and tracer experiments are being performed. The design and construction of the facility and the development of the testing plan moved rapidly over the course of the year. As data are produced from the Busted Butte studies, the Board will evaluate their validity and significance.

Despite the substantial effort that has gone into the reassessment of the solubility data for Np, at least three important questions remain to be answered. First, does the new evaluation use the proper conceptual model? Second, has the role of secondary mineral precipitates been evaluated adequately? Third, have the starting Np-bearing solid phases in the spent nuclear fuel been characterized adequately? Each question is discussed below.

The first question deals with the use of proper conceptual models. The DOE's reassessment of the experimental data, as well as the computer simulations, assumes that the Np-bearing spent nuclear fuel dissolves in a water-saturated system. In other words, the use of data from a state of undersaturation assumes that the spent nuclear fuel will dissolve directly into water and then move out of the repository. The primary Np-bearing solid phases in the spent nuclear fuel will control the solubility of Np in the migrating water. This is the initial conceptual model.

6. Because of the significance of bomb-pulse ^{36}Cl, the Board's understanding is that the DOE plans additional tests to verify its presence.

A different conceptual model would assume that (1) the primary Np-bearing solid phases dissolve into water in a partially saturated system and that (2) secondary Np-bearing minerals then precipitate from that water. The secondary minerals could precipitate on or within the waste package itself, on or within the backfill material (if present), or within the fractures and matrix of the volcanic tuff that constitutes the repository host rock. The secondary Np-bearing minerals then could be redissolved at a later time. If this conceptual model is more accurate, then the solubility of Np in subsequent flushes of water that may come through the repository will be controlled by the secondary Np-bearing mineral precipitates, not by the primary solids in the spent nuclear fuel. Secondary mineral precipitates can be more or less soluble than the primary solids from which they are derived, and the calculated dose due to Np per unit of water could, as a result, be higher or lower. This alternative conceptual model would require the solubilities of the secondary mineral precipitates of Np to be evaluated.

The second question concerns the identity and solubility of possible secondary mineral precipitates of Np. If such compounds control the solubility of Np in water that may subsequently move through the repository, then it is important to identify and characterize the secondary Np-bearing precipitates and to evaluate their solubilities.

The third question concerns the characterization and identification of the primary Np-bearing solids in the spent nuclear fuel. The recent reevaluation of the solubility of Np assumes that the controlling solid form in the spent nuclear fuel is NpO_2. However, nonstoichiometric forms of Np-oxygen compounds also may exist in the spent nuclear fuel, and they conceivably could control the solubility of Np. Metallic forms of Np, rather than NpO_2, may exist in the spent nuclear fuel, and such phases also may exert some control over the solubility of the Np. This possibility should be evaluated before a final solubility value is selected.

In sum, the remaining questions about the conceptual model and about the occurrence and characteristics of the Np-bearing solid phases introduce significant uncertainty into the selection of the expected value of the solubility of Np. Thus, acknowledging a very broad range of uncertainty about Np solubility would be prudent.

The observations made at the Nevada Test Site and laboratory experiments indicate that colloidal transport of plutonium cannot be ignored and can contribute to the transport of strongly sorbing radionuclides, potentially increasing the dose at the accessible environment. The DOE will have to gather data, such as the reversibility of sorption on colloids and colloid stability, to estimate or bound the importance of colloidal transport.

D. The Board's Conclusions

The UZ of Yucca Mountain may potentially be shown to be an important component of a defense-in-depth repository design. The following are the Board's conclusions about the current state of knowledge of the UZ.

- Seepage flux under ambient conditions can be estimated through the proposed in situ experiments, by analog studies at the Nevada Test Site, and by numerical simulations. Seepage after the thermal period has not been addressed experimentally, but planned experiments may produce relevant data.

- The effects of repository heat on thermohydrologic conditions near the repository are not well understood. Tests that have been initiated at Yucca Mountain must be completed to improve understanding and reduce uncertainties. However, their results will not be fully available for 7 more years.

- The testing at Busted Butte is being conducted to assess the transport of colloids and other aqueous species through the UZ below the repository. If successful, the tests could provide information for reducing uncertainty in these areas.

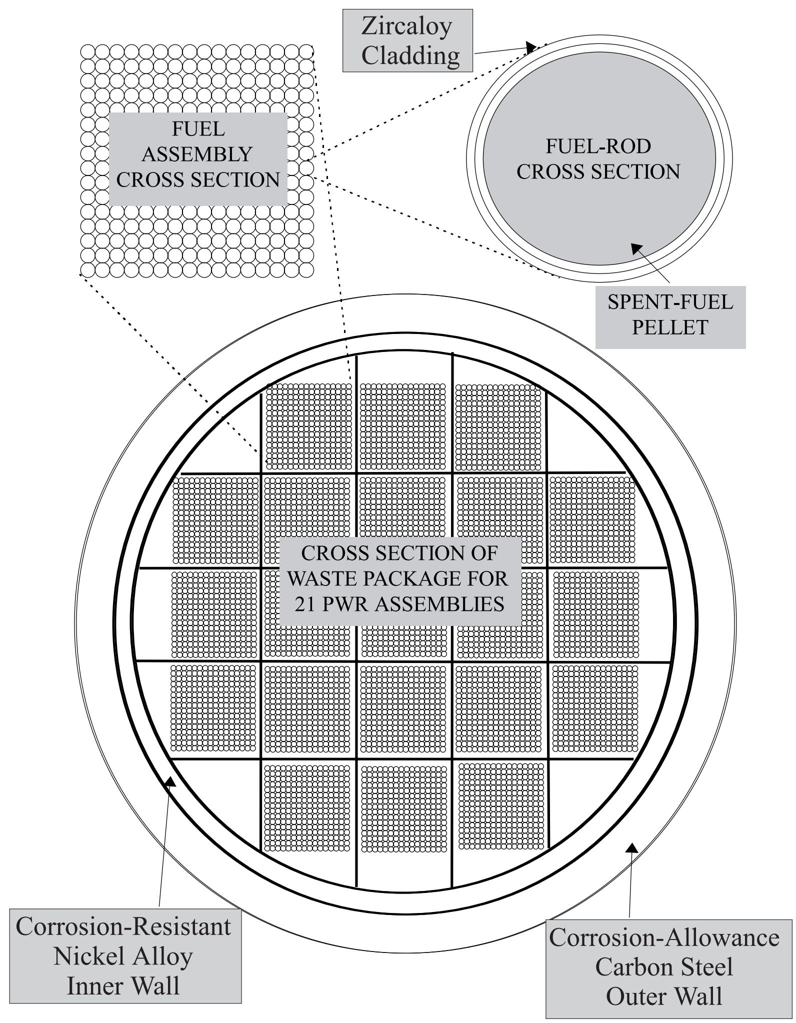
- Despite recent progress in reevaluating the solubility of Np, significant uncertainties (possibly as much as five orders of magnitude) remain. Because the long-range dose potential of ^{237}Np is so significant, additional effort is needed to narrow these large uncertainties.

II. Waste Package Design

A. Overview

According to regulations, "waste package" means the radioactive waste materials and any encapsulating and stabilizing matrix, as well as any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container (10 CFR 60). That is, the term includes not only the waste container but also its contents. In the reference design, a waste package containing spent commercial fuel[7] will have at least four distinct barriers that contribute to defense-in-depth: (1) a 10-cm-thick carbon-steel outer wall; (2) a 2-cm-thick nickel-alloy inner wall; (3) cladding, usually zircaloy, surrounding the spent fuel; and (4) the spent fuel itself, which consists of degraded uranium oxide ceramic pellets containing fission products and actinides. In general, the processes leading to failure of an inner barrier would not begin until the barrier immediately outside of it is penetrated (see Figure 1-2).

Figure 1-2. Cross Section of 21-PWR Spent-Fuel Waste Package



Waste packages emplaced in an underground facility at Yucca Mountain will undergo a range of external environmental conditions that will affect the rate of corrosion of the packages. The range of external environmental conditions (pressures, temperatures, and the chemical compositions of the near-field gases, liquids, and solids before they contact the waste packages) is reasonably well bracketed.

Predicting corrosion with reasonable confidence, however, requires knowledge not only of the waste package materials and external environmental conditions but also of the modified environmental conditions that would evolve on (or inside) waste packages as a result of interactions among waste package materials, corrosion products, radiation, and external environmental conditions. The modified environmental conditions on or in a package can vary widely over just a few millimeters, depending on where drips contact the package, the presence or absence of crevices, and the amount of corrosion that has occurred already. TSPA-VA indicates that for the reference design, the nickel-alloy inner wall and the zircaloy cladding are by far more important barriers than the carbon-steel outer wall. Therefore, the discussion below is limited to these two barriers.

7. On the basis of radioactivity, spent fuel will comprise well over 90 percent of the waste to be disposed of at the proposed Yucca Mountain repository.

1. Nickel-Alloy Inner Wall

The material for the inner wall is a chromium-rich nickel-base alloy with the designation Alloy 22.[8] The corrosion resistance of the alloy is due to a microscopically thin passive film on the surface of the alloy that separates the alloy from the surrounding environment. Research has shown that passivity can be compromised under certain severe conditions, even for highly corrosion-resistant alloys, such as Alloy 22, and that rapid corrosion follows when passivity is compromised. Research also has shown that those alloys remain protected by passive layers under less severe conditions and thus have extremely low corrosion rates.

Combinations of ferric and chloride ions[9] in water are known to generate low-pH oxidizing environments that cause passivity breakdown in corrosion-resistant alloys. Conceivably, these ionic combinations could result from the presence of iron-corrosion products (e.g., from corrosion of the carbon-steel outer layer) and chloride ions concentrated by evaporation of seepage water. However, partly because of lack of long-term direct experience and partly because of uncertainties about the severity of the conditions that corrosion-resistant alloys might be exposed to in Yucca Mountain, the ability to demonstrate that these alloys would survive many thousands of years in a repository remains a matter of debate among materials experts.

Even in the absence of ferric ion sources, localized attack of the passive layer protecting high-performance alloys can occur through pitting or crevice corrosion if aggressive microenvironments form at the surface of the passive layer. This may occur, for example, at contacts between the metal and tunnel debris; at metal-metal openings, including surface rolling imperfections; and at places where the package rests on its pedestal. Another form of localized failure is stress-corrosion cracking,[10] which could affect the zone of the final closure weld of the package or other regions of unrelieved stresses. Information available to date suggests, but does not ensure, that Alloy 22 has little susceptibility to these forms of corrosion under the expected repository service conditions, pending resolution of the issue involving ferric and chloride ions noted earlier.

Future research may prove that the environment immediately next to the metal surface will be only moderately aggressive. In that case, present understanding of corrosion phenomena (based on short-term investigations) indicates that the nickel-alloy wall should remain passive and corrode at a very slow rate. However, Alloy 22 and related materials are relatively new and have been investigated for only a limited time (decades) under any conditions and for only a few years under conditions that directly apply to the expected waste package environment in Yucca Mountain. Historical experience with any alloy relying on passivity for corrosion protection also is relatively short. How stable the passive layers will remain, even in benign surroundings, over the extremely long repository time scale is a vital question.

2. Zircaloy Cladding

Like nickel-based alloys, zirconium alloys depend on the formation and stability of passive films for protection against corrosion. Titanium alloys, which are under consideration as an alternative waste package material and as a drip shield material, also rely on passivity for adequate performance. Although data on general corrosion of zircaloy cladding are extensive, they are mostly at conditions within nuclear reactors—conditions significantly different from, but not necessarily more severe than, some of the more extreme conditions that the cladding could be exposed to in a repository at Yucca Mountain. As is the case for nickel-based and titanium alloys, the environments formed by the combined interactions of corrosion products, radiolysis, pore water, and elevated temperatures need to be determined for cladding, as do the effects of these environments on the cladding.

8. The nominal composition of Alloy 22, in weight percent, is Ni 56, Cr 22, Mo 13, Co 2.5, W 3, and Fe 3.

9. Ferric ion [Fe(III)] hydrolyzes readily. A solution of the salt of any ferric ion and any of a number of anions (e.g., chloride) in pure water will be acidic and oxidizing. The same is true for Ni(IV) and Cr(VI) ions.

10. Stress-corrosion cracking is a cracking process that requires the simultaneous action of a corrosion mechanism and sustained tensile stress.

Zircaloy cladding clearly is an egress barrier, and it may well be a significant one. In TSPA-VA, the corrosion rates assumed for zircaloy were significantly lower than those used for Alloy 22. Quantifying the contribution of cladding to performance is difficult because (1) a small fraction of the cladding fails during nuclear power plant operation; (2) few data exist for estimating the damage (if any) to cladding during storage (particularly dry storage), handling, and transportation and the effects of such damage on performance; (3) little study has been done of the potential for cladding damage in an intact container (e.g., by attack from aggressive chemicals resulting from the radiolysis of water and air inadvertently trapped in the waste package during loading); (4) the potential for hydride embrittlement of irradiated zircaloy cladding has not been addressed fully; (5) limited study has been done of the potential for degradation of cladding by mechanical forces after a waste package is breached; (6) essentially no data exist on the extent of localized corrosion of zircaloy under Yucca Mountain conditions; and (7) long-term zircaloy performance depends on extrapolation of short-term data for very long periods.

B. The DOE's Scientific and Technical Work

Experimental work supporting the waste package development program continued in 1998. Much of the experimental work in corrosion was carried out at Lawrence Livermore National Laboratory. A large and important part of the experimental work in corrosion research is the Long Term Materials Testing Program, which utilizes temperature-controlled vats partially filled with water containing dissolved minerals at concentrations that might be encountered by waste packages emplaced in Yucca Mountain. Samples of metals that are candidates for use underground at Yucca Mountain reside in the vats below, at, and above the waterline. The first samples were placed in some of the vats in September 1996. Periodically, samples are removed to ascertain the degree of corrosion. Most samples of corrosion-resistant materials were not among the first batches of samples placed in the vats, so data on these materials are limited.

During the last half of 1998, several additions were made to the corrosion research program. The additions appear to have come about partly as a result of the Board's Waste Package Workshop (NWTRB 1998d) and the Advisory Committee on Nuclear Waste's June 1998 working group meeting on near-field environment and engineered barriers.[11] All additions are short-term experiments, studies, or modeling exercises aimed primarily at achieving better understanding of localized corrosion (e.g., stress-corrosion cracking and crevice corrosion) of Alloy 22, titanium alloys, and other corrosion-resistant materials.

The results so far of the DOE's corrosion testing program indicate that corrosion rates are very low for candidate corrosion-resistant waste-package materials, consistent with predictions. The tests are scheduled to continue for at least the next several years. In general, the longer the tests continue, the greater the confidence in the results and the greater the confidence that unanticipated corrosion mechanisms having prolonged incubation periods do not exist. Thus, continuing the testing well into the "performance confirmation" period is important.[12]

C. The Board's Review Activities

The Board's review activities for the waste package in 1998 consisted primarily of (1) organizing and conducting the Waste Package Workshop in May, (2) reviewing progress in waste package and waste form modeling for TSPA-VA, and (3) attending the final waste package and waste form expert elicitation workshops and reviewing the subsequent final reports from the expert elicitations (Geomatrix 1998).

The final report from the waste form expert elicitation provided little support for taking a significant amount of cladding credit. One expert even indicated

11. The Board's Waste Package Workshop is discussed elsewhere in this document. Issues and recommendations from the June 1998 meeting of the Advisory Committee on Nuclear Waste are in Garrick 1998.

12. "Performance confirmation" means the program of tests, experiments, and analyses that is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met. The performance confirmation program starts during site characterization and continues until permanent closure. [10CFR60.2 and 10CFR60.140(b)]

that cladding credit probably could never be taken because of the large uncertainties in the environmental conditions surrounding the cladding. Despite these objections, the DOE took full cladding credit in the TSPA-VA. The Board is concerned that the DOE seemingly ignored the judgments of its own experts on this issue.

D. The Board's Conclusions

On the basis of its review of the DOE's scientific and technical investigations, the Board has reached the following conclusion about the current state of knowledge with respect to waste package design.

- Predicting the performance of a waste package design is a matter of predicting the external near-field environment surrounding the waste package, how the waste package and its environment would interact to modify the environment, and how the materials used in the waste package would degrade (corrode) in response to the modified environment. High confidence in performance predictions for the nickel-alloy inner wall of the current design is needed because of its importance to waste package longevity. Research should determine if the present package design could easily generate, beneath the remains of the carbon-steel outer wall, an environment aggressive enough to deteriorate the corrosion-resistant alloy quickly. Research also is needed to confirm long-term predictions (e.g., corrosion rates, phase stability over tens of thousands of years). These predictions are based on knowledge gained during only the past several decades for materials that rely on passive films for corrosion protection (e.g., zircaloy, Alloy-22, and titanium) and on data gained during only the last year or so for Alloy 22 under Yucca Mountain-simulated conditions. Therefore, results from ongoing and planned research on corrosion of waste package materials will be essential to establishing the technical parameters of the design.

III. Repository Design

A. Overview

The reference design of the underground facility is based on a 1995 study (CRWMS 1995a) and a DOE decision to focus on designs with high areal mass loading (i.e., 80-100 metric tons of uranium [MTU] per acre). This decision resulted in large part from the hypothesis that the heat from the decay of the radioactive waste could provide an above-boiling environment for waste packages for up to thousands of years and that such an environment would result in low humidity, low waste package corrosion, and therefore low waste package failure rates. A significant effect of the decision was that the entire 70,000 MTU specified by Congress as the capacity limit for the first geologic repository could be accommodated in the area under Yucca Mountain nominally bounded by the Ghost Dance fault on the east and the Solitario Canyon fault on the west. The reference design of the underground facility results in peak temperatures of nearly 200°C in the tunnel (drift) walls and 250°C on a waste package's outer surfaces.

In the VA design, the waste-emplacement tunnels are lined with precast-concrete floor and ground-support segments. Ventilation is provided by the north and south access ramps and two shafts connecting to a central 7.62-meter-diameter north-south exhaust tunnel below the underground facility. This system is ducted to the center of each waste-emplacement tunnel. The ventilation system provides separate air-flow systems for simultaneous emplacement of waste in completed emplacement tunnels and for construction of additional tunnels. In this hot repository design, each emplacement tunnel would be closed after it is filled, and ventilation of the closed tunnel would be reduced to a very low rate until repository closure.

The ambient temperature of the underground facility host rock at Yucca Mountain is approximately 25°C. If the average temperature of a waste-emplacement tunnel rises to 160°C (CRWMS 1997a), modeling indicates that the tunnel could expand vertically 8 to 10 mm while shrinking horizontally the same amount

(Elsworth 1998). These heat-induced deformations could increase the probability of rockfalls in the long term, possibly leading to localized tunnel collapse.[13]

Rockfalls make predicting the flow pattern and the amount of water contacting a waste package more difficult. The rockfalls would affect the local characteristics of the rock in the tunnel roof, making seepage flux more uncertain. Depending on the size and distribution of the rock fragments, localized tunnel collapse could create a zone of rock fragments around the waste package that could draw water toward the waste package in quantities far in excess of seepage flux predictions, or a collapse could create a region in which the water is dispersed around the waste package that could reduce the quantity of water contacting the waste package.

Tunnel stability also is important for waste package performance. For example, tunnel debris on a package surface may promote localized corrosion, which could shorten the life of a waste package. In addition, rocks falling from the roof of a tunnel could break through the wall(s) of a waste package already thinned by corrosion. For example, an analysis shows that a 350-kilogram rock falling 2.4 meters could cause the failure of a waste package that has lost 85 percent of its outer-wall thickness because of corrosion (CRWMS 1996, Barnard 1998).

In the hot repository design, rock temperatures would peak about 50 years after waste is emplaced. If closure of the underground facility were delayed for about 300 years, the temperatures of the tunnels would have decreased to around 120°C and the rock would have passed through its period of maximum thermal response. By then, if the rock were still stable, it likely would remain stable indefinitely, barring significant seismic activity. If it has failed, repairs might be possible before closure of the underground facility.

B. The DOE's Scientific and Technical Work

1. Design Work

The DOE's management and operating contractor (M&O) continued to refine the reference repository design. The design is being altered so that the repository can be developed incrementally. In addition, design studies continued to address the problem of silica dust generation, which arose during excavation of the ESF.

At the June Board meeting, the M&O reported on plans for a major alternative repository design study, which is scheduled to produce a preferred repository design by mid-1999. The design will be developed for use in the license application to the NRC in 2002.

2. Tunnel Stability Workshop

A workshop on tunnel stability, sponsored by the DOE, was organized by the M&O's repository design group in December. A panel of seven geotechnical specialists was taken on a field trip to Yucca Mountain to view the geologic strata in which the repository would be built. The visit was followed by a series of presentations by the repository designers on the current repository design.

The morning was spent reviewing the geology of the repository horizon and hearing a presentation on the layout and details of the VA repository design. The afternoon consisted of a tour of the ESF and the east-west drift. On the following day, the repository designers made presentations on the repository layout, ground-support designs and analyses, key-block analyses of several geologic zones constituting the repository block, rock properties, and seismic analysis of drifts. The alternative design studies were discussed briefly.

The presentations were limited to the repository preclosure period and were oriented toward analysis of the VA repository design. There was no discussion of postclosure (i.e., long-term) drift stability or the effects of the thermal pulse on long-term drift

13. Localized tunnel collapse may be thought of as a progression of many rockfalls until the tunnel is filled with rock particles of various sizes and no further collapse can occur.

stability. Information that had been sent to the panelists ahead of time was focused only on the VA ground-support design. The questions were posed: "Is this lining design satisfactory? If not, then why not, and what would be satisfactory?"

The focus was limited to the middle nonlithophysal rock properties as opposed to the lower lithophysal, which is where 70 percent of the repository would be located. The M&O has operated on the assumption that concrete liners are needed to provide support until repository closure and that repository design considerations end at closure. The designers have not considered the effects of geologic heterogeneities, differences in the properties of the rock strata, or the excavation-damage zone created by different types of excavation equipment.

Preliminary comments from the panelists indicated that repository ground support for waste emplacement drifts could be provided by rock bolts and wire mesh, which are needed for operational and worker safety. Rock-failure mode will be through localized raveling (i.e., progressive small-rock fallout).

C. The Board's Review Activities

During 1998, the Board focused its efforts on encouraging the DOE to examine a range of alternative repository designs and conduct trade-off analyses before selecting any one of them.[14] Although the DOE had to adopt a "reference design" early in the VA process and believed that it could not undertake a comprehensive assessment of alternative designs at the same time that it was preparing the VA, the DOE made a commitment to the Board that it would seriously explore other designs before taking one forward into the site-suitability process.[15]

D. The Board's Conclusions

On the basis of its review of the reference design, the Board reaffirms the conclusion it reached in its report to the U.S. Congress and the Secretary of Energy (NWTRB 1998a):

- Evaluations of alternative concepts for underground facility design are needed, especially of concepts that may provide the same level of performance but with less uncertainty than provided by the current underground facility design. For example, a ventilated repository design with lower peak temperatures could reduce current uncertainties about the heat-induced, mechanical, and chemical changes in the rock surrounding tunnels and could reduce the rates of waste package corrosion and radionuclide mobilization from the waste.

IV. Characterization of the Saturated Zone

A. Overview

The SZ at Yucca Mountain lies at depths of 500 or more meters below the surface. The dominant recharge of water to the SZ occurs north of Yucca Mountain at higher elevations, where precipitation is greater and temperatures are lower. The dominant flow direction in the SZ from the Yucca Mountain site is southeast toward and below Fortymile Wash, then south to Amargosa Valley.

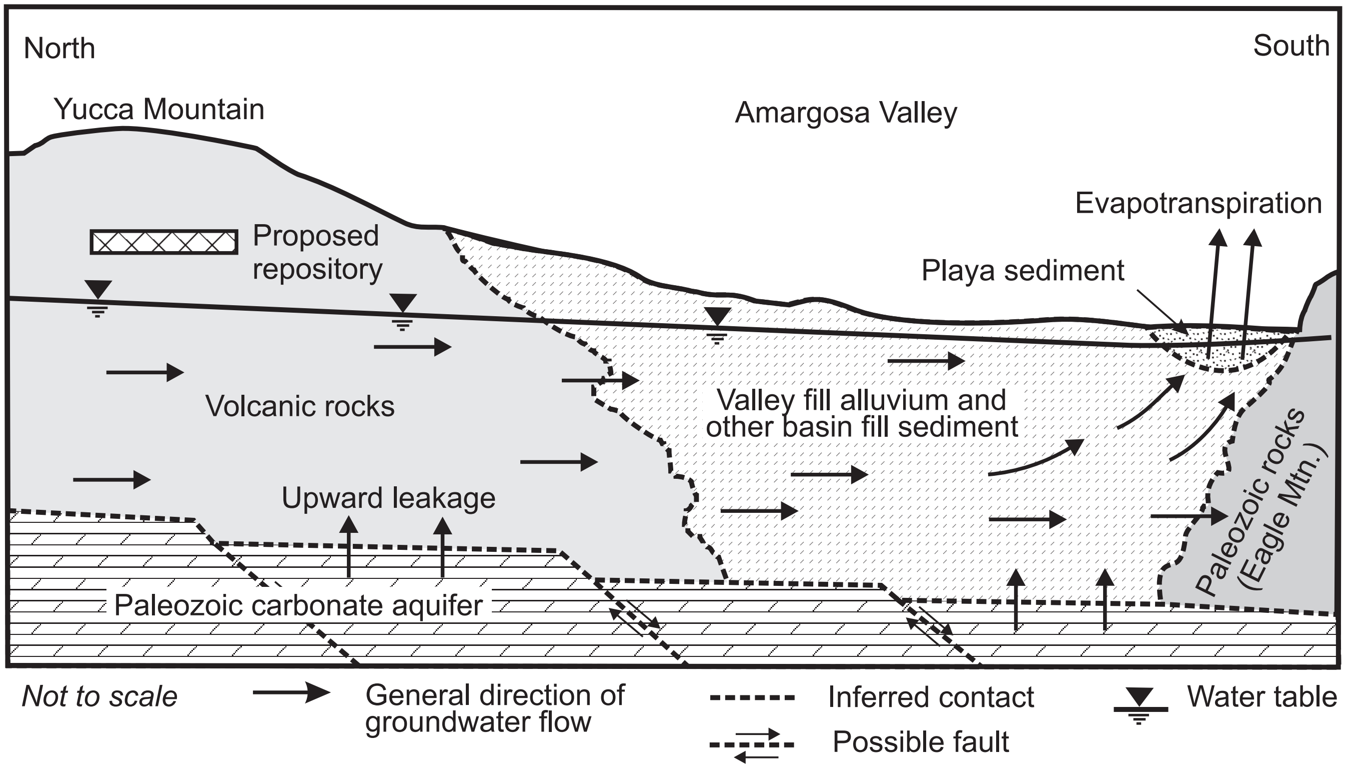
The primary hydrogeologic units that carry and influence the flow are the volcanic aquifer (consisting of the Upper Tram, Bullfrog, and Prow Pass formations), the volcanic aquitards (confining units) of the Calico Hills formation, the underlying and more permeable Paleozoic carbonate aquifer, and, to the south, the valley-fill alluvium. An idealized geohydrologic cross section from Yucca Mountain to Amargosa Valley is shown in Figure 1-3.

The SZ contributes as a natural barrier in two ways: (1) The SZ delays the transport of radionuclides to the accessible environment (increases the travel time); (2) The SZ reduces the concentration of radionuclides that entered from the UZ before they reach the accessible environment (through dilution). Characterization of the SZ has been influenced by

14. See July 30 letter from Jared L. Cohon to Lake Barrett (Cohon, 1998b).

15. The DOE initiated a License Application Design Study (LADS) in early 1999.

Figure 1-3. North-South Cross Section of SZ (after Czarnecki 1989)



the regulations that existed in the past. Under the previous "release-based" standard, dilution in the SZ did not play a significant role. Only the delay aspect of the SZ was important because of the requirement for a minimum groundwater travel time at the site (10 CFR 60). Now that a change is anticipated from a release-based to a dose- or risk-based standard, the SZ is a more important natural barrier because of its potential to decrease radionuclide concentration. Dilution is particularly important for reducing the peak dose from very-long-lived radionuclides (e.g., ^{237}Np), where delay does not result in significant radioactive decay.

SZ dilution and travel times are directly related to repository performance. They address the "How much will arrive?" and "How long will it take?" aspects of the SZ.

The amount of dilution that will occur in the SZ has been one of the key uncertainties in assessing the performance of the natural barriers. The primary reason is that dilution factors[16] cannot be measured directly and require model predictions. The SZ transport model, which was to provide the expected dilution factor for the TSPA, was discarded in 1998. Because of the lack of data, SZ radionuclide transport was modeled for TSPA-VA by using a one-dimensional stream-tube model. The dilution factors for each stream tube were sampled randomly from the probability distribution functions elicited from experts (range of 1 to 100, expected value of 10) (Andrews 1998). Because of the short (modeled) travel times and small (assumed) dilution factors, the SZ contributed relatively little to repository performance as modeled in TSPA-VA.

16. The dilution factor for the SZ is defined as the ratio of the average radionuclide concentration in groundwater entering the SZ from the UZ to the average radionuclide concentration being withdrawn from the SZ for human use.

B. The DOE's Scientific and Technical Work

Because of lack of funding, the anticipated pumping and tracer test facility, an analog to the C-well complex at a new location,[17] was postponed. Some additional hydraulic tests using reactive tracers were conducted in the Prow Pass interval at the C-well complex.

Additional hydraulic data were to have been obtained from the SD-6 and WT-24 boreholes. The work at SD-6 encountered drilling difficulties, so no information could be gathered below the water table. The drilling at the WT-24 well hole reached its planned depth, but it encountered a relatively tight part of the regional aquifer, so no pump testing could be conducted.

The regional 3-D groundwater-flow model of Death Valley Basin will be combined with the similar project being carried out at the Nevada Test Site by GeoTrans. This combination of resources and data will greatly enhance the possibility that a comprehensive model of the Yucca Mountain region will be forthcoming in a shorter time. A considerable amount of regional data downgradient of Yucca Mountain is expected from the proposed Nye County Early Warning Drilling Program (EWDP). There are almost no data about the alluvium and volcanics interface in this region.

C. The Board's Review Activities

Because of the much greater role that the SZ potentially plays in an evaluation of compliance with a dose-based standard, the Board extensively reviewed the DOE's work on the SZ during its January meeting in Amargosa Valley (NWTRB 1998b).

An overview of the SZ program and its objectives was presented by the DOE. The regional picture of the flow domain was summarized in three presentations on the regional 3-D groundwater-flow model of Death Valley Basin, the significance of hydrochemical domains in the SZ at Yucca Mountain, and a model for major ion chemistry of SZ waters along flow lines through Yucca Mountain. Although much has been learned in the last few years, the presentations illustrated the overall lack of hydrologic and geochemical data downgradient of Yucca Mountain. Alternative and additional testing and hypotheses of the SZ were presented by the State of Nevada and the Nye County EWDP.

Little transport data are available. The best data have been gathered at the C-well complex and were reviewed in the presentation on hydraulic and tracer testing at the C-well. These pumping tests and multiple tracer tests are at a single location in a single unit (the Bullfrog) and perhaps are not representative of the area between Yucca Mountain and Amargosa Valley. The potential "dilution" of the radionuclide concentrations as they move from Yucca Mountain to the accessible environment is a controversial subject. The subject was reviewed in the presentations on the preliminary 3-D finite-element groundwater-flow model of the SZ, on the status of the SZ flow-and-transport model, and on SZ flow-and-transport analyses in the TSPA.

The DOE had convened an expert panel to assess the status of the data and modeling of the SZ. Among the conclusions reached were (1) the data on the SZ are insufficient to elicit confidence in the model predictions; (2) the large hydraulic gradient north of Yucca Mountain is a common feature in this region and is consistent with the regional stratigraphy and hydrologic properties, and the probability that it is a concern for repository performance is exceedingly small; and (3) the large dispersion / dilution predicted by the transport model in the SZ is not based on any data and is scientifically unsupportable. The last conclusion caused the DOE and the M&O to change their transport computation for TSPA-VA. During the January Board meeting, two of the panel members were invited to present their views on the key issues and uncertainties for the SZ.

D. The Board's Conclusions

The Board believes that the SZ is an essential natural component of a defense-in-depth repository design for Yucca Mountain. The following are the Board's conclusions about the SZ.

17. Three closely spaced wells were drilled near the proposed repository for conducting flow-and-transport tests in the SZ.

- Groundwater appears to move through Yucca Mountain to the accessible environment 20 to 30 km away in less than the regulatory period of 10,000 years. Although retardation in fractured rocks may be ineffective because highly transmissive regions within the SZ may allow dissolved radionuclides to bypass sorptive minerals, retardation in the alluvium near Amargosa Valley may be greater. If so, the SZ could significantly delay transport of radionuclides between the repository and the accessible environment.

- Parts of the SZ may be a chemically reducing environment where some of the very-long-lived radionuclides, including Np and uranium, would precipitate, permanently removing them from the groundwater and reducing predicted radiation doses at the biosphere.

- More data are required to support modeling of the SZ, especially for the regional flow system between the repository and the accessible environment 20 to 30 km away. Key geologic, hydrologic, and geochemical data, including information about long-range colloid transport, have the potential to answer specific questions, such as the role of stratigraphy and structure, recharge and discharge locations, and possible ages of water. Obtaining these data is likely to improve the understanding of SZ characteristics much more than additional modeling efforts will.

- Current estimates of SZ dilution eventually may prove to be conservative, but supporting a larger dilution factor will be difficult unless new data are obtained to support the estimates produced by numerical models. The wells and experiments planned by Nye County should provide valuable information on the part of the SZ downgradient of Yucca Mountain. However, the wells may not provide sufficient data, and additional testing may be needed at other sites closer to Yucca Mountain.

V. Total System Performance Assessment

A. Overview

Total system performance assessment (TSPA) is the principal method of evaluating the ability of the proposed repository (engineered and natural components acting together) to contain and isolate waste. It is essentially a predictive-computational model or, more accurately, a collection of models of repository performance over time. Before completion of the TSPA for the VA (TSPA-VA) (USDOE YMPO 1998), major iterations of performance assessments were completed by DOE contractors for the Yucca Mountain site in 1991, 1993, and 1995. The initial TSPAs were conducted, although not always used, to provide guidance in gathering data and setting priorities in the scientific and engineering investigations being conducted by the Yucca Mountain Project. In addition to fulfilling that role, present and future TSPAs will be used to judge whether and to what extent the proposed repository is likely to meet the developing U.S. Environmental Protection Agency (EPA) and NRC safety standards.

B. The DOE's Scientific and Technical Work

In recent years, the primary focus of the DOE's effort in performance assessment has been the development of the TSPA-VA. As indicated previously, Congress directed the DOE to include in the VA a TSPA based on "... the design concept and on the scientific data and analysis available by September 30, 1998, describing the probable behavior of the repository in the Yucca Mountain geological setting in relation to the overall system performance standards" (U.S. Congress 1996).

A great deal of effort has been expended on the TSPA-VA. For example, in preparing for the TSPA-VA, the DOE conducted two lengthy series of workshops (mostly in 1997). The first series, called "abstraction and testing workshops," brought together field and laboratory scientists, modelers, and performance-assessment analysts from within the program to better define the process by which the highly complex models and data used to describe important phenomena in various areas could be simplified for inclusion in the TSPA-VA. The second series of workshops involved eliciting expert judgment, primarily from outside the Yucca Mountain Project, on the conceptual and parameter uncertainty associated with critical components and assumptions used in the TSPA.[18]

In 1998, the DOE devoted its efforts primarily to integrating the input from its own investigators and from external experts into the TSPA-VA. The results of the TSPA-VA consists of two main parts: (1) a base case emphasizing what the DOE considers the repository's expected or probable behavior and (2) a series of sensitivity tests aimed at estimating the effect on performance of different scenarios and alternative input parameters and design features.

An important part of the DOE's effort associated with the TSPA-VA has been an external peer review panel (TSPA Panel 1998). In 1998, the panel issued the third of its interim reports on the DOE's efforts. As in the previous reports (issued in 1997), the panel has shown itself to be both incisive and independent. In general, the panel pointed out the lack of site-specific data and the need to verify, as much as possible, the hypotheses, models, and abstractions used in the TSPA. The specific issues raised include the less-than-satisfactory characterization of SZ flow; the superficial treatment of coupled thermohydrologic, mechanical, and chemical interactions; the importance of crevice corrosion; and the need to provide experimental support for any credit taken for zircaloy cladding. A final panel report was released in February 1999. The DOE is to be commended for convening this panel.

C. The Board's Review Activities

In 1998, the Board's review activities that were related to TSPA centered on two meetings: an April 23-24 meeting of the Board's Panel on Performance Assessment in Albuquerque, New Mexico (NWTRB 1998c), and a presentation on TSPA at the June 24 summer Board meeting in Las Vegas, Nevada (NWTRB 1998e). At those meetings, the developing TSPA-VA was presented by the DOE and its contractors and discussed by Board members. Although the Board is continuing its review of the final version of the TSPA-VA, comments on these initial presentations were sent in a July 30, 1998, letter to Lake Barrett, Acting Director of the DOE's Office of Civilian Radioactive Waste Management (OCRWM) (Cohon 1998b). They are discussed below.

D. The Board's Conclusions

In general, the Board was pleased to see the refinements and improvements in the DOE's TSPA efforts. They were particularly evident in the efforts to make the TSPA more transparent—that is, understandable.

This latest analysis leaves the clear impression that the projected performance of the repository is very dependent on the corrosion resistance of the waste package and cladding. Any set of calculations, however, is only as valid as the underlying assumptions, models, and data. For example, the uncertainty analyses were highly dependent on the range of assigned parameter values. Important issues, such as cladding performance, did not appear important only because they were assigned a low uncertainty. Also not evident was whether the correlation between parameters, such as infiltration and seepage fraction, had been taken fully into account.

The Board recognizes the need to make judgments in any analysis. However, these judgments and their bases need to be stated explicitly and clearly. In 1997, the Board provided suggestions on how the DOE could meet this and other challenges. The suggestions appear in the Board report on its 1996 activities (NWTRB 1997a) and in a letter sent to April Gil (Cohon 1997) in response to the OCRWM's request for comments on proposed revisions to 10 CFR 960. In the report and the letter, the Board laid out suggestions on how to prepare a technically persuasive and robust performance assessment. The Board believes that the OCRWM's assessments should incorporate those ideas in its upcoming performance assessment for site recommendation.

18. The Board's 1997 summary report contains an extensive discussion of the DOE's use of expert judgment (NWTRB 1998a).

Chapter 2
Other Board Activities

During 1998, the Board evaluated elements of the DOE's radioactive waste management program in addition to the site-characterization efforts at Yucca Mountain. In this chapter, the Board reports on those evaluation activities.

I. Review of Material Related to Hydrothermal Upwelling at Yucca Mountain

The Board completed its review of material (11 reports) first submitted to it in summary form by Mr. Jerry Szymanski at its January 1997 meeting in Pahrump, Nevada. The documents argue that there is evidence of ongoing, intermittent hydrothermal upwelling at Yucca Mountain and that large earthquake-induced changes in the water table are likely at Yucca Mountain. As a result, the documents maintain that the Yucca Mountain site is unsuitable for development as a repository for spent nuclear fuel and high -level radioactive waste. After its January 1997 meeting, the Board received requests from both the Committee for the Truth about Yucca Mountain (Chrisman 1997) and the Attorney General of the State of Nevada (Del Papa 1997) to review this material.

This is not the first time that Mr. Szymanski has raised these questions. His ideas were thoroughly reviewed by outside experts, including a panel appointed by the National Research Council of the National Academy of Sciences (NAS). This prestigious and broadly based review was published in 1992 by the National Academy Press in a report titled *Ground Water at Yucca Mountain—How High Can It Rise?* (NAS / NRC 1992). As stated in the Board's December 1992 report (NWTRB 1992), the Board saw no reason to disagree with the 17-person NAS panel's unanimous conclusion: "The panel concludes from the geological features observed in the field and geochemical data that there is no evidence to support the assertion [by Mr. Szymanski] that the water table has risen periodically hundreds of meters from deep within the crust" (NAS / NRC 1992). The Board's December 1992 report also noted that if significant new data or modifications were presented in the future, the Board would consider reviewing them at that time.

The Board examined the material submitted in 1997, and, because some new information had been presented, the Board decided to evaluate the quality and significance of this information. For assistance in this evaluation, the Board contracted with four highly qualified scientists. The scientists were chosen because of their expertise in critical areas, their reputations among their peers (many of whom the Board staff spoke to), their lack of affiliation with the Yucca Mountain Project, and their lack of previous involvement in evaluating Mr. Szymanski's ideas.

The consultants were Dr. Robert J. Bodnar, C. C. Garvin Professor of Geochemistry and Director of the Fluids Research Laboratory, Department of Geological Sciences, Virginia Polytechnic Institute & State University (Dr. Bodnar's expertise is in fluid inclusions and the geology and geochemistry of ore deposits.); Dr. Patrick R. L. Browne, Associate Professor and Director of the Geothermal Institute, University of Auckland, New Zealand (Dr. Browne's expertise is in hydrothermal alteration of volcanic rocks and fluid-rock interactions.); Dr. Stuart Rojstaczer, Associate Professor and Director of the

Center for Hydrologic Science, Duke University (Dr. Rojstaczer's expertise is in the role of subsurface fluid flow in geologic and human-induced hazards and the hydrologic effects of earthquakes.); and Dr .John Valley, Professor and Chairman of the Department of Geology and Geophysics, University of Wisconsin-Madison (Dr. Valley's expertise is in metamorphic petrology and stable-isotope geochemistry.).

The Board conducted its review, making use of its own expertise and that of its consultants. Four questions were posed to the consultants (Drs. Bodnar, Browne, and Valley for evidence of hydrothermal activity and Dr. Rojstaczer for earthquake-induced changes in the water table) that centered on the significance of the new information presented with respect to the conclusions drawn in the 1992 NAS report (NAS / NRC 1992). These questions also were the focus of the Board's review:

1. Are there significant new data and interpretations since the 1992 NAS report?

2. What is the quality of these data and interpretations?

3. How much credence do these data and interpretations lend to the hypothesis of ongoing, intermittent hydrothermal activity and large earthquake-induced changes in the water table at Yucca Mountain?

4. If these data and interpretations significantly affect the conclusions of the 1992 NAS report, how can the issue be resolved?

The Board emphasizes that the purpose of its review was to evaluate the information submitted to the Board, not to conduct a systematic review of all the information that has been collected on this topic, including the extensive work carried out for the DOE's Yucca Mountain Project by the U.S. Geological Survey (USGS) and the National Laboratories. A systematic review of all the information available by 1992 was carried out by the panel that prepared the 1992 NAS report.

In addition to reviewing the 11 reports submitted by Mr. Szymanski, 3 additional reports provided by the Nevada Attorney General's office, and a number of other important documents referenced in these reports, Board staff spoke directly to several of the reports' authors. A Board member (Dr. Donald Runnells), a Board staff member (Dr. Leon Reiter), and Dr. Bodnar also attended an international meeting in which fluid inclusion evidence for and against future hydrothermal upwelling at Yucca Mountain was presented and discussed. Following that meeting, Dr. Yuri Dublyansky (the lead author of several of the reports) spent several days with Dr. Bodnar at Dr. Bodnar's Fluids Research Laboratory at Virginia Polytechnic Institute.

The Board has reached the following conclusions:

- The material reviewed by the Board does not make a credible case for the assertion that there has been ongoing, intermittent hydrothermal activity at Yucca Mountain or that large earthquake-induced changes in the water table are likely at Yucca Mountain. This material does not significantly affect the conclusions of the 1992 NAS report.

- There are several areas where additional research could be used to evaluate further the hypotheses of ongoing, intermittent hydrothermal activity and large earthquake-induced changes in the water table at Yucca Mountain. However, because of the lack of any substantive evidence supporting either of these hypotheses, the Board views additional research on these issues, if not already carried out, as generally having a lower priority than more important issues in the evaluation of repository performance.

- However, some fluid inclusions found in mineral deposits at Yucca Mountain do provide direct evidence of the past presence of fluids at elevated temperatures (at least 72°C) in the vicinity of the proposed repository. This could be an indicator of some degree of past hydrothermal activity. The critical question is, "At what time in the past were such fluids present?" If fluids at elevated temperatures were present less than 100,000 years ago, as some of the reviewed reports claim, this could lend credence to the hypothesis of ongoing hydrothermal activity at Yucca Mountain. On the other hand, if these fluids were present around 10,000,000 years ago or earlier, they could be associated with volcanic events related to the original formation of

Yucca Mountain and would have no bearing on the hypothesis of ongoing hydrothermal activity. The Board believes that the ages of fluid inclusions should be determined. A joint program between federal and State of Nevada scientists for collecting, dating, and analyzing fluid inclusions would be one way to make this determination in a way that would reduce some of the past disagreements associated with sample collection and handling.

II. Waste Package Workshop

In its recent reports and correspondence, the Board has urged strongly that the DOE identify, and then carefully examine, alternative designs for the subsurface facility and for the waste packages (NWTRB 1997a and 1998b; Cohon 1998a and 1998b). Examples of alternative waste package designs that could merit examination include (1) a waste package design with the materials of the outer and inner shells reversed in comparison to the current design and (2) a double-shell waste package with the outer shell made of a corrosion-resistant material and the inner shell made of a different corrosion-resistant material. The Board convened a waste package workshop in May 1998 to identify alternative waste package designs and associated research needs.

A. Planning for the Workshop

The 1½-day workshop was held on May 18 and 19, 1998, in Falls Church, Virginia (NWTRB 1998d). It was conducted as a panel meeting under the aegis of the Board's Panel on the Repository. The primary purpose of the workshop was to develop a firm technical basis for reviewing and evaluating the scientific and technical merits of any waste package designs arising from the DOE's program. The primary products of the workshop were a list of alternative waste package designs and a list of associated research needs. For encouraging a free exchange of ideas and as much "brainstorming" as possible, as well as participation by the public, a roundtable format was used for the entire workshop, except for a few initial presentations.

Participants in the roundtable included five Board members (Drs. Bullen, Craig, Nelson, Parizek, and Sagüés), two members of the Board's staff (Drs. William Barnard and Carl Di Bella), and five invited panelists: Dr. John Kessler (of EPRI), Dr. Digby Macdonald (of SRI International), Dr. Joe Payer (of the Department of Materials Science and Engineering, Case Western Reserve University), Dr. David Shoesmith (of the Department of Chemistry, University of Western Ontario, formerly with Atomic Energy of Canada, Limited), and Dr. Michael Streicher (a corrosion consultant, formerly with E. I. Du Pont de Nemours and Co., Inc., and the University of Delaware). Dr. Kevin Coppersmith of Geomatrix, Inc., served as facilitator for the workshop.

The workshop began with a few short presentations giving (1) the ground rules for the workshop, (2) the status of the DOE's program for disposing of spent fuel, and (3) the description of the current waste package design. A fourth presentation, proposing a simple way to approximate the interactions that various underground facility designs would have with various waste package designs, also was made.

The purpose of the fourth presentation was to separate underground facility design from waste package design. The separation was considered necessary because the duration of the workshop was too brief to allow full discussion of both underground facility design and waste package design and their associated research needs. Although the separation worked for the workshop, it is clear that underground facility design and waste package design are highly interdependent and therefore must be taken together for any comprehensive examination.

B. Alternative Waste Package Designs

In the reference waste package design, the waste package has a 10-cm-thick carbon-steel outer wall and a 2-cm-thick nickel-alloy inner wall. The current design includes four waste package capacities for commercial spent fuel: 12 pressurized-water reactor (PWR) assemblies, 21 PWR assemblies, 24 boiling-water reactor (BWR) assemblies, and 44 BWR assemblies. The packages are up to 1.7 m in diameter and 5.4 m in length. Alternative designs identified at the workshop are listed below.

1. Current base design: a carbon-steel outer shell shrunkfit over an Alloy 22 inner shell.

1a. Same as 1 except that the outer shell fits loosely over the inner shell.

2. An Alloy 22 outer shell over a carbon-steel inner shell (i.e., reversal of the two shells of the current base design).

3. An Alloy 22 outer shell over a nodular cast-iron inner shell.

3a. Same as 3 except that rod consolidation would be used (to increase waste package capacity), thickness of the waste package wall would be increased (so that the radiation field outside the waste packages would be low enough for humans to work near the waste packages), and significant ventilation would be used (to maintain temperatures low enough for humans to work near the waste packages).

4. An Alloy 22 outer shell over a graphite inner shell.

5. A titanium outer shell over an Alloy 22 inner shell.

6. A titanium or Alloy 22 outer shell over a "structural material" (e.g., stainless steel or a low-cost nickel alloy) inner shell.

7. A three-shell waste package with a titanium or Alloy 22 outer shell, an Alloy 22 or titanium middle shell, and a "structural material" inner shell.

8. Any waste package design that would allow emplacement in vertical boreholes (with ventilation).

9. Lower-capacity waste packages and extensive use of backfill.

10. Any waste package design that would allow emplacement in horizontal boreholes (with ventilation).

Although the panelists did not state that the list of design alternatives was necessarily the complete list of all reasonable alternatives, no additional alternatives were identified during the workshop. The Board will use these alternatives to help evaluate the completeness of the DOE's studies on alternative waste package designs. The Board does not take the position that one or more of these alternatives is superior to the reference waste package design. The Board believes that all the alternatives are worthy of at least a screening evaluation and expects that the screening evaluation will result in some of the alternatives being chosen for comprehensive evaluation.

C. Research Needs

After examining waste package alternatives, the panelists identified research needed to support alternatives. "Research" was defined in a very broad sense: It could include laboratory or field experiments, analysis (e.g., running thermodynamic models on computers), more-complete specification of requirements, or even the novel application of commercially available technology. The panelists developed a list of research needs for each alternative.

The Board has not reviewed the DOE's waste package research program formally since the workshop. Informally, the Board is aware that some of the research needs identified at the workshop were being addressed in the DOE program at the time the workshop was held and that the other research needs are being supported by new DOE initiatives.

Longer-range programs also need to be started. These programs are needed for improving the fundamental understanding of long-term corrosion resistance of passive films and long-term stability of metastable phases (such as in Alloy 22).

D. Conclusions

- The workshop resulted in the identification of several waste package alternatives that deserve careful examination by the DOE.

- Numerous research needs were developed at the workshop, most of which are applicable regardless of the waste package design that finally is chosen. Much of the research is under way. There are a few conspicuous gaps, however, and they need to be addressed. Short-term gaps include (1) the determination of the chemistry of the water after it has interacted with the waste package and (2) the study of natural analogues. Long-term gaps include programs for improving the fundamental understanding of long-term behavior of passive films and long-term phase stability.

- Although a simple method for separating waste package design from underground design sufficed for the purposes of the workshop, one of the clear lessons from the workshop is that the waste package and the underground facility (together, the engineered barrier system) are too interdependent to be separated. Thus, the development and analysis of each alternative waste package design must be accompanied by the simultaneous development and analysis of an underground facility design that is most appropriate for it.

III. Transportation

Although no immediate activity is expected, transportation of spent nuclear fuel continued to be of significant interest to the Board in 1998.

In developing its transportation program, the DOE might learn much from experiences in Europe and Japan, where there is already large-scale transportation activity. In those countries, there is an antinuclear element that the industry must deal with. Germany has had a great deal of difficulty in moving spent nuclear fuel, and the shipments from Japan to France and the United Kingdom have generated protests.

The DOE also might learn some lessons from what is taking place in Europe and should make every effort to build trust and a good working relationship with the groups, especially in Nevada, that will be affected by a large-scale shipping campaign. One possible approach to maximizing safety and to preventing undue burdens on the nationwide railroad network could be the use of dedicated trains for transporting spent nuclear fuel. The Board also feels that the design of the transportation cask should be integrated with that of the rail car. An integrated design concept would be a way to increase safety and performance.

IV. Environmental Impact Statement for a Yucca Mountain Repository

The DOE is preparing an environmental impact statement (EIS) for a Yucca Mountain repository (Dixon 1998). The EIS would accompany a recommendation to the President (currently scheduled for 2001) for developing a repository at the site and also would be submitted to the NRC, accompanying the application for a license for the facility in 2002. The proposed action in the EIS is to construct, operate, and eventually close a repository at Yucca Mountain for the geologic disposal of 63,000 metric tons of commercial spent nuclear fuel and 7,000 metric tons of DOE-owned spent nuclear fuel and high-level radioactive waste. The no-action alternative would be to leave those materials in storage at their current locations.

Three “implementing alternatives” will be evaluated for developing a repository, defined by low, intermediate, and high thermal loads.[19] For each alternative, two packaging options will be evaluated: (1) sealing wastes in multipurpose canisters at the generator sites and (2) transporting wastes in casks and repackaging the wastes at the repository site. For each implementing alternative, five transportation options also will be evaluated, consisting of predominantly (1) truck or (2) rail cross-country shipment to Nevada and (3) rail, (4) heavy-haul, or (5) legal-weight truck shipment within Nevada. Two expanded inventory “modules” will be considered: (1) disposal at Yucca Mountain of the entire U.S. inventory of spent nuclear fuel and high-level radioactive waste and (2) disposal of other highly radioactive wastes that may require permanent isolation (USDOE, YMPO 1997). For the no-action alternative, two scenarios will be evaluated: (1) loss of institutional controls at storage sites after 100 years and (2) continuation of institutional controls at those sites for 10,000 years (Dixon 1998).

The DOE plans to publish its draft EIS in July 1999, initiating a public comment period of several months. The final EIS is scheduled to be published in August 2000. The Board plans to review and comment on the draft EIS after its publication.

19. “Thermal load” is the amount of waste emplaced per unit area of the repository. In the EIS, thermal loads of less than 40 metric tons per acre, 40-80 metric tons per acre, and more than 80 metric tons will be considered.

V. Strategic and Performance Plans

In late 1997, the Board developed a 5-year strategic plan in compliance with the Government Performance Results Act. The Board also established its performance plan for fiscal year 1999, which includes specific objectives to be accomplished during that period. In January 1998, the Board held a public session in conjunction with its regular Board meeting in Amargosa Valley, Nevada, to obtain comments from the interested public on both its strategic and its performance plans. The Board also solicited comments on both plans from others having oversight roles for, or involvement in, nuclear waste management issues, including key congressional staff, the DOE, and the NRC. Copies of the strategic plan and the performance plan for the coming year are included in appendices to this report.

The Board's strategic plan underscores the importance of an independent technical and scientific review of the civilian radioactive waste management program for achieving the overall national goal of ensuring that civilian spent nuclear fuel and high-level radioactive waste are safely packaged, transported to, and disposed of in a permanent repository at a suitable site. The Board's performance objectives for fiscal year 1999 reflect the goals stated in the strategic plan and flow from the Board's technical and scientific review of DOE work, including (1) designing components of an engineered barrier system, (2) developing an environmental assessment of the site, (3) planning related to the safety of waste-transportation corridors, and (4) conducting research supporting a decision on the suitability of the site.

Procedures were established in the performance plan for conducting an annual evaluation of the Board's performance in meeting its objectives for the previous year. The Board will consider whether the reviews, evaluations, and other activities included in its performance goals have been completed; whether the results of reviews, evaluations, and other activities undertaken under the auspices of the program have been communicated in a timely, understandable, and appropriate way to the Secretary of Energy and Congress; and whether the recommendations made by the Board had a positive effect on the program. The first of these program evaluations will be conducted at the end of fiscal year 1999, and the results will be included in the Board's summary report for that period.

VI. Board Visit to Waste Isolation Pilot Plant

Members of the Board met with managers of the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, and toured the facilities on March 10, 1998. The visit included the opportunity to hear firsthand from George Dials, then general manager of the Carlsbad Area Office of the DOE, and Wendell Weart, formerly Senior Scientist for the WIPP program and now Senior Fellow at Sandia National Laboratories in Los Alamos, New Mexico. The Board's visit included a tour of the waste-handling building and the underground facilities. Board members also were briefed on the WIPP compliance- and application-review processes. On the basis of their experience, those involved made the following observations to the Board.

- In evaluating the performance assessment for WIPP, the regulator(s) tended to make conservative assumptions in assessing the probabilities and consequences of events and processes.

- When submitting the license application for a first-of-a-kind facility, such as WIPP, having credible sources, other than the proponent, provide analysis of the scientific and technical conclusions of the proponent was helpful.

- Strong leadership is required to integrate and focus scientific investigations. A shared vision and a focused management plan can help eliminate unnecessary work and help complete necessary work more quickly.

The Board members also noted that the managers instituted a ranking system to manage the science at WIPP. This major effort resulted in reducing the experimental work in progress from 116 activities to 8. Other important decisions that affected the scientific and technical work at WIPP were to (1) evaluate 18 different engineered alternatives, (2) adopt a more-phased approach to securing a license, and (3) commission an international peer review.[20]

VII. International Activities

Several members of the Board participated in two international trips in 1998 in an effort to continue the Board's objective of remaining informed about scientific, technical, and program developments in the nuclear waste disposal programs of selected developed countries. Board members traveled to Sweden and Finland from May 4 to 9. A second delegation of five members visited Germany from June 8 to 11. One major purpose of the visits was to give new Board members the opportunity to visit several nuclear waste facilities firsthand and to receive briefings on the scientific and technical progress in the nuclear waste programs of the countries.

In addition to the two trips, the Board participated in several briefings in the Washington, D.C., area. The first, arranged by the British Embassy, consisted of a meeting of selected Board members with five members of the Select Committee on Science and Technology of the House of Lords, United Kingdom. The committee is conducting an inquiry into the management of nuclear waste following the decision of the government in 1997 to uphold Cumbria County's decision to deny U.K. Nirex Ltd.'s planning application for a rock-characterization laboratory near Sellafield. Members of the Board and staff also met with representatives from a study committee organized by The Institute of Applied Energy in Japan, who were visiting several foreign countries collecting research on international approaches to postclosure management of potential repositories for high-level radioactive waste. Last, the Board and staff met with a delegation of France's Atomic Energy Commission (CEA), who were visiting various organizations and facilities as part of an ongoing study of the long-term conditioning and storage of high-level radioactive waste, mandated in 1991 by French law.

A. Germany

A delegation of the Board traveled to Germany to visit nuclear waste facilities. From June 8 to 11, the delegates visited several sites[21] and were briefed on many of the scientific and technical aspects of the management, storage, transportation, and potential disposal of high-level radioactive waste and spent nuclear fuel in Germany. The Board's visit focused on the design, development, testing, and fabrication of storage, transportation, and disposal casks; the site-characterization work at the potential disposal site at Gorleben; and the system for moving spent nuclear fuel and for storing and preparing high-level waste for permanent disposal.

Considerable progress has been made in developing the Pollux cask, a packaging system for the transport, interim storage, and final disposal of spent-fuel rods (Janberg and Spilker 1998). The Board members believe that the effort that has gone into designing, fabricating, and testing this cask is worth exploration by those involved in similar work for the U.S. program.

The Board members noted the use of natural convection to ventilate the entire underground exploratory system at Gorleben. The exploratory facility at Gorleben is at the southern edge of the proposed repository block and is accessed by two shafts that are approximately 7 m in diameter. The intake shaft extends to 940 m, and the exhaust shaft extends to 840 m. Work is under way to extend the facility around the proposed block. There is no forced-draft fan on the intake shaft and no induced-draft fan on the exhaust.

20. The DOE commissioned an international review team in June 1996. It included experts appointed by the Organization for Economic Cooperation and Development, the Nuclear Energy Agency, and the International Atomic Energy Agency.

21. The Board's visit included the following sites: (1) Gesellschaft für Nuklear-Service mbH and Gesellschaft für Nuklear Behälter mbh cask development, fabrication, and testing facilities in Essen; (2) the Ahaus interim storage site, operated by Brennelement-Zwischenlager Ahaus GmbH; (3) the Pilot Conditioning Plant, Radwaste Interim Storage Facility, and Transport Cask Interim Storage Facility, which are located at Gorleben and are operated by Brennelementlager Gorleben mbH; (4) the proposed site of a permanent repository, which is located at Gorleben and is undergoing site characterization by Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH; and (5) the Endlager für radioaktive Abfälle Morsleben, which is a permanent disposal site for low- and intermediate-level radioactive waste near Morsleben.

Unrestricted natural convection flow in the winter is high enough that a damper at the exploratory facility level has to be used to reduce air flow. In designing any alternative repository plans for Yucca Mountain, it may be worth drawing on the experience of those involved in designing the ventilation system at Gorleben, as well as the ventilation studies undertaken by Nye County, Nevada.

B. Sweden

A small delegation from the Board visited the municipality of Oskarshamn in southeastern Sweden on May 4 and 5. The purpose of the visit was to tour the Swedish Nuclear Waste Company's (SKB) facilities and to meet with representatives of Oskarshamn, one of four municipalities that have volunteered to undertake the first step in a process that could result in a permanent repository being located in their municipality. Three other municipalities have volunteered and are in the first phase of the prestudy process. They are Nyköping, Östhammar, and Tierp.

Members of the Board had the opportunity to meet with the people in Oskarshamn who are heavily involved in establishing an environmental impact assessment (EIA) process. The EIA Forum was created by the community after it volunteered to undertake the first of three phases of a volunteer process established in Sweden to designate a final repository site. The three phases are (1) feasibility studies, (2) site investigations, and (3) detailed investigations. The EIA forum is intended, among other objectives, to enable the residents of the municipality to participate in the decision-making as the community moves to determine whether it wants to proceed to site investigation.[22]

The EIA Forum is a significant effort in that it is the first initiative of its kind in the world for disposing of spent nuclear fuel. Through the EIA Forum, the municipality has formalized a process in which the locality is empowered to make key decisions about whether it wants to proceed to other phases of the site selection process. The community has organized six working groups: long-term safety and geoscience, technologies, land use and environment, social science, encapsulation, and information. Their effort to date is aimed at reaching a realistic assessment of the effect that a permanent repository would have on their community.

During its visit, members of the Board's delegation had the opportunity to tour the following SKB facilities: the Hard Rock Laboratory at Äspö, the interim storage facility (CLAB), and the Encapsulation Laboratory in Oskarshamn. During its visit, the Board also was briefed on the scientific and technical work being performed in support of the SKB's KBS-3 waste isolation concept.[23] The purpose of the Encapsulation Laboratory is to demonstrate on a full-scale basis that one canister per day that meets the safety requirements can be produced. The Encapsulation Laboratory also will be used to test operational problems, estimate the reliability and maintenance of the equipment and the plant, and estimate the capability of the equipment.

The SKB canister, which is undergoing full-scale laboratory manufacturing trials, is an evolution of past designs. It consists of 50 mm of copper with cast iron inside. The cast-iron inner component has been added as a stand for the fuel elements and as a support for the copper mantle. The canister serves as two barriers; the copper prevents groundwater from contacting the fuel, and the cast iron converts what water may be left into hydrogen gas and iron oxide. SKB states that if the canister is manufactured properly, galvanic interactions will not be a problem. The design basis for the canister includes a corrosion allowance and takes into account hydrostatic pressure and the forces from the packing material around the canister. Plans are to pack sodium bentonite around the waste packages to minimize water ingress. The tunnels will be backfilled with sodium bentonite and (1) sand or (2) sand and crushed rock.

A prototype repository is being built at the Äspö laboratory. Canisters made at the canister laboratory

22. Details of the process and policy that constitute Oskarshamn's EIA Forum are in *EIA Forum for Studies of the Final Disposal System for Spent Nuclear Fuel in Oskarshamn Municipality* (Kalmar 1998).

23. A summary of this concept is in *This Is How We Manage Sweden's Radioactive Waste: Activities 1997* (SKB 1998b). More-detailed descriptions are available in SKB's RD&D Programme 98, (SKB 1998a).

will be emplaced with precompacted bentonite buffer blocks and rings. No nuclear fuel will be used, but some of the canisters will be heated with electricity. Instruments will be used to verify predictions about the performance of the repository during its initial operating stage and to provide practical experience in handling and retrieving of waste. The prototype will be in operation for at least 20 years.

C. Finland

The same delegation that visited representatives of the Swedish program traveled on to Finland for meetings and a site visit on May 7 and 8. The visit included meetings with representatives of Posiva Oy, a small company responsible for the management and final disposal of spent nuclear fuel in Finland. The Board members also met with representatives of the Radiation and Nuclear Safety Authority (STUK) and the Ministry of Trade and Industry, which oversees the policy, licensing, and funding of nuclear waste activities in Finland. The Board members then traveled to Loviisa to tour the site characterization in progress at Hästholmen, one of four sites undergoing preliminary site characterization. The three other sites are Olkiluoto in Eurajoki, Romuvaara in Kuhmo, and Kivetty in Äänekoski. The sites also have been evaluated as part of an EIA program conducted by Posiva Oy.[24]

The Finnish nuclear waste management and disposal program continues to operate effectively and efficiently. Posiva Oy has approximately 30 full-time employees, and contractors are used to a great extent. The program remains on schedule. That schedule calls for completion of a preliminary site investigation at each of the four sites in 1999. In 2000, a final disposal site will be selected. An investigation shaft will be built, and underground site characterization will be conducted from 2000 to 2010, when construction of the encapsulation plant and the final repository will begin. The established date for beginning final disposal is 2020.

Posiva Oy estimates that approximately 1,500 canisters of spent fuel, or 2,600 metric tons, will need to be disposed of. This is based on a 40-year life of the nuclear power plants at Olkiluoto and Loviisa. Current plans are to build 15 kilometers of underground tunnels, on the floor of which holes for fuel canisters will be bored. The fuel will be transported by road or rail and, in a few alternatives, by sea. The disposal concept is very similar to the SKB's in Sweden because of the similarities in the geology and hydrology of the two countries. The canister that will be used for disposal, however, differs somewhat from the Swedish canister. It consists of an external canister of copper tightly surrounding an inner canister of nodular cast iron. The copper is used to prevent corrosion caused by groundwater; the nodular cast iron is used because it is strong enough to withstand the mechanical stresses prevailing in the bedrock.

24. A description of the EIA process in Finland, including a description of the current waste isolation concept and a summary of the conditions that must be met at each of the sites in order to build a repository there, is in *The Final Disposal of Spent Nuclear Fuel—Environmental Impact Assessment Programme* (Posiva Oy 1998).

Abbreviations and Acronyms

ACNW	Advisory Committee on Nuclear Waste
Board	U. S. Nuclear Waste Technical Review Board
BWR	boiling-water reactor
CFR	*Code of Federal Regulations*
CFu	Crater Flat undifferentiated unit
CHn	Calico Hills nonwelded unit
^{36}Cl	chlorine-36
DOE	U.S. Department of Energy
EBS	engineered barrier system
ECRB	enhanced characterization of the repository block
EIA	environmental impact assessment
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESF	Exploratory Studies Facility
EWDP	Early Warning Drilling Program
GWTT	groundwater travel time
HLW	high-level radioactive waste
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
M&O	DOE's management and operating contractor
MTU	metric ton of uranium
NAS	National Academy of Sciences
Np	neptunium
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWPAA	Nuclear Waste Policy Amendments Act
NWTRB	U.S. Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management, U.S. Department of Energy
PTn	Paintbrush Tuff nonwelded unit
PWR	pressurized-water reactor
RFP	request for proposal
SKB	Svensk Kärnsbränslehantering (Swedish Nuclear Fuel and Waste Management Company)
SZ	saturated zone
SZEE	saturated zone expert elicitation
TBM	tunnel-boring machine
TCw	Tiva Canyon welded unit
TSw	Topopah Spring welded unit
TSPA	total system performance assessment
TSPA-VA	total system performance assessment-viability assessment
USGS	U.S. Geological Survey
UZ	unsaturated zone
VA	viability assessment
WIPP	Waste Isolation Pilot Plant
WPDEE	waste package degradation expert elicitation

Glossary

The following list of terms has been compiled to aid in the reading of this report. It is not meant to be a formal glossary or to have the completeness of a dictionary; rather, it is meant to help the reader understand some of the terms used regularly by the Board.

accessible environment. The earth's surface and the rock more than 5 kilometers beyond the repository.

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

analogue. A thing or part that is analogous. As used in this report, 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.

aquifer. Permeable saturated rock through which groundwater flows.

areal mass loading. The concentration of emplaced spent fuel, averaged over the area of the repository and expressed in kilograms per square meter or in metric tons per acre.

backfill. Solid materials placed in excavated areas underground to fill voids (i.e., crushed tuff).

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

canister. The structure surrounding a waste form (e.g., high-level waste immobilized in borosilicate glass) that facilitates handling, storage, transportation, or disposal. Before being emplaced in a repository, the canister may be placed in a disposal container.

characterization. Collecting information necessary to evaluate the suitability of a region or site for geologic disposal. Data from characterization also will be used during the licensing process.

chlorine-36 (^{36}Cl). 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 precipitation from the 1950's has moved through soil and rocks, such as those present at Yucca Mountain.

cladding. Thin metallic material that encases nuclear fuel

colloid. A particle that can be suspended easily, or a suspension of very fine particles.

colloidal transport. Because colloidal particles can be suspended for long periods without settling, they may be transported at the same velocity as groundwater.

container. A receptacle used to hold radioactive waste (usually spent fuel).

corrosion-allowance materials. Materials that fail because of generalized corrosion and that tend to fail more rapidly than corrosion-resistant materials.

corrosion-resistant materials. Materials that fail primarily because of localized corrosion and that tend to fail more slowly than corrosion-allowance materials.

critical group. The group that is representative of the individuals in the population who, on the basis of cautious but reasonable assumptions, are at the highest risk from exposure to repository releases.

defense-in-depth. Incorporation of multiple barriers in the design of a repository to make the performance of the overall system less susceptible to the unexpected failure of any individual barrier.

infiltration. Water entering soil or rock after precipitation rather than becoming runoff into rivers, streams, ponds, etc. The terms "infiltration" and "net infiltration" also are used to refer to water that penetrates deeply into soil or rock (beneath plant root zones) rather than returning to the atmosphere by evapotranspiration.

infiltration flux. The rate at which water from precipitation enters the rock below the surface root zone. See **flux**.

interim storage. Storage of spent fuel or high-level radioactive waste with the intention and expectation that the waste will be moved later to a permanent repository.

license application. A document submitted to the Nuclear Regulatory Commission containing general information and a safety analysis for a nuclear reactor, a geologic repository, or an interim storage facility for spent nuclear fuel and high-level radioactive waste.

lithophysal, nonlithophysal. Lithophysal and nonlithophysal zones denote the relative abundance of lithophysae found in different rock strata. Lithophysae, sometimes called "stone bubbles," are cavities in silicic volcanic rock that are formed, soon after the volcanic rocks are deposited, because of the presence of vapors under very high pressure.

matrix. In hydrology, the solid framework of a porous system.

near field. The region where the natural hydrologic system has been altered by the excavation of the repository or by the thermal environment created by the emplacement of high-level waste.

nonwelded tuff. A tuff that has not been hardened and welded together by intense temperature and pressure and that contains fewer fractures than welded tuff does.

Nuclear Waste Policy Act (PL 97-425). The federal statute enacted in 1982 that established the Office of Civilian Radioactive Waste Management and defined its mission for developing 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 states, local governments, and Indian tribes.

Nuclear Waste Policy Amendments Act of 1987 (P0-203). The legislation that amended the Nuclear Waste Policy Act to limit repository site-characterization activities to Yucca Mountain, Nevada; establish the Office of the Nuclear Waste Negotiator for seeking a state or an Indian tribe willing to host a repository or a monitored retrievable storage facility; create the Nuclear Waste Technical Review Board; and increase state and local government participation in the waste management program.

peak dose. The largest dose projected per unit time (e.g., per year or human lifetime) after repository closure.

performance assessment (PA). An analysis that predicts the behavior of an entire system or a part of a system under a given set of conditions on the basis of an assumed measure of performance.

postclosure. The time after the closure of the repository.

preclosure. The time before the closure of the repository.

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

radionuclide. An atomic nucleus that is radioactive.

radionuclide transport. The movement of radionuclides, generally as dissolved solids or gaseous forms, through a rock formation.

recharge. The addition of water to the saturated zone or the water added.

repository. See **geologic repository**.

repository block. The part of Yucca mountain in which placement of the proposed repository is being considered.

retardation. The physical or chemical process that causes some dissolved radionuclides to move more slowly than the water they are dissolved in.

saturated zone (SZ). The part of the earth's crust in which all voids are filled with water under pressure at least as great as atmospheric pressure.

seepage flux. The magnitude and distribution of percolating water that drips into the emplacement drifts and, potentially, onto the waste packages.

self-shielded waste package. A waste package with sufficient intrinsic radiation shielding so that people can perform occasional activities on or near it without receiving radiation exceeding standards for workers.

shrinkfitting. Joining (or mating) layers of metal by using heat to expand the outer shell, inserting the inner shell, and allowing the outer shell to cool around the inner shell.

site assessment. The full range of activities needed to evaluate the suitability of the Yucca Mountain site, including site characterization; laboratory research; performance assessment; and design of the repository, waste packages, and engineered barriers.

site characterization. See **characterization**.

sorption. The binding, on a microscopic scale, of dissolved molecules or atoms on mineral surfaces in contact with fluid. The sorption of dissolved radionuclides can lead to their retardation.

sorption characteristics. The ability of rocks and minerals to bind, reversibly or irreversibly, radionuclides or other chemical species on their surfaces.

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. Fuel that has been withdrawn from a nuclear reactor after irradiation, the constituent elements of which have not been separated by reprocessing.

structural geology. Study of the deformational features of rocks induced by processes such as folding, faulting, and igneous activity. Study of the processes.

suitability determination. The formal recommendation by the DOE to the President on whether the Yucca Mountain site can safely host a repository for high-level waste.

thermal energy. Heat produced by the radioactive decay of waste.

thermal load. The amount of heat produced by emplaced waste and affecting the near field and overall repository material, including geophysical and engineered barriers (usually measured in kilowatts per acre).

thermohydrology. The study of how heat affects the movement of water in geologic formations.

total system performance assessment (TSPA). Analyses undertaken by the DOE to assess the ability of the potential repository at Yucca Mountain to provide long-term waste isolation.

transparent (performance assessment). Easy to detect or perceive. Using clear language and easily understood concepts or assumptions to arrive at credible, traceable, and logical conclusions.

unsaturated zone (UZ). Geologic formations located above the regional groundwater table.

viability assessment (VA). A congressionally mandated report that the Secretary of Energy provided to the President and Congress in 1998 and that includes repository and waste package designs, a total system performance assessment, a license application plan, and estimates of repository cost and schedule.

volcanism. The process by which molten rock and its associated gases rise from within the earth and are extruded onto the earth's surface and into the atmosphere.

waste acceptance. The processes necessary for the DOE to take title to and physical possession of spent nuclear fuel or high-level radioactive waste from owners and generators of the wastes.

waste containment and isolation. Separation of waste from the environment so that any radioactive material reentering the environment will be kept within prescribed limits.

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

waste package. The radioactive waste materials and any encapsulating and stabilizing matrix, as well as any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.

water table. An underground boundary below which the rock pores are completely filled with water and above which they are only partly filled with water.

welded tuff. Rock made of volcanic ash that has been hardened and welded together by heat, pressure, and possibly the introduction of cementing minerals. Welded tuff contains more fractures than nonwelded tuff does.

References

Andrews, R.W. 1998. "Basic Structure, Conceptual Model, and Results of the TSPA-VA." Presentation to Nuclear Waste Technical Review Board's Panel on Performance Assessment. Albuquerque, New Mexico. April 23, 1998.

Barnard, Ralston. 1998. "Analysis of Disturbed Events for TSPA-VA." Presentation to Nuclear Waste Technical Review Board's Panel on Performance Assessment. Albuquerque, New Mexico. April 24, 1998.

Chrisman, Robert. 1997. February 21 letter from Mr. Robert Chrisman, Chairman of Committee for the Truth About Yucca Mountain, to Dr. Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board.

Civilian Radioactive Waste Management System. Management & Operating Contractor (M&O). 1995a. *Thermal Loading Study for FY 1995*. B00000000-01717-5705-00016. Las Vegas, Nevada: TRW Environmental Safety Systems, Inc.

———. 1995b. *Total-System Performance Assessment - 1995: An Evaluation of the Potential Yucca Mountain Repository*. B00000000-0717-2200-00099-Rev. 01. Las Vegas, Nevada: TRW Environmental Safety Systems, Inc.

———. 1996. *Emplaced Waste Package Structural Capability Through Time Report*. B00000000-01717-5705-00001 Rev 00. Las Vegas, Nevada: TRW Environmental Safety Systems, Inc.

———. 1997. "Management Design Review, Presentation Materials." Presentation to Management. Las Vegas, Nevada. June 23-24, 1997.

———. 1998. *Constraints on Solubility-Limited Neptunium Concentrations for Use in Performance Assessment Analyses*. B00000000-01717-2200-00191, Rev. 00, January 23, 1997. Las Vegas, Nevada: TRW Environmental Safety Systems, Inc.

Cohon, Jared L. 1997. April 15 letter from Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board, to April V. Gil, Yucca Mountain Site Characterization Office: "Comments on the proposed revisions to the Department of Energy's G*eneral Guidelines for the Recommendation of Sites for Nuclear Waste Repositories* (10 CFR 960)."

———. 1998a. January 12 letter From Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board, to Lake Barrett, Acting Director, Office of Civilian Radioactive Waste Management: "Comments from the Board's October Meeting."

———. 1998b. July 30 letter from Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board, to Lake Barrett, Acting Director, Office of Civilian Radioactive Waste Management: "Comments on the June 1998 meeting."

Czarnecki, John B. 1989. "Characterization of the Subregional Ground-Water Flow System at Yucca Mountain and Vicinity, Nevada and California." *Radioactive Waste Management and the Nuclear Fuel Cycle*. Vol. 13, No. 1-4: pp. 51-61.

Del Papa, Frankie Sue. 1997. March 25 letter from Frankie Sue Del Papa, Attorney General, State of Nevada, to Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board: "Yucca Mountain Characterization Studies."

Dixon, Wendy R. 1998. "Presentation to the Nuclear Waste Technical Review Board, January 20, 1998, Wendy R. Dixon, Repository EIS Project Manager, Yucca Mountain Project." Las Vegas, Nevada.

Elsworth, Derek. 1998. "TM Drift Stability—Preliminary Evaluation." Presentation at Workshop on Preliminary Interpretations, Near-Field / Altered Zone Coupled Effects, Expert Elicitation Project. South San Francisco, California. January 7, 1998.

Garrick, B. John. 1998. September 9 letter from B. John Garrick, Chairman, Advisory Council on Nuclear Waste, to Shirley Ann Jackson, Chairman, Nuclear Regulatory Commission: "Issues and Recommendations Concerning the Near-Field Environment and the Performance of Engineered Barriers at Yucca Mountain."

Geomatrix Consultants, Inc. 1998. *Waste Form Degradation and Radionuclide Mobilization Expert Elicitation Project*. San Francisco, California

Janberg, Klaus and Harry Spilker. "Status of the development of final disposal casks in Germany." *Nuclear Technology*. Vol. 121., February 1998: pp. 1-12.

Kalmar County, Sweden. County Administrative Board. 1998. *EIA Forum for Studies of the Final Disposal System for Spent Nuclear Fuel in Oskarshamn Municipality, Policy and Document Work Procedures.* February 5, 1998.

Kersting, A.B.; D.K. Smith; D.W. Efurd; D.L. Finnegan; D.J. Rokop; and J.L. Thompson. 1999. "Plutonium in Groundwater at the Nevada Test Site." *Nature*. 397: 56-59.

National Research Council. Panel on Coupled Hydrologic / Tectonic / Hydrothermal Systems at Yucca Mountain (NAS / NRC). 1992. *Ground Water at Yucca Mountain How High Can it Rise?* Washington, D.C.: National Academy Press.

Nuclear Waste Technical Review Board (NWTRB). 1992. *Sixth Report to The U.S. Congress and The U.S. Secretary of Energy*. December 1992. Arlington, Virginia.

———. 1997a. *Report to The U.S. Congress and The Secretary of Energy, January-December 1996.* Arlington, Virginia,.

———. 1997b. "Conduct Engineered Barrier Studies Now." *NWTRB Viewpoint*. March 1997. Arlington, Virginia.

———. 1998a. *1997 Findings and Recommendations: Report to The U.S. Congress and The Secretary of Energy*. April 1998. Arlington, Virginia.

———. 1998b. Winter Board Meeting; January 20-21, 1998; Amargosa Valley, Nevada (transcript of proceedings). Arlington, Virginia.

———. 1998c. Meeting on TSPA-VA; April 23-24, 1998; Albuquerque, New Mexico (transcript of proceedings). Arlington, Virginia.

———. 1998d. Waste Package Workshop; May 18-19, 1998. Falls Church, Virginia (transcript of proceedings). Arlington, Virginia

———. 1998e. Summer Board Meeting; June 24, 1998; Las Vegas, Nevada (transcript of proceedings). Arlington, Virginia

Posiva Oy. 1998. *The Final Disposal Facility of Spent Nuclear Fuel: Environmental Impact Assessment Programme.* Helsinki.

Svensk Karnbranslehantering AB (SKB). 1998a. *SKB's RD&D Programme 95: Treatment and Final Disposal of Nuclear Waste.* Stockholm

———. 1998b. *This is How We Manage Sweden's Radioactive Waste: Activities 1997.* Stockholm.

Total System Performance Assessment Peer Review Panel (TSPA Panel). 1998. *Third Interim Report, June 25, 1998.*

U.S. Department of Energy. Yucca Mountain Site Characterization Office (USDOE, YMPO). 1997. *Summary of Public Scoping Comments Related to the 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.* Las Vegas, Nevada.

———. Office of Civilian Radioactive Waste Management (USDOE, OCRWM). 1998. *Acquisition of Waste Acceptance and Transportation Services for OCRWM*. Draft, September 1998.

———. 1998. *Viability Assessment of a Repository At Yucca Mountain*. Vols. 1- 5. Las Vegas, Nevada.

Laws and Legislation

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

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

———. 1996. *Energy and Water Development Appropriations for 1997*. 104th Congress, 2nd Session. Washington, D.C.: Government Printing Office.

10 CFR 60 (*Code of Federal Regulations*). Title 10, *Energy*. Part 60. "Disposal of High-Level Radioactive Wastes in Geologic Repositories." Washington, D.C.: U.S. Government Printing Office.

Chapter 2
Other Board Activities

During 1998, the Board evaluated elements of the DOE's radioactive waste management program in addition to the site-characterization efforts at Yucca Mountain. In this chapter, the Board reports on those evaluation activities.

I. Review of Material Related to Hydrothermal Upwelling at Yucca Mountain

The Board completed its review of material (11 reports) first submitted to it in summary form by Mr. Jerry Szymanski at its January 1997 meeting in Pahrump, Nevada. The documents argue that there is evidence of ongoing, intermittent hydrothermal upwelling at Yucca Mountain and that large earthquake-induced changes in the water table are likely at Yucca Mountain. As a result, the documents maintain that the Yucca Mountain site is unsuitable for development as a repository for spent nuclear fuel and high -level radioactive waste. After its January 1997 meeting, the Board received requests from both the Committee for the Truth about Yucca Mountain (Chrisman 1997) and the Attorney General of the State of Nevada (Del Papa 1997) to review this material.

This is not the first time that Mr. Szymanski has raised these questions. His ideas were thoroughly reviewed by outside experts, including a panel appointed by the National Research Council of the National Academy of Sciences (NAS). This prestigious and broadly based review was published in 1992 by the National Academy Press in a report titled *Ground Water at Yucca Mountain—How High Can It Rise?* (NAS / NRC 1992). As stated in the Board's December 1992 report (NWTRB 1992), the Board saw no reason to disagree with the 17-person NAS panel's unanimous conclusion: "The panel concludes from the geological features observed in the field and geochemical data that there is no evidence to support the assertion [by Mr. Szymanski] that the water table has risen periodically hundreds of meters from deep within the crust" (NAS / NRC 1992). The Board's December 1992 report also noted that if significant new data or modifications were presented in the future, the Board would consider reviewing them at that time.

The Board examined the material submitted in 1997, and, because some new information had been presented, the Board decided to evaluate the quality and significance of this information. For assistance in this evaluation, the Board contracted with four highly qualified scientists. The scientists were chosen because of their expertise in critical areas, their reputations among their peers (many of whom the Board staff spoke to), their lack of affiliation with the Yucca Mountain Project, and their lack of previous involvement in evaluating Mr. Szymanski's ideas.

The consultants were Dr. Robert J. Bodnar, C. C. Garvin Professor of Geochemistry and Director of the Fluids Research Laboratory, Department of Geological Sciences, Virginia Polytechnic Institute & State University (Dr. Bodnar's expertise is in fluid inclusions and the geology and geochemistry of ore deposits.); Dr. Patrick R. L. Browne, Associate Professor and Director of the Geothermal Institute, University of Auckland, New Zealand (Dr. Browne's expertise is in hydrothermal alteration of volcanic rocks and fluid-rock interactions.); Dr. Stuart Rojstaczer, Associate Professor and Director of the

Center for Hydrologic Science, Duke University (Dr. Rojstaczer's expertise is in the role of subsurface fluid flow in geologic and human-induced hazards and the hydrologic effects of earthquakes.); and Dr .John Valley, Professor and Chairman of the Department of Geology and Geophysics, University of Wisconsin-Madison (Dr. Valley's expertise is in metamorphic petrology and stable-isotope geochemistry.).

The Board conducted its review, making use of its own expertise and that of its consultants. Four questions were posed to the consultants (Drs. Bodnar, Browne, and Valley for evidence of hydrothermal activity and Dr. Rojstaczer for earthquake-induced changes in the water table) that centered on the significance of the new information presented with respect to the conclusions drawn in the 1992 NAS report (NAS / NRC 1992). These questions also were the focus of the Board's review:

1. Are there significant new data and interpretations since the 1992 NAS report?

2. What is the quality of these data and interpretations?

3. How much credence do these data and interpretations lend to the hypothesis of ongoing, intermittent hydrothermal activity and large earthquake-induced changes in the water table at Yucca Mountain?

4. If these data and interpretations significantly affect the conclusions of the 1992 NAS report, how can the issue be resolved?

The Board emphasizes that the purpose of its review was to evaluate the information submitted to the Board, not to conduct a systematic review of all the information that has been collected on this topic, including the extensive work carried out for the DOE's Yucca Mountain Project by the U.S. Geological Survey (USGS) and the National Laboratories. A systematic review of all the information available by 1992 was carried out by the panel that prepared the 1992 NAS report.

In addition to reviewing the 11 reports submitted by Mr. Szymanski, 3 additional reports provided by the Nevada Attorney General's office, and a number of other important documents referenced in these reports, Board staff spoke directly to several of the reports' authors. A Board member (Dr. Donald Runnells), a Board staff member (Dr. Leon Reiter), and Dr. Bodnar also attended an international meeting in which fluid inclusion evidence for and against future hydrothermal upwelling at Yucca Mountain was presented and discussed. Following that meeting, Dr. Yuri Dublyansky (the lead author of several of the reports) spent several days with Dr. Bodnar at Dr. Bodnar's Fluids Research Laboratory at Virginia Polytechnic Institute.

The Board has reached the following conclusions:

- The material reviewed by the Board does not make a credible case for the assertion that there has been ongoing, intermittent hydrothermal activity at Yucca Mountain or that large earthquake-induced changes in the water table are likely at Yucca Mountain. This material does not significantly affect the conclusions of the 1992 NAS report.

- There are several areas where additional research could be used to evaluate further the hypotheses of ongoing, intermittent hydrothermal activity and large earthquake-induced changes in the water table at Yucca Mountain. However, because of the lack of any substantive evidence supporting either of these hypotheses, the Board views additional research on these issues, if not already carried out, as generally having a lower priority than more important issues in the evaluation of repository performance.

- However, some fluid inclusions found in mineral deposits at Yucca Mountain do provide direct evidence of the past presence of fluids at elevated temperatures (at least 72°C) in the vicinity of the proposed repository. This could be an indicator of some degree of past hydrothermal activity. The critical question is, "At what time in the past were such fluids present?" If fluids at elevated temperatures were present less than 100,000 years ago, as some of the reviewed reports claim, this could lend credence to the hypothesis of ongoing hydrothermal activity at Yucca Mountain. On the other hand, if these fluids were present around 10,000,000 years ago or earlier, they could be associated with volcanic events related to the original formation of

Yucca Mountain and would have no bearing on the hypothesis of ongoing hydrothermal activity. The Board believes that the ages of fluid inclusions should be determined. A joint program between federal and State of Nevada scientists for collecting, dating, and analyzing fluid inclusions would be one way to make this determination in a way that would reduce some of the past disagreements associated with sample collection and handling.

II. Waste Package Workshop

In its recent reports and correspondence, the Board has urged strongly that the DOE identify, and then carefully examine, alternative designs for the subsurface facility and for the waste packages (NWTRB 1997a and 1998b; Cohon 1998a and 1998b). Examples of alternative waste package designs that could merit examination include (1) a waste package design with the materials of the outer and inner shells reversed in comparison to the current design and (2) a double-shell waste package with the outer shell made of a corrosion-resistant material and the inner shell made of a different corrosion-resistant material. The Board convened a waste package workshop in May 1998 to identify alternative waste package designs and associated research needs.

A. Planning for the Workshop

The 1½-day workshop was held on May 18 and 19, 1998, in Falls Church, Virginia (NWTRB 1998d). It was conducted as a panel meeting under the aegis of the Board's Panel on the Repository. The primary purpose of the workshop was to develop a firm technical basis for reviewing and evaluating the scientific and technical merits of any waste package designs arising from the DOE's program. The primary products of the workshop were a list of alternative waste package designs and a list of associated research needs. For encouraging a free exchange of ideas and as much "brainstorming" as possible, as well as participation by the public, a roundtable format was used for the entire workshop, except for a few initial presentations.

Participants in the roundtable included five Board members (Drs. Bullen, Craig, Nelson, Parizek, and Sagüés), two members of the Board's staff (Drs. William Barnard and Carl Di Bella), and five invited panelists: Dr. John Kessler (of EPRI), Dr. Digby Macdonald (of SRI International), Dr. Joe Payer (of the Department of Materials Science and Engineering, Case Western Reserve University), Dr. David Shoesmith (of the Department of Chemistry, University of Western Ontario, formerly with Atomic Energy of Canada, Limited), and Dr. Michael Streicher (a corrosion consultant, formerly with E. I. Du Pont de Nemours and Co., Inc., and the University of Delaware). Dr. Kevin Coppersmith of Geomatrix, Inc., served as facilitator for the workshop.

The workshop began with a few short presentations giving (1) the ground rules for the workshop, (2) the status of the DOE's program for disposing of spent fuel, and (3) the description of the current waste package design. A fourth presentation, proposing a simple way to approximate the interactions that various underground facility designs would have with various waste package designs, also was made.

The purpose of the fourth presentation was to separate underground facility design from waste package design. The separation was considered necessary because the duration of the workshop was too brief to allow full discussion of both underground facility design and waste package design and their associated research needs. Although the separation worked for the workshop, it is clear that underground facility design and waste package design are highly interdependent and therefore must be taken together for any comprehensive examination.

B. Alternative Waste Package Designs

In the reference waste package design, the waste package has a 10-cm-thick carbon-steel outer wall and a 2-cm-thick nickel-alloy inner wall. The current design includes four waste package capacities for commercial spent fuel: 12 pressurized-water reactor (PWR) assemblies, 21 PWR assemblies, 24 boiling-water reactor (BWR) assemblies, and 44 BWR assemblies. The packages are up to 1.7 m in diameter and 5.4 m in length. Alternative designs identified at the workshop are listed below.

1. Current base design: a carbon-steel outer shell shrunkfit over an Alloy 22 inner shell.

1a. Same as 1 except that the outer shell fits loosely over the inner shell.

2. An Alloy 22 outer shell over a carbon-steel inner shell (i.e., reversal of the two shells of the current base design).

3. An Alloy 22 outer shell over a nodular cast-iron inner shell.

3a. Same as 3 except that rod consolidation would be used (to increase waste package capacity), thickness of the waste package wall would be increased (so that the radiation field outside the waste packages would be low enough for humans to work near the waste packages), and significant ventilation would be used (to maintain temperatures low enough for humans to work near the waste packages).

4. An Alloy 22 outer shell over a graphite inner shell.

5. A titanium outer shell over an Alloy 22 inner shell.

6. A titanium or Alloy 22 outer shell over a "structural material" (e.g., stainless steel or a low-cost nickel alloy) inner shell.

7. A three-shell waste package with a titanium or Alloy 22 outer shell, an Alloy 22 or titanium middle shell, and a "structural material" inner shell.

8. Any waste package design that would allow emplacement in vertical boreholes (with ventilation).

9. Lower-capacity waste packages and extensive use of backfill.

10. Any waste package design that would allow emplacement in horizontal boreholes (with ventilation).

Although the panelists did not state that the list of design alternatives was necessarily the complete list of all reasonable alternatives, no additional alternatives were identified during the workshop. The Board will use these alternatives to help evaluate the completeness of the DOE's studies on alternative waste package designs. The Board does not take the position that one or more of these alternatives is superior to the reference waste package design. The Board believes that all the alternatives are worthy of at least a screening evaluation and expects that the screening evaluation will result in some of the alternatives being chosen for comprehensive evaluation.

C. Research Needs

After examining waste package alternatives, the panelists identified research needed to support alternatives. "Research" was defined in a very broad sense: It could include laboratory or field experiments, analysis (e.g., running thermodynamic models on computers), more-complete specification of requirements, or even the novel application of commercially available technology. The panelists developed a list of research needs for each alternative.

The Board has not reviewed the DOE's waste package research program formally since the workshop. Informally, the Board is aware that some of the research needs identified at the workshop were being addressed in the DOE program at the time the workshop was held and that the other research needs are being supported by new DOE initiatives.

Longer-range programs also need to be started. These programs are needed for improving the fundamental understanding of long-term corrosion resistance of passive films and long-term stability of metastable phases (such as in Alloy 22).

D. Conclusions

- The workshop resulted in the identification of several waste package alternatives that deserve careful examination by the DOE.

- Numerous research needs were developed at the workshop, most of which are applicable regardless of the waste package design that finally is chosen. Much of the research is under way. There are a few conspicuous gaps, however, and they need to be addressed. Short-term gaps include (1) the determination of the chemistry of the water after it has interacted with the waste package and (2) the study of natural analogues. Long-term gaps include programs for improving the fundamental understanding of long-term behavior of passive films and long-term phase stability.

- Although a simple method for separating waste package design from underground design sufficed for the purposes of the workshop, one of the clear lessons from the workshop is that the waste package and the underground facility (together, the engineered barrier system) are too interdependent to be separated. Thus, the development and analysis of each alternative waste package design must be accompanied by the simultaneous development and analysis of an underground facility design that is most appropriate for it.

III. Transportation

Although no immediate activity is expected, transportation of spent nuclear fuel continued to be of significant interest to the Board in 1998.

In developing its transportation program, the DOE might learn much from experiences in Europe and Japan, where there is already large-scale transportation activity. In those countries, there is an antinuclear element that the industry must deal with. Germany has had a great deal of difficulty in moving spent nuclear fuel, and the shipments from Japan to France and the United Kingdom have generated protests.

The DOE also might learn some lessons from what is taking place in Europe and should make every effort to build trust and a good working relationship with the groups, especially in Nevada, that will be affected by a large-scale shipping campaign. One possible approach to maximizing safety and to preventing undue burdens on the nationwide railroad network could be the use of dedicated trains for transporting spent nuclear fuel. The Board also feels that the design of the transportation cask should be integrated with that of the rail car. An integrated design concept would be a way to increase safety and performance.

IV. Environmental Impact Statement for a Yucca Mountain Repository

The DOE is preparing an environmental impact statement (EIS) for a Yucca Mountain repository (Dixon 1998). The EIS would accompany a recommendation to the President (currently scheduled for 2001) for developing a repository at the site and also would be submitted to the NRC, accompanying the application for a license for the facility in 2002. The proposed action in the EIS is to construct, operate, and eventually close a repository at Yucca Mountain for the geologic disposal of 63,000 metric tons of commercial spent nuclear fuel and 7,000 metric tons of DOE-owned spent nuclear fuel and high-level radioactive waste. The no-action alternative would be to leave those materials in storage at their current locations.

Three “implementing alternatives” will be evaluated for developing a repository, defined by low, intermediate, and high thermal loads.[19] For each alternative, two packaging options will be evaluated: (1) sealing wastes in multipurpose canisters at the generator sites and (2) transporting wastes in casks and repackaging the wastes at the repository site. For each implementing alternative, five transportation options also will be evaluated, consisting of predominantly (1) truck or (2) rail cross-country shipment to Nevada and (3) rail, (4) heavy-haul, or (5) legal-weight truck shipment within Nevada. Two expanded inventory “modules” will be considered: (1) disposal at Yucca Mountain of the entire U.S. inventory of spent nuclear fuel and high-level radioactive waste and (2) disposal of other highly radioactive wastes that may require permanent isolation (USDOE, YMPO 1997). For the no-action alternative, two scenarios will be evaluated: (1) loss of institutional controls at storage sites after 100 years and (2) continuation of institutional controls at those sites for 10,000 years (Dixon 1998).

The DOE plans to publish its draft EIS in July 1999, initiating a public comment period of several months. The final EIS is scheduled to be published in August 2000. The Board plans to review and comment on the draft EIS after its publication.

19. “Thermal load” is the amount of waste emplaced per unit area of the repository. In the EIS, thermal loads of less than 40 metric tons per acre, 40-80 metric tons per acre, and more than 80 metric tons will be considered.

V. Strategic and Performance Plans

In late 1997, the Board developed a 5-year strategic plan in compliance with the Government Performance Results Act. The Board also established its performance plan for fiscal year 1999, which includes specific objectives to be accomplished during that period. In January 1998, the Board held a public session in conjunction with its regular Board meeting in Amargosa Valley, Nevada, to obtain comments from the interested public on both its strategic and its performance plans. The Board also solicited comments on both plans from others having oversight roles for, or involvement in, nuclear waste management issues, including key congressional staff, the DOE, and the NRC. Copies of the strategic plan and the performance plan for the coming year are included in appendices to this report.

The Board's strategic plan underscores the importance of an independent technical and scientific review of the civilian radioactive waste management program for achieving the overall national goal of ensuring that civilian spent nuclear fuel and high-level radioactive waste are safely packaged, transported to, and disposed of in a permanent repository at a suitable site. The Board's performance objectives for fiscal year 1999 reflect the goals stated in the strategic plan and flow from the Board's technical and scientific review of DOE work, including (1) designing components of an engineered barrier system, (2) developing an environmental assessment of the site, (3) planning related to the safety of waste-transportation corridors, and (4) conducting research supporting a decision on the suitability of the site.

Procedures were established in the performance plan for conducting an annual evaluation of the Board's performance in meeting its objectives for the previous year. The Board will consider whether the reviews, evaluations, and other activities included in its performance goals have been completed; whether the results of reviews, evaluations, and other activities undertaken under the auspices of the program have been communicated in a timely, understandable, and appropriate way to the Secretary of Energy and Congress; and whether the recommendations made by the Board had a positive effect on the program. The first of these program evaluations will be conducted at the end of fiscal year 1999, and the results will be included in the Board's summary report for that period.

VI. Board Visit to Waste Isolation Pilot Plant

Members of the Board met with managers of the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, and toured the facilities on March 10, 1998. The visit included the opportunity to hear firsthand from George Dials, then general manager of the Carlsbad Area Office of the DOE, and Wendell Weart, formerly Senior Scientist for the WIPP program and now Senior Fellow at Sandia National Laboratories in Los Alamos, New Mexico. The Board's visit included a tour of the waste-handling building and the underground facilities. Board members also were briefed on the WIPP compliance- and application-review processes. On the basis of their experience, those involved made the following observations to the Board.

- In evaluating the performance assessment for WIPP, the regulator(s) tended to make conservative assumptions in assessing the probabilities and consequences of events and processes.

- When submitting the license application for a first-of-a-kind facility, such as WIPP, having credible sources, other than the proponent, provide analysis of the scientific and technical conclusions of the proponent was helpful.

- Strong leadership is required to integrate and focus scientific investigations. A shared vision and a focused management plan can help eliminate unnecessary work and help complete necessary work more quickly.

The Board members also noted that the managers instituted a ranking system to manage the science at WIPP. This major effort resulted in reducing the experimental work in progress from 116 activities to 8. Other important decisions that affected the scientific and technical work at WIPP were to (1) evaluate 18 different engineered alternatives, (2) adopt a more-phased approach to securing a license, and (3) commission an international peer review.[20]

VII. International Activities

Several members of the Board participated in two international trips in 1998 in an effort to continue the Board's objective of remaining informed about scientific, technical, and program developments in the nuclear waste disposal programs of selected developed countries. Board members traveled to Sweden and Finland from May 4 to 9. A second delegation of five members visited Germany from June 8 to 11. One major purpose of the visits was to give new Board members the opportunity to visit several nuclear waste facilities firsthand and to receive briefings on the scientific and technical progress in the nuclear waste programs of the countries.

In addition to the two trips, the Board participated in several briefings in the Washington, D.C., area. The first, arranged by the British Embassy, consisted of a meeting of selected Board members with five members of the Select Committee on Science and Technology of the House of Lords, United Kingdom. The committee is conducting an inquiry into the management of nuclear waste following the decision of the government in 1997 to uphold Cumbria County's decision to deny U.K. Nirex Ltd.'s planning application for a rock-characterization laboratory near Sellafield. Members of the Board and staff also met with representatives from a study committee organized by The Institute of Applied Energy in Japan, who were visiting several foreign countries collecting research on international approaches to postclosure management of potential repositories for high-level radioactive waste. Last, the Board and staff met with a delegation of France's Atomic Energy Commission (CEA), who were visiting various organizations and facilities as part of an ongoing study of the long-term conditioning and storage of high-level radioactive waste, mandated in 1991 by French law.

A. Germany

A delegation of the Board traveled to Germany to visit nuclear waste facilities. From June 8 to 11, the delegates visited several sites[21] and were briefed on many of the scientific and technical aspects of the management, storage, transportation, and potential disposal of high-level radioactive waste and spent nuclear fuel in Germany. The Board's visit focused on the design, development, testing, and fabrication of storage, transportation, and disposal casks; the site-characterization work at the potential disposal site at Gorleben; and the system for moving spent nuclear fuel and for storing and preparing high-level waste for permanent disposal.

Considerable progress has been made in developing the Pollux cask, a packaging system for the transport, interim storage, and final disposal of spent-fuel rods (Janberg and Spilker 1998). The Board members believe that the effort that has gone into designing, fabricating, and testing this cask is worth exploration by those involved in similar work for the U.S. program.

The Board members noted the use of natural convection to ventilate the entire underground exploratory system at Gorleben. The exploratory facility at Gorleben is at the southern edge of the proposed repository block and is accessed by two shafts that are approximately 7 m in diameter. The intake shaft extends to 940 m, and the exhaust shaft extends to 840 m. Work is under way to extend the facility around the proposed block. There is no forced-draft fan on the intake shaft and no induced-draft fan on the exhaust.

20. The DOE commissioned an international review team in June 1996. It included experts appointed by the Organization for Economic Cooperation and Development, the Nuclear Energy Agency, and the International Atomic Energy Agency.

21. The Board's visit included the following sites: (1) Gesellschaft für Nuklear-Service mbH and Gesellschaft für Nuklear Behälter mbh cask development, fabrication, and testing facilities in Essen; (2) the Ahaus interim storage site, operated by Brennelement-Zwischenlager Ahaus GmbH; (3) the Pilot Conditioning Plant, Radwaste Interim Storage Facility, and Transport Cask Interim Storage Facility, which are located at Gorleben and are operated by Brennelementlager Gorleben mbH; (4) the proposed site of a permanent repository, which is located at Gorleben and is undergoing site characterization by Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH; and (5) the Endlager für radioaktive Abfälle Morsleben, which is a permanent disposal site for low- and intermediate-level radioactive waste near Morsleben.

Unrestricted natural convection flow in the winter is high enough that a damper at the exploratory facility level has to be used to reduce air flow. In designing any alternative repository plans for Yucca Mountain, it may be worth drawing on the experience of those involved in designing the ventilation system at Gorleben, as well as the ventilation studies undertaken by Nye County, Nevada.

B. Sweden

A small delegation from the Board visited the municipality of Oskarshamn in southeastern Sweden on May 4 and 5. The purpose of the visit was to tour the Swedish Nuclear Waste Company's (SKB) facilities and to meet with representatives of Oskarshamn, one of four municipalities that have volunteered to undertake the first step in a process that could result in a permanent repository being located in their municipality. Three other municipalities have volunteered and are in the first phase of the prestudy process. They are Nyköping, Östhammar, and Tierp.

Members of the Board had the opportunity to meet with the people in Oskarshamn who are heavily involved in establishing an environmental impact assessment (EIA) process. The EIA Forum was created by the community after it volunteered to undertake the first of three phases of a volunteer process established in Sweden to designate a final repository site. The three phases are (1) feasibility studies, (2) site investigations, and (3) detailed investigations. The EIA forum is intended, among other objectives, to enable the residents of the municipality to participate in the decision-making as the community moves to determine whether it wants to proceed to site investigation.[22]

The EIA Forum is a significant effort in that it is the first initiative of its kind in the world for disposing of spent nuclear fuel. Through the EIA Forum, the municipality has formalized a process in which the locality is empowered to make key decisions about whether it wants to proceed to other phases of the site selection process. The community has organized six working groups: long-term safety and geoscience, technologies, land use and environment, social science, encapsulation, and information. Their effort to date is aimed at reaching a realistic assessment of the effect that a permanent repository would have on their community.

During its visit, members of the Board's delegation had the opportunity to tour the following SKB facilities: the Hard Rock Laboratory at Äspö, the interim storage facility (CLAB), and the Encapsulation Laboratory in Oskarshamn. During its visit, the Board also was briefed on the scientific and technical work being performed in support of the SKB's KBS-3 waste isolation concept.[23] The purpose of the Encapsulation Laboratory is to demonstrate on a full-scale basis that one canister per day that meets the safety requirements can be produced. The Encapsulation Laboratory also will be used to test operational problems, estimate the reliability and maintenance of the equipment and the plant, and estimate the capability of the equipment.

The SKB canister, which is undergoing full-scale laboratory manufacturing trials, is an evolution of past designs. It consists of 50 mm of copper with cast iron inside. The cast-iron inner component has been added as a stand for the fuel elements and as a support for the copper mantle. The canister serves as two barriers; the copper prevents groundwater from contacting the fuel, and the cast iron converts what water may be left into hydrogen gas and iron oxide. SKB states that if the canister is manufactured properly, galvanic interactions will not be a problem. The design basis for the canister includes a corrosion allowance and takes into account hydrostatic pressure and the forces from the packing material around the canister. Plans are to pack sodium bentonite around the waste packages to minimize water ingress. The tunnels will be backfilled with sodium bentonite and (1) sand or (2) sand and crushed rock.

A prototype repository is being built at the Äspö laboratory. Canisters made at the canister laboratory

22. Details of the process and policy that constitute Oskarshamn's EIA Forum are in *EIA Forum for Studies of the Final Disposal System for Spent Nuclear Fuel in Oskarshamn Municipality* (Kalmar 1998).

23. A summary of this concept is in *This Is How We Manage Sweden's Radioactive Waste: Activities 1997* (SKB 1998b). More-detailed descriptions are available in SKB's RD&D Programme 98, (SKB 1998a).

will be emplaced with precompacted bentonite buffer blocks and rings. No nuclear fuel will be used, but some of the canisters will be heated with electricity. Instruments will be used to verify predictions about the performance of the repository during its initial operating stage and to provide practical experience in handling and retrieving of waste. The prototype will be in operation for at least 20 years.

C. Finland

The same delegation that visited representatives of the Swedish program traveled on to Finland for meetings and a site visit on May 7 and 8. The visit included meetings with representatives of Posiva Oy, a small company responsible for the management and final disposal of spent nuclear fuel in Finland. The Board members also met with representatives of the Radiation and Nuclear Safety Authority (STUK) and the Ministry of Trade and Industry, which oversees the policy, licensing, and funding of nuclear waste activities in Finland. The Board members then traveled to Loviisa to tour the site characterization in progress at Hästholmen, one of four sites undergoing preliminary site characterization. The three other sites are Olkiluoto in Eurajoki, Romuvaara in Kuhmo, and Kivetty in Äänekoski. The sites also have been evaluated as part of an EIA program conducted by Posiva Oy.[24]

The Finnish nuclear waste management and disposal program continues to operate effectively and efficiently. Posiva Oy has approximately 30 full-time employees, and contractors are used to a great extent. The program remains on schedule. That schedule calls for completion of a preliminary site investigation at each of the four sites in 1999. In 2000, a final disposal site will be selected. An investigation shaft will be built, and underground site characterization will be conducted from 2000 to 2010, when construction of the encapsulation plant and the final repository will begin. The established date for beginning final disposal is 2020.

Posiva Oy estimates that approximately 1,500 canisters of spent fuel, or 2,600 metric tons, will need to be disposed of. This is based on a 40-year life of the nuclear power plants at Olkiluoto and Loviisa. Current plans are to build 15 kilometers of underground tunnels, on the floor of which holes for fuel canisters will be bored. The fuel will be transported by road or rail and, in a few alternatives, by sea. The disposal concept is very similar to the SKB's in Sweden because of the similarities in the geology and hydrology of the two countries. The canister that will be used for disposal, however, differs somewhat from the Swedish canister. It consists of an external canister of copper tightly surrounding an inner canister of nodular cast iron. The copper is used to prevent corrosion caused by groundwater; the nodular cast iron is used because it is strong enough to withstand the mechanical stresses prevailing in the bedrock.

24. A description of the EIA process in Finland, including a description of the current waste isolation concept and a summary of the conditions that must be met at each of the sites in order to build a repository there, is in *The Final Disposal of Spent Nuclear Fuel—Environmental Impact Assessment Programme* (Posiva Oy 1998).

Abbreviations and Acronyms

ACNW	Advisory Committee on Nuclear Waste
Board	U. S. Nuclear Waste Technical Review Board
BWR	boiling-water reactor
CFR	*Code of Federal Regulations*
CFu	Crater Flat undifferentiated unit
CHn	Calico Hills nonwelded unit
^{36}**Cl**	chlorine-36
DOE	U.S. Department of Energy
EBS	engineered barrier system
ECRB	enhanced characterization of the repository block
EIA	environmental impact assessment
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESF	Exploratory Studies Facility
EWDP	Early Warning Drilling Program
GWTT	groundwater travel time
HLW	high-level radioactive waste
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
M&O	DOE's management and operating contractor
MTU	metric ton of uranium
NAS	National Academy of Sciences
Np	neptunium
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWPAA	Nuclear Waste Policy Amendments Act
NWTRB	U.S. Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management, U.S. Department of Energy
PTn	Paintbrush Tuff nonwelded unit
PWR	pressurized-water reactor
RFP	request for proposal
SKB	Svensk Kärnsbränslehantering (Swedish Nuclear Fuel and Waste Management Company)
SZ	saturated zone
SZEE	saturated zone expert elicitation
TBM	tunnel-boring machine
TCw	Tiva Canyon welded unit
TSw	Topopah Spring welded unit
TSPA	total system performance assessment
TSPA-VA	total system performance assessment-viability assessment
USGS	U.S. Geological Survey
UZ	unsaturated zone
VA	viability assessment
WIPP	Waste Isolation Pilot Plant
WPDEE	waste package degradation expert elicitation

Glossary

The following list of terms has been compiled to aid in the reading of this report. It is not meant to be a formal glossary or to have the completeness of a dictionary; rather, it is meant to help the reader understand some of the terms used regularly by the Board.

accessible environment. The earth's surface and the rock more than 5 kilometers beyond the repository.

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

analogue. A thing or part that is analogous. As used in this report, 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.

aquifer. Permeable saturated rock through which groundwater flows.

areal mass loading. The concentration of emplaced spent fuel, averaged over the area of the repository and expressed in kilograms per square meter or in metric tons per acre.

backfill. Solid materials placed in excavated areas underground to fill voids (i.e., crushed tuff).

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

canister. The structure surrounding a waste form (e.g., high-level waste immobilized in borosilicate glass) that facilitates handling, storage, transportation, or disposal. Before being emplaced in a repository, the canister may be placed in a disposal container.

characterization. Collecting information necessary to evaluate the suitability of a region or site for geologic disposal. Data from characterization also will be used during the licensing process.

chlorine-36 (^{36}Cl). 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 precipitation from the 1950's has moved through soil and rocks, such as those present at Yucca Mountain.

cladding. Thin metallic material that encases nuclear fuel

colloid. A particle that can be suspended easily, or a suspension of very fine particles.

colloidal transport. Because colloidal particles can be suspended for long periods without settling, they may be transported at the same velocity as groundwater.

container. A receptacle used to hold radioactive waste (usually spent fuel).

corrosion-allowance materials. Materials that fail because of generalized corrosion and that tend to fail more rapidly than corrosion-resistant materials.

corrosion-resistant materials. Materials that fail primarily because of localized corrosion and that tend to fail more slowly than corrosion-allowance materials.

critical group. The group that is representative of the individuals in the population who, on the basis of cautious but reasonable assumptions, are at the highest risk from exposure to repository releases.

defense-in-depth. Incorporation of multiple barriers in the design of a repository to make the performance of the overall system less susceptible to the unexpected failure of any individual barrier.

infiltration. Water entering soil or rock after precipitation rather than becoming runoff into rivers, streams, ponds, etc. The terms “infiltration” and “net infiltration” also are used to refer to water that penetrates deeply into soil or rock (beneath plant root zones) rather than returning to the atmosphere by evapotranspiration.

infiltration flux. The rate at which water from precipitation enters the rock below the surface root zone. See **flux**.

interim storage. Storage of spent fuel or high-level radioactive waste with the intention and expectation that the waste will be moved later to a permanent repository.

license application. A document submitted to the Nuclear Regulatory Commission containing general information and a safety analysis for a nuclear reactor, a geologic repository, or an interim storage facility for spent nuclear fuel and high-level radioactive waste.

lithophysal, nonlithophysal. Lithophysal and nonlithophysal zones denote the relative abundance of lithophysae found in different rock strata. Lithophysae, sometimes called “stone bubbles,” are cavities in silicic volcanic rock that are formed, soon after the volcanic rocks are deposited, because of the presence of vapors under very high pressure.

matrix. In hydrology, the solid framework of a porous system.

near field. The region where the natural hydrologic system has been altered by the excavation of the repository or by the thermal environment created by the emplacement of high-level waste.

nonwelded tuff. A tuff that has not been hardened and welded together by intense temperature and pressure and that contains fewer fractures than welded tuff does.

Nuclear Waste Policy Act (PL 97-425). The federal statute enacted in 1982 that established the Office of Civilian Radioactive Waste Management and defined its mission for developing 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 states, local governments, and Indian tribes.

Nuclear Waste Policy Amendments Act of 1987 (P0-203). The legislation that amended the Nuclear Waste Policy Act to limit repository site-characterization activities to Yucca Mountain, Nevada; establish the Office of the Nuclear Waste Negotiator for seeking a state or an Indian tribe willing to host a repository or a monitored retrievable storage facility; create the Nuclear Waste Technical Review Board; and increase state and local government participation in the waste management program.

peak dose. The largest dose projected per unit time (e.g., per year or human lifetime) after repository closure.

performance assessment (PA). An analysis that predicts the behavior of an entire system or a part of a system under a given set of conditions on the basis of an assumed measure of performance.

postclosure. The time after the closure of the repository.

preclosure. The time before the closure of the repository.

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

radionuclide. An atomic nucleus that is radioactive.

radionuclide transport. The movement of radionuclides, generally as dissolved solids or gaseous forms, through a rock formation.

recharge. The addition of water to the saturated zone or the water added.

repository. See **geologic repository**.

repository block. The part of Yucca mountain in which placement of the proposed repository is being considered.

retardation. The physical or chemical process that causes some dissolved radionuclides to move more slowly than the water they are dissolved in.

saturated zone (SZ). The part of the earth’s crust in which all voids are filled with water under pressure at least as great as atmospheric pressure.

seepage flux. The magnitude and distribution of percolating water that drips into the emplacement drifts and, potentially, onto the waste packages.

self-shielded waste package. A waste package with sufficient intrinsic radiation shielding so that people can perform occasional activities on or near it without receiving radiation exceeding standards for workers.

shrinkfitting. Joining (or mating) layers of metal by using heat to expand the outer shell, inserting the inner shell, and allowing the outer shell to cool around the inner shell.

site assessment. The full range of activities needed to evaluate the suitability of the Yucca Mountain site, including site characterization; laboratory research; performance assessment; and design of the repository, waste packages, and engineered barriers.

site characterization. See **characterization**.

sorption. The binding, on a microscopic scale, of dissolved molecules or atoms on mineral surfaces in contact with fluid. The sorption of dissolved radionuclides can lead to their retardation.

sorption characteristics. The ability of rocks and minerals to bind, reversibly or irreversibly, radionuclides or other chemical species on their surfaces.

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. Fuel that has been withdrawn from a nuclear reactor after irradiation, the constituent elements of which have not been separated by reprocessing.

structural geology. Study of the deformational features of rocks induced by processes such as folding, faulting, and igneous activity. Study of the processes.

suitability determination. The formal recommendation by the DOE to the President on whether the Yucca Mountain site can safely host a repository for high-level waste.

thermal energy. Heat produced by the radioactive decay of waste.

thermal load. The amount of heat produced by emplaced waste and affecting the near field and overall repository material, including geophysical and engineered barriers (usually measured in kilowatts per acre).

thermohydrology. The study of how heat affects the movement of water in geologic formations.

total system performance assessment (TSPA). Analyses undertaken by the DOE to assess the ability of the potential repository at Yucca Mountain to provide long-term waste isolation.

transparent (performance assessment). Easy to detect or perceive. Using clear language and easily understood concepts or assumptions to arrive at credible, traceable, and logical conclusions.

unsaturated zone (UZ). Geologic formations located above the regional groundwater table.

viability assessment (VA). A congressionally mandated report that the Secretary of Energy provided to the President and Congress in 1998 and that includes repository and waste package designs, a total system performance assessment, a license application plan, and estimates of repository cost and schedule.

volcanism. The process by which molten rock and its associated gases rise from within the earth and are extruded onto the earth's surface and into the atmosphere.

waste acceptance. The processes necessary for the DOE to take title to and physical possession of spent nuclear fuel or high-level radioactive waste from owners and generators of the wastes.

waste containment and isolation. Separation of waste from the environment so that any radioactive material reentering the environment will be kept within prescribed limits.

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

waste package. The radioactive waste materials and any encapsulating and stabilizing matrix, as well as any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.

water table. An underground boundary below which the rock pores are completely filled with water and above which they are only partly filled with water.

welded tuff. Rock made of volcanic ash that has been hardened and welded together by heat, pressure, and possibly the introduction of cementing minerals. Welded tuff contains more fractures than nonwelded tuff does.

References

Andrews, R.W. 1998. "Basic Structure, Conceptual Model, and Results of the TSPA-VA." Presentation to Nuclear Waste Technical Review Board's Panel on Performance Assessment. Albuquerque, New Mexico. April 23, 1998.

Barnard, Ralston. 1998. "Analysis of Disturbed Events for TSPA-VA." Presentation to Nuclear Waste Technical Review Board's Panel on Performance Assessment. Albuquerque, New Mexico. April 24, 1998.

Chrisman, Robert. 1997. February 21 letter from Mr. Robert Chrisman, Chairman of Committee for the Truth About Yucca Mountain, to Dr. Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board.

Civilian Radioactive Waste Management System. Management & Operating Contractor (M&O). 1995a. *Thermal Loading Study for FY 1995*. B00000000-01717-5705-00016. Las Vegas, Nevada: TRW Environmental Safety Systems, Inc.

———. 1995b. *Total-System Performance Assessment - 1995: An Evaluation of the Potential Yucca Mountain Repository*. B00000000-0717-2200-00099-Rev. 01. Las Vegas, Nevada: TRW Environmental Safety Systems, Inc.

———. 1996. *Emplaced Waste Package Structural Capability Through Time Report*. B00000000-01717-5705-00001 Rev 00. Las Vegas, Nevada: TRW Environmental Safety Systems, Inc.

———. 1997. "Management Design Review, Presentation Materials." Presentation to Management. Las Vegas, Nevada. June 23-24, 1997.

———. 1998. *Constraints on Solubility-Limited Neptunium Concentrations for Use in Performance Assessment Analyses*. B00000000-01717-2200-00191, Rev. 00, January 23, 1997. Las Vegas, Nevada: TRW Environmental Safety Systems, Inc.

Cohon, Jared L. 1997. April 15 letter from Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board, to April V. Gil, Yucca Mountain Site Characterization Office: "Comments on the proposed revisions to the Department of Energy's G*eneral Guidelines for the Recommendation of Sites for Nuclear Waste Repositories* (10 CFR 960)."

———. 1998a. January 12 letter From Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board, to Lake Barrett, Acting Director, Office of Civilian Radioactive Waste Management: "Comments from the Board's October Meeting."

———. 1998b. July 30 letter from Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board, to Lake Barrett, Acting Director, Office of Civilian Radioactive Waste Management: "Comments on the June 1998 meeting."

Czarnecki, John B. 1989. "Characterization of the Subregional Ground-Water Flow System at Yucca Mountain and Vicinity, Nevada and California." *Radioactive Waste Management and the Nuclear Fuel Cycle*. Vol. 13, No. 1-4: pp. 51-61.

Del Papa, Frankie Sue. 1997. March 25 letter from Frankie Sue Del Papa, Attorney General, State of Nevada, to Jared L. Cohon, Chairman, Nuclear Waste Technical Review Board: "Yucca Mountain Characterization Studies."

Dixon, Wendy R. 1998. "Presentation to the Nuclear Waste Technical Review Board, January 20, 1998, Wendy R. Dixon, Repository EIS Project Manager, Yucca Mountain Project." Las Vegas, Nevada.

Elsworth, Derek. 1998. "TM Drift Stability—Preliminary Evaluation." Presentation at Workshop on Preliminary Interpretations, Near-Field / Altered Zone Coupled Effects, Expert Elicitation Project. South San Francisco, California. January 7, 1998.

Garrick, B. John. 1998. September 9 letter from B. John Garrick, Chairman, Advisory Council on Nuclear Waste, to Shirley Ann Jackson, Chairman, Nuclear Regulatory Commission: "Issues and Recommendations Concerning the Near-Field Environment and the Performance of Engineered Barriers at Yucca Mountain."

Geomatrix Consultants, Inc. 1998. *Waste Form Degradation and Radionuclide Mobilization Expert Elicitation Project*. San Francisco, California

Janberg, Klaus and Harry Spilker. "Status of the development of final disposal casks in Germany." *Nuclear Technology*. Vol. 121., February 1998: pp. 1-12.

Kalmar County, Sweden. County Administrative Board. 1998. *EIA Forum for Studies of the Final Disposal System for Spent Nuclear Fuel in Oskarshamn Municipality, Policy and Document Work Procedures.* February 5, 1998.

Kersting, A.B.; D.K. Smith; D.W. Efurd; D.L. Finnegan; D.J. Rokop; and J.L. Thompson. 1999. "Plutonium in Groundwater at the Nevada Test Site." *Nature.* 397: 56-59.

National Research Council. Panel on Coupled Hydrologic / Tectonic / Hydrothermal Systems at Yucca Mountain (NAS / NRC). 1992. *Ground Water at Yucca Mountain How High Can it Rise?* Washington, D.C.: National Academy Press.

Nuclear Waste Technical Review Board (NWTRB). 1992. *Sixth Report to The U.S. Congress and The U.S. Secretary of Energy*. December 1992. Arlington, Virginia.

———. 1997a. *Report to The U.S. Congress and The Secretary of Energy, January-December 1996.* Arlington, Virginia,.

———. 1997b. "Conduct Engineered Barrier Studies Now." *NWTRB Viewpoint*. March 1997. Arlington, Virginia.

———. 1998a. *1997 Findings and Recommendations: Report to The U.S. Congress and The Secretary of Energy*. April 1998. Arlington, Virginia.

———. 1998b. Winter Board Meeting; January 20-21, 1998; Amargosa Valley, Nevada (transcript of proceedings). Arlington, Virginia.

———. 1998c. Meeting on TSPA-VA; April 23-24, 1998; Albuquerque, New Mexico (transcript of proceedings). Arlington, Virginia.

———. 1998d. Waste Package Workshop; May 18-19, 1998. Falls Church, Virginia (transcript of proceedings). Arlington, Virginia

———. 1998e. Summer Board Meeting; June 24, 1998; Las Vegas, Nevada (transcript of proceedings). Arlington, Virginia

Posiva Oy. 1998. *The Final Disposal Facility of Spent Nuclear Fuel: Environmental Impact Assessment Programme.* Helsinki.

Svensk Karnbranslehantering AB (SKB). 1998a. *SKB's RD&D Programme 95: Treatment and Final Disposal of Nuclear Waste.* Stockholm

———. 1998b. *This is How We Manage Sweden's Radioactive Waste: Activities 1997.* Stockholm.

Total System Performance Assessment Peer Review Panel (TSPA Panel). 1998. *Third Interim Report, June 25, 1998.*

U.S. Department of Energy. Yucca Mountain Site Characterization Office (USDOE, YMPO). 1997. *Summary of Public Scoping Comments Related to the 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.* Las Vegas, Nevada.

———. Office of Civilian Radioactive Waste Management (USDOE, OCRWM). 1998. *Acquisition of Waste Acceptance and Transportation Services for OCRWM*. Draft, September 1998.

———. 1998. *Viability Assessment of a Repository At Yucca Mountain.* Vols. 1- 5. Las Vegas, Nevada.

Laws and Legislation

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

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

———. 1996. *Energy and Water Development Appropriations for 1997*. 104th Congress, 2nd Session. Washington, D.C.: Government Printing Office.

10 CFR 60 (*Code of Federal Regulations*). Title 10, *Energy*. Part 60. "Disposal of High-Level Radioactive Wastes in Geologic Repositories." Washington, D.C.: U.S. Government Printing Office.

Appendices

Appendix A
Nuclear Waste Technical Review Board Members: Curricula Vitae

Jared L. Cohon, Ph.D.; Chairman

On June 29, 1995, President Bill Clinton appointed Jared Cohon to the Nuclear Waste Technical Review Board. President Clinton appointed Dr. Cohon chairman on January 17, 1997.

Dr. Cohon is president of Carnegie Mellon University in Pittsburgh, Pennsylvania. He has more than 25 years of teaching and research experience, has written one book, and is author, coauthor, or editor of more than 80 professional publications. Among other awards, Dr. Cohon received the 1996 Joan Hodges Queneau Medal for outstanding engineering achievement in environmental conservation, awarded jointly by the American Association of Engineering Societies and the National Audubon Society. He is a member of Tau Beta Pi, the National Engineering Honor Society, and of Sigma Xi, the Scientific Research Society. Dr. Cohon is a registered Professional Engineer.

Dr. Cohon brings to the Board special expertise as a national authority on environmental and water resource systems analysis. His research interests focus on multiobjective programming, a technique for decision-making in situations with multiple conflicting objectives. He also has focused on water resources planning and management in the United States, South America, and Asia and on energy facility siting, including nuclear waste shipping and storage. In addition to his academic experience, he served as legislative assistant for energy and environment to the Honorable Daniel P. Moynihan, United States Senator from New York, from 1977 to 1978.

Dr. Cohon is a member of the American Geophysical Union, the Institute for Operations Research and Management Science, the American Water Resources Association, and the American Society of Civil Engineers. He has served on several committees for the National Research Council, chairing the studies on the probabilities of extreme floods and on measuring and improving infrastructure.

In 1969, Dr. Cohon earned a bachelor of science degree in civil engineering from the University of Pennsylvania. He worked as a construction inspector in Philadelphia and as an engineering assistant for the Philadelphia Water Department before attending the Massachusetts Institute of Technology, where he earned a master's degree in civil engineering in 1972 and a Ph.D. in civil engineering in 1973. Dr. Cohon began his teaching career in 1973 at Johns Hopkins University, where he served as assistant, associate, and full professor in the Department of Geography and Environmental Engineering and as Assistant and Associate Dean of Engineering and Vice Provost for Research. In 1992, he became dean of the School of Forestry and Environmental Studies and professor of environmental systems analysis at Yale University. Dr. Cohon assumed his duties as president of Carnegie Mellon University in July 1997.

Dr. Cohon resides in Pittsburgh, Pennsylvania.

John W. Arendt, P.E.

On June 29, 1995, President Bill Clinton appointed John Arendt to the Nuclear Waste Technical Review Board.

John W. Arendt is senior consultant and founder of John W. Arendt Associates, Inc. Created in 1986, the firm offers consultation on program and project management, safety assessments and investigations, quality assurance, standards and regulations for uranium handling and processing, chemical safety audits, and safeguards and accountability. Mr. Arendt is a registered Professional Engineer and a certified nuclear materials manager.

Mr. Arendt brings to the Board five decades of experience in various phases of the nuclear fuel cycle, especially uranium processing, handling, safeguards and accountability, packaging, and transportation. He has extensive experience in the management of engineering projects, including uranium processing facilities and their quality assurance, quality control, and inspection. He is chairman of American National Standards Institute (ANSI) Accredited Standards Committee N14 on packaging and transportation of radioactive materials and nonnuclear hazardous wastes.

Mr. Arendt earned a bachelor of science degree in chemical engineering from Marquette University in 1943 and was a research engineer for the Manhattan Project at the University of Chicago from 1943 to 1945. He gained the bulk of his experience with Union Carbide Corporation's Nuclear Division in Oak Ridge, Tennessee, where he began as a production supervisor in 1945 and served in various department and project management positions through 1984. Before founding John W. Arendt Associates, Inc., in 1986, Mr. Arendt was a senior engineer with JBF Associates, Inc., where he provided technical and management assistance in uranium enrichment, standards and regulations, waste management, packaging and shipping, reactor activities, quality assurance, and safety.

Mr. Arendt resides in Oak Ridge, Tennessee.

Daniel B. Bullen, Ph.D.

On January 17, 1997, President Bill Clinton appointed Daniel Bullen to the Nuclear Waste Technical Review Board.

Dr. Daniel B. Bullen is director of the Nuclear Reactor Laboratory and associate professor of mechanical engineering, Department of Mechanical Engineering, at Iowa State University in Ames, Iowa. He has been teaching since 1989, served as Nuclear Engineering Program Coordinator at Iowa State University from 1993 to 1996, and has 11 years of industry experience in nuclear engineering and materials science. He has edited and reviewed articles for such professional publications as Nuclear Technology, Journal of the American Ceramic Society, American Nuclear Society Transactions, and Encyclopedia of Chemical Technology. He has written or co-written more than 50 technical publications and reports and has contributed to three books. He is a registered Professional Engineer in mechanical, metallurgical, and nuclear engineering. Dr. Bullen's honors and awards include Tau Beta Pi (National Engineering Honor Society), Phi Kappa Phi, Sigma Xi (The Scientific Research Society), Alpha Nu Sigma (Nuclear Engineering Scholastic Honor Society), a Lilly Teaching Fellowship to the Georgia Institute of Technology (1991), and two Outstanding Professor awards. He has appeared in *Who's Who in California*, *Who's Who in Technology*, and *Who's Who in Science & Engineering*.

Dr. Bullen brings to the Board special expertise in performance assessment modeling of radioactive waste disposal facilities, performance assessment of engineered barrier systems, radiolysis effects in spent-fuel dry casks in storage environments, radiation effects on materials, and materials degradation in severe service environments.

Dr. Bullen is a member of the American Nuclear Society; the American Ceramic Society; ASM International; the Materials Research Society; the American Society of Mechanical Engineers; the National Society of Professional Engineers; the Minerals, Metals & Materials Society; and the American Society for Engineering Education.

In 1978, Dr. Bullen earned a bachelor of science degree in engineering science from Iowa State University. He was a research assistant at the University of Wisconsin-Madison while earning master of science degrees in nuclear engineering in 1979 and materials science in 1981 and a Ph.D. in nuclear engineering in 1984. He then worked for Lawrence Livermore National Laboratory as an engineer until 1986, when he became senior engineer for Science & Engineering Associates, Inc., in Pleasanton, California. In 1988, he became president of DG Engineering Associates, providing technical consulting services to Lawrence Livermore National Laboratory. Dr. Bullen moved to North Carolina State University in 1989 as an assistant professor of nuclear engineering and to the Georgia Institute of Technology in 1990 as an assistant professor of mechanical engineering. He moved to Iowa State University in 1992 as an associate professor of nuclear engineering and assumed his current duties in 1993.

Dr. Bullen resides in Ames, Iowa.

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

On January 17, 1997, President Bill Clinton appointed Norman Christensen to the Nuclear Waste Technical Review Board.

Dr. Norman L. Christensen, Jr., is professor of ecology and dean of the Nicholas School of the Environment at Duke University in Durham, North Carolina. He has been teaching for more than 27 years and has more than 80 scientific articles and books to his credit. Dr. Christensen is the recipient of the 1977 Duke Endowment Award for Teaching Excellence, the 1991 Distinguished Teaching Award for Trinity College of Arts and Sciences at Duke, and the 1994 Distinguished Scholar-Alumni Award from California State University-Fresno. He was the E.V. Komarek Lecturer at the 1989 Tall Timbers Fire Ecology Conference, a Fellow of the American Association for the Advancement of Science in 1993, and a recipient of the National Park Service's A. Starker Leopold Award for distinguished service. Dr. Christensen has served on more than 25 national and regional panels and commissions and on the editorial boards of *American Midland Naturalist, Journal of Vegetation Science*, and *Journal of Wildland Fire.*

Dr. Christensen brings to the Board special expertise in biology and ecology. His research interests include the effects of disturbance on structure and function of populations and communities; comparative biogeochemical and community responses to varying fire regimes; use of remote sensing systems (such as synthetic aperture radar) to evaluate long-term changes in forest ecosystems; and pattern analysis of forest development following cropland abandonment as affected by environment, stand history, and plant demographic patterns. He has written widely on the importance of natural disturbance in the management of forests, shrublands, and wetlands, and he is interested in applying basic ecological theory and models to ecosystem management.

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

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

Dr. Christensen resides in Chapel Hill, North Carolina

Paul P. Craig, Ph.D.

On January 30, 1997, President Bill Clinton appointed Paul Craig to the Nuclear Waste Technical Review Board.

Dr. Paul P. Craig is Professor of Engineering Emeritus at the University of California, Davis, and is a member of the university's Graduate Group in Ecology. He has more than 21 years of teaching experience and more than 100 refereed publications to his credit. Dr. Craig is a member of the Sierra Club's Global Warming and Energy committees and of the American Association for the Advancement of Science and is a Fellow of the American Physical Society. His awards include a John Simon Guggenheim Memorial Foundation Fellowship and a National Science Foundation Meritorious Service Award. He is a member of Phi Beta Kappa.

Dr. Craig brings to the Board special expertise and research interest in energy policy issues associated with energy system responses to global environmental change.

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

Until his appointment to the Nuclear Waste Technical Review Board, Dr. Craig was a Lawrence Berkeley National Laboratory Participating Guest Scientist (beginning in 1976) and a member of the National Academy of Sciences–National Research Council Board on Radioactive Waste Management.

Dr. Craig resides in Martinez, California.

Debra S. Knopman, Ph.D.

On January 17, 1997, President Bill Clinton appointed Debra Knopman to the Nuclear Waste Technical Review Board.

Dr. Debra S. Knopman is the director of the Center for Innovation and the Environment of the Progressive Policy Institute in Washington, D.C. She has more than 24 publications in scientific and technical journals to her credit. Dr. Knopman is a member of the National Research Council's Commission on Geosciences, Environment, and Resources, and she served briefly on the Board on Radioactive Waste Management and the Panel for the Review of the DOE Environmental Restoration Priority System before accepting a position in the Clinton administration in 1993. She is a member of the American Geophysical Union. Dr. Knopman was a 1978-1979 Henry Luce Foundation Scholar.

Dr. Knopman brings to the Board special expertise in hydrology, environmental and natural resources policy, systems analysis, and public administration.

In 1975, Dr. Knopman earned a bachelor's degree in chemistry from Wellesley College. She completed a master of science degree in civil engineering from the Massachusetts Institute of Technology in 1978 and earned a Ph.D. from the Department of Geography and Environmental Engineering at Johns Hopkins University in 1986. Dr. Knopman began her career as a freelance science writer and editor in Israel and the United States in 1975. Following her Luce Scholar fellowship, which she served in Taiwan from 1978 to 1979, she served as legislative assistant for energy and environmental issues to Senator Daniel P. Moynihan in Washington, D.C., from 1979 to 1980. She served as a professional staff member of the U.S. Senate Committee on Environment and Public Works from 1980 to 1983. She moved to the U.S. Geological Survey in 1984, beginning as a student assistant and progressing through being a research hydrologist to becoming chief of the systems analysis branch. In 1993, Dr. Knopman was appointed Deputy Assistant Secretary for Water and Science, Department of the Interior. She became director of the Center for Innovation and the Environment in 1995.

Dr. Knopman resides in Washington, D.C.

Priscilla P. Nelson, Ph.D.

On January 17, 1997, President Bill Clinton appointed Priscilla Nelson to the Nuclear Waste Technical Review Board.

Dr. Priscilla P. Nelson is program director and senior engineering coordinator for the Directorate for Engineering at the National Science Foundation. She formerly was professor of civil engineering at The University of Texas at Austin. Dr. Nelson has more than 13 years of teaching experience and more than 100 technical and scientific publications to her credit. She has served as a member of the U.S. National Committee for Rock Mechanics, the U.S. National Committee for Tunneling Technology, and the Board on Radioactive Waste Management, all activities of the National Research Council. She is a member of the American Rock Mechanics Association, the American Society of Civil Engineers (ASCE), the International Tunnelling Association, the American Underground Construction Association, the Association of Engineering Geologists, the British Tunnelling Society, and other professional organizations. She serves as vice president and president-elect of the Geo-Institute of ASCE. Her honors and awards include the Lattimore Prize for Field Study from the University of Rochester (1969), an Exxon Teaching Fellowship at The University of Texas at Austin (1985-1987), the Case Studies Award from the U.S. National Committee for Rock Mechanics (1988), the Haliburton Education Foundation Award of Excellence (1991), the Basic Research Award from the U.S. National Committee for Rock Mechanics (1993), and election to The Moles, an association for the heavy construction industry (1995). At the National Science Foundation, she twice has received the Director's Award for Integrative Collaboration, and she received the Director's Award for Meritorious Service in 1997.

Dr. Nelson brings to the Board special expertise in rock engineering and underground construction. Her current research interests are development of a probabilistic risk analysis approach to prediction of underground construction project performance.

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

Dr. Nelson resides in Arlington, Virginia.

Richard R. Parizek, Ph.D.

On February 11, 1997, President Bill Clinton appointed Richard Parizek to the Nuclear Waste Technical Review Board.

Dr. Richard R. Parizek is a professor of geology and geoenvironmental engineering at The Pennsylvania State University; president of Richard R. Parizek and Associates, consulting hydrogeologists and environmental geologists; and a registered Professional Geologist. He has more than 37 years of teaching experience and numerous journal publications to his credit. His awards include a cooperative fellowship from the National Science Foundation (1960), a superior achievement award from the U.S. Environmental Protection Agency (1976), the Clearwater Conservancy Award (1985), the Matthew J. and Anne C. Wilson Teaching Award (1986), and the medal for distinguished service to environmental science and engineering of the Institute of Meteorology and Water Management, Warsaw, Poland (1991). Dr. Parizek was appointed an administrative law judge of the Atomic Safety and Licensing Board Panel of the U.S. Nuclear Regulatory Commission in 1990, a position he left upon appointment to the Nuclear Waste Technical Review Board.

Dr. Parizek brings to the Board special expertise in hydrogeology and environmental geology. His research interests include the hydrogeology of karst, fractured rock, and glaciated terranes; factors controlling groundwater occurrence and movement; and the relationship between land use and groundwater pollution resulting from disposal of nuclear waste and other hazardous substances.

Dr. Parizek is a member of the American Association for the Advancement of Science, the American Geophysical Union, the American Institute of Hydrology, the Geological Society of America, and Sigma Xi.

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

Dr. Parizek resides in State College, Pennsylvania.

Donald D. Runnells, Ph.D.

On June 23, 1998, President Bill Clinton appointed Donald Runnells to the Nuclear Waste Technical Review Board.

Dr. Donald D. Runnells is professor emeritus in the Department of Geological Sciences at the University of Colorado. He also is vice president of Shepherd Miller, Inc., a firm providing environmental and engineering consultation primarily to the mining industry and to government agencies and other concerns. He has more than 27 years of teaching experience and numerous journal publications to his credit. Dr. Runnells is a Fellow of the Geological Society of America. His awards include selection as a National Science Foundation Graduate Fellow, election to Phi Kappa Phi Honorary Scholastic Fraternity, and selection as a Fellow of the Cooperative Institute for Research in the Environmental Sciences at the University of Colorado. Dr. Runnells has been an editor or on the editorial board for *Journal of Geochemical Exploration, Interface, Science of the Total Environment, Chemical Geology*, and *Journal of Applied Geochemistry*. He has been a member of the Colorado Governor's Council on Science and Technology, the Review Board on Disposal and Permanent Storage of Inactive Uranium Tailings at Sandia National Laboratory, the Materials Review Board at Argonne National Laboratory, the Scientific Advisory Board on Toxics in Water for the Electric Power Research Institute, and several boards and panels of the National Research Council of the National Academy of Sciences.

Dr. Runnells brings to the Board special expertise in geochemistry, hydrochemistry, and mineral deposits.

He is a member of the Geochemical Society, the Society of Economic Paleontologists and Mineralogists, the Association of Exploration Geochemists, the Association of Ground Water Scientists and Engineers, and the American Chemical Society.

In 1958, Dr. Runnells earned a bachelor's degree in geology from the University of Utah. He earned a master of arts degree in geology in 1960 and a Ph.D. in geochemistry and geology in 1964, both from Harvard University. Dr. Runnells began his career as a teaching assistant at Harvard University in 1961. In 1963, he began working with Shell Development Company as a geochemist. He returned to teaching in 1967 as an assistant professor at the University of California. He moved to the University of Colorado in 1969. He was appointed full professor and chairman of the Department of Geological Sciences in 1975 and continued until 1993, when he became vice president of Shepherd Miller, Inc.

Dr. Runnells resides in Fort Collins, Colorado.

Alberto A. Sagüés, Ph.D.

On January 17, 1997, President Bill Clinton appointed Alberto Sagüés to the Nuclear Waste Technical Review Board.

Dr. Alberto A. Sagüés is professor of materials engineering in the Department of Civil and Environmental Engineering at the University of South Florida and is a registered Professional Engineer. He has 20 years of teaching experience and 120 technical publications to his credit. From 1988 to 1992, Dr. Sagüés served as an expert task group member of the Strategic Highway Research Program of the National Research Council. He has made technical presentations to professional and scientific audiences across the United States and Canada and throughout Europe and Central and South America. He holds three patents related to corrosion control.

Dr. Sagüés brings to the Board special expertise in corrosion and materials engineering, physical metallurgy, and scientific instrumentation. His research interests are in corrosion of reinforcing steel in concrete and durability forecasting of civil infrastructure.

Dr. Sagüés is a member of NACE International (formerly the National Association of Corrosion Engineers), the Electrochemical Society, the American Society for Testing and Materials, the American Concrete Institute, and ASM International (formerly the American Society for Metals).

A native of Argentina, Dr. Sagüés earned his undergraduate degree in physics from the National University in Rosario, Argentina, in 1968. He earned a Ph.D. in metallurgy from Case Western Reserve University in Cleveland in 1972. A citizen of the United States since 1979, Dr. Sagüés began his career as a visiting assistant professor at Columbia University in 1972, performed postdoctoral research in 1973, and was a guest scientist at the Solid State Research Institute of the Jülich Nuclear Research Center in West Germany from 1974 to 1976. He served as a research associate at Argonne National Laboratory from 1976 to 1978 and as senior metallurgist, manager, and associate laboratory director of the Kentucky Center for Energy Research Laboratory from 1978 to 1985. At the same time, he continued his teaching career at the University of Kentucky. In 1985, he moved to the University of South Florida as an associate professor. Dr. Sagüés became professor of materials engineering, Department of Civil and Environmental Engineering in 1991.

Dr. Sagüés resides in Lutz, Florida.

Jeffrey J. Wong, Ph.D.

On June 29, 1995, President Bill Clinton appointed Jeffrey Wong to the Nuclear Waste Technical Review Board.

Dr. Jeffrey Wong is chief of the Human and Ecological Risk Division of the Department of Toxic Substances Control, California Environmental Protection Agency. Dr. Wong has more than 14 years of experience in toxicology, including assessment of exposure risks at hazardous waste sites, at hazardous waste treatment, storage, and disposal facilities, and at hazardous material spills and accidents. He is an instructor in environmental toxicology at the University of California, Davis, and he has worked with the California Department of Justice in forensic toxicology. Dr. Wong was a National Institutes of Environmental Health Sciences Predoctoral Fellow in environmental toxicology and was the recipient of the American Academy of Forensic Sciences Regional Award in Toxicology in 1984.

Dr. Wong brings to the Board extensive experience in risk assessment and scientific team management. He served as the risk evaluation expert on the external expert review panel to the Consortium for Environmental Risk Evaluation, a program of Tulane and Xavier universities. Dr. Wong also has served on National Academy of Sciences / National Research Council committees relating to remedial action for hazardous waste sites and the U.S. Department of Energy's environmental restoration program. He is a member of the editorial board of *Journal of Contaminated Soils* and is an advisory board member for the Association for the Environmental Health of Soils.

Dr. Wong earned a bachelor of arts degree in bacteriology in 1973, a master of science degree in food science and technology in 1976, and a Ph.D. in pharmacology and toxicology in 1981, all from the University of California, Davis. He worked for the California Department of Justice as a senior forensic toxicologist after his doctoral work. He moved to the California Department of Food and Agriculture as a staff toxicologist before beginning his career with the California Environmental Protection Agency in July 1985.

Dr. Wong resides in Sacramento, California.

Appendix B
Meeting List for 1998

January 20 and 22
Board Business Meeting
Amargosa Valley and Las Vegas, Nevada
Minutes available

January 20-21
Full Board Meeting
Amargosa Valley, Nevada
Topics
- Yucca Mountain program updates
- Government Performance and Results Act
- Public comments
- Saturated zone hydrology and expert elicitation
- Thermal testing at Yucca Mountain site

Transcripts available

March 11-12
Board Business Meeting
Santa Fe, New Mexico
Annotated notes available

April 23-24
Meeting of Panel on Performance Assessment
Albuquerque, New Mexico
Topics
- TSPA-VA base case and selected sensitivity tests

Transcripts available

May 18-19
Workshop on Waste Package
Falls Church, Virginia
Topics
- Alternative designs and materials research needs

Transcripts available

June 22 and 25
Board Business Meeting
Las Vegas, Nevada
Minutes available

June 23
Board tour of Yucca Mountain facility
Las Vegas, Nevada

June 24
Full Board Meeting
Las Vegas, Nevada
Topics
- Waste package and repository design alternatives
- Environmental impact statement update
- Nye County drilling program
- Public comments

Transcripts available

September 15-18
Board Business Meeting
Pittsburgh, Pennsylvania
Annotated notes available

Appendix C
Panel Organization

1. Panel on Site Characterization

Chairman:	Dr. Debra S. Knopman	Staff:	Leon Reiter*
Members:	Dr. Priscilla P. Nelson		Russell K. McFarland
	Dr. Richard R. Parizek		Victor V. Palciauskas
	Dr. Alberto A. Sagüés		

2. Panel on the Repository

Chairman:	Dr. Priscilla P. Nelson	Staff:	Russell K. McFarland*
Members:	Mr. John W. Arendt		Carlos A. W. Di Bella
	Dr. Daniel B. Bullen		Victor V. Palciauskas
	Dr. Alberto A. Sagüés		

3. Panel on the Waste Management System

Chairman:	Mr. John W. Arendt	Staff:	Michael G. Carroll*
Members:	Dr. Daniel B. Bullen		Carlos A. W. Di Bella
	Dr. Norman L. Christensen, Jr.		Daniel S. Metlay
	Dr. Paul P. Craig		
	Dr. Debra S. Knopman		

4. Panel on the Environment, Regulations, and Quality Assurance

Chairman:	Dr. Jeffrey J. Wong	Staff:	Daniel J. Fehringer*
Members:	Mr. John W. Arendt		Daniel S. Metlay
	Dr. Norman L. Christensen, Jr.		
	Dr. Paul P. Craig		
	Dr. Debra S. Knopman		

5. Panel on Performance Assessment

Chairman:	Dr. Daniel B. Bullen	Staff:	Carlos A. W. Di Bella*
Members:	Dr. Paul P. Craig		Daniel S. Metlay
	Dr. Richard R. Parizek		Victor V. Palciauskas
	Dr. Alberto A. Sagüés		Leon Reiter
	Dr. Jeffrey J. Wong		

*Staff coordinator

Appendix D
U.S. Nuclear Waste Technical Review Board Strategic Plan for FY 1998-2003 (Updated) December 1, 1998

Statement of the Chairman

The U.S. Nuclear Waste Technical Review Board was established as an independent agency of the United States Government on December 22, 1987, in the Nuclear Waste Policy Amendments Act. Congress charged the Board with evaluating the technical and scientific validity of activities undertaken by the Secretary of Energy related to civilian radioactive waste management, including characterizing a site at Yucca Mountain, Nevada, for its suitability as the location of a permanent repository for civilian spent nuclear fuel and high-level radioactive waste and packaging and transporting such waste.

In creating the Board, Congress recognized that an unbiased technical and scientific evaluation of the credibility of site-evaluation and other waste-management activities would be crucial to public acceptance of any approach for disposing of high-level radioactive waste. The Board takes very seriously its role as the main source of ongoing technical and scientific review of the Department of Energy's civilian radioactive waste management program. The Board strives to provide Congress and the Secretary of Energy with timely, independent, and credible technical and scientific program evaluations and recommendations achieved through peer review of the highest quality. The Board's technical and scientific findings and recommendations are included in reports that are submitted at least twice each year to the Secretary of Energy and the Congress. The Board can make recommendations but cannot compel the Department of Energy to comply.

The attached strategic plan includes the Board's goals and objectives for 1998 through 2003. These years will be critical to the success of waste management initiatives in the United States. Because many critical activities will be undertaken throughout this period, we believe that the Board's ongoing review of these efforts will be especially important.

On behalf of the Board,
Jared L. Cohon, Chairman

Mission

The Board's mission, established in the Nuclear Waste Policy Amendments Act of 1987 (Public Law 100-203), is to "evaluate the technical and scientific validity of activities undertaken by the Secretary of Energy, including site-characterization activities; and activities related to the packaging or transportation of high-level radioactive waste and spent nuclear fuel."

Vision

To make a unique and essential contribution to the success of the nation's efforts in the safe disposal of spent nuclear fuel and high-level radioactive waste by providing ongoing technical and scientific peer review of the highest quality.

Values

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

- The Board's practices and procedures are open and conducted so that its integrity and objectivity are above reproach.

- The Board's findings and recommendations are technically and scientifically sound and based on the best available technical analysis and information.

- The Board communicates its findings and recommendations clearly and in a timely manner that is most beneficial to Congress, the Department of Energy (DOE), and the public.

General Goals and Objectives

The overarching goal for national radioactive waste management established by Congress is to ensure that civilian spent nuclear fuel and high-level radioactive waste are safely packaged, transported, and disposed of in a permanent repository at a suitable site. The Administration, state and local governments, and the public all have important parts to play in achieving a safe waste-management program. Federal agencies with important, often cross-cutting, roles include the DOE, the Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA), the Department of Transportation (DOT), the United States Geological Survey (USGS), and the Board. (See discussion under "Key External Factors.")

NWTRB General Goals

As a key contributor to this national waste-management effort, the Board has established two general goals:

- Help ensure that site-characterization activities undertaken at Yucca Mountain, Nevada, establish a sound technical basis for an eventual decision concerning the suitability and licensability of a permanent repository for the disposal of commercial spent fuel and high-level radioactive waste.

- Convey effectively and in a timely manner technical and scientific findings and recommendations that can be used in decision-making related to the management of spent fuel and high-level radioactive waste.

Objectives

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

Site Characterization

- Determine the relative importance of the hydrology, radionuclide transport, and other natural processes that establish the foundation for assessing repository performance. Board members will focus their evaluation on the methodologies used (e.g., selection of data, elicitation of expert judgment, and treatment of uncertainties) and on integration of basic science and engineering in the total system performance assessment (TSPA).

- Determine the appropriate program emphasis on repository design activities, plans for repository construction and operation, engineered-barrier design activities, supporting testing activities, and the source-term and other process models that support an assessment of repository performance.

- Identify key environmental monitoring activities at Yucca Mountain required for preparing an environmental impact statement for the site, evaluate regulations applicable to the program and potential effects of regulatory changes on the program, and monitor the adequacy of the program's quality assurance programs.

- Encourage the DOE to address concerns of the public related to the scientific and technical validity of site-characterization activities.

Transportation and Packaging

- Ensure the accuracy of analyses, methods, and major assumptions used by the DOE and other federal agencies in estimating health and safety risks associated with transporting spent fuel. Assess the reasonableness of the approaches and the assumptions embodied in the analyses.

- Determine the adequacy of plans and requirements for the transportation infrastructure to move significant amounts of spent fuel from individual reactor sites to a DOE storage or disposal site. Compare these requirements with current transportation capabilities, and determine the overall effort needed to bring about a large-scale transportation capability.

- Ensure that the DOE adequately addresses public safety concerns and plans for enhancing safety capabilities along the transportation corridors. This includes activities related to planning and coordination (e.g., route selection), accident prevention (e.g., improved inspections and enforcement), and emergency response.

Achieving the Goals and Objectives

The Board was granted significant investigatory powers by Congress in the Nuclear Waste Policy Amendments Act of 1987. In accordance with the Act, the Board may hold such hearings, sit and act at such times and places, take such testimony, and receive such evidence as it considers appropriate. Subject to existing law, the DOE is directed 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, by providing this access, Congress expected that the Board would review and comment on DOE decisions, plans, and actions as they occurred, not after the fact. The Board believes that it has adequate powers under current law to achieve its goals and objectives.

The Board uses the powers granted to it by the Congress to review the scientific and technical adequacy of the DOE's work. Much of the Board's information gathering is done at meetings, open to the public, where the DOE, its contractors, and other parties make formal presentations of technical information. To help achieve its goals and objectives, the Board has organized itself into five panels to address a variety of critical issues. The full Board meets three or four times each year, and each panel typically meets at least once a year. The Board also gathers information through field trips to the Yucca Mountain site, visits to contractor laboratories and facilities, and informal meetings with individuals working on the project. Although the Board's information-gathering activities are carried out primarily for the Board's benefit, they have the collateral benefit of promoting communication and integration of technical information within the DOE's program and communication with interested parties outside the program.

Analyses of the information gathered by the Board are carried out by its members, the Board's professional staff, and consultants hired to supplement the expertise of the Board and the staff. The Board evaluates whether the DOE's work is of high quality and whether it is focused correctly to achieve higher-level program objectives. The Board also evaluates the processes used by the DOE to reach decisions, especially for assigning priorities to activities and evaluating the results of studies. In the years ahead, assessing the viability of the Yucca Mountain site and then determining whether the site is suitable for development as a repository are major decisions facing the program. The Board expects to review the decision processes, as well as the database of technical information used by the DOE in making these decisions.

The Board formally reports the results of its reviews at least twice each year to Congress and the Secretary of Energy. Additional informal communication occurs as needed. All such communications are available to the public either by request or on the Board's Web site at www.nwtrb.gov.

The Board has evaluated its data processing needs and has recently updated its computer hardware and software to achieve its goals and objectives. The Board's data system currently includes no mission-critical or legacy software that will be affected by the Year 2000 changeover. The Board also plans to ensure that all workstations and the network operating system are Year 2000 compliant and will upgrade hardware and software as needed.

Cross-Cutting Functions

As noted under "Goals and Objectives," a number of entities and agencies share responsibility for the ultimate national goal established by Congress of ensuring that civilian spent fuel and high-level radioactive waste are safely packaged, transported, and disposed of in a permanent repository at a suitable site. Although there may be cross-cutting areas of interest, the Board's role is different from those of others involved in managing high-level radioactive waste. For example:

- **Congress and the Administration, including the Secretary of Energy**, make policy decisions about what the national goals will be and how they will be implemented. *The Board's only role in this process is to provide policy makers with unbiased and credible technical and scientific analyses and information.*

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

- **Other federal agencies** that have roles in achieving a safe waste management program include the DOE, the NRC, the EPA, the DOT, and the USGS. The DOE and its contractors are responsible for developing and implementing the waste management system and planning and conducting research activities related to disposal, packaging, and transportation of spent fuel and high-level radioactive waste. The NRC is the regulatory body authorized to license the construction and operation of the repository to ensure protection of public health and safety and the environment. The EPA is the agency given the responsibility to issue health-based safety standards. The DOT will be involved extensively in planning and regulating the transportation of waste, either to a repository or to a storage facility. The USGS participates in site-characterization activities at the Yucca Mountain site. *The Board's role is unique among these entities: To provide ongoing, independent peer review and oversight of the technical and scientific validity of the Secretary of Energy's activities related to civilian radioactive waste management, including site-characterization and packaging and transportation of spent fuel and radioactive high-level waste, and to communicate its findings and recommendations to Congress and the Secretary.*

The Board's evaluation of the technical and scientific validity of the Secretary's activities related to civilian radioactive waste management complements and enhances the work of other entities involved in achieving the national goal.

Key External Factors

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

- **The Board has no implementing authority.** Therefore, the DOE is under no obligation to accept any of the Board's recommendations. To increase its effectiveness, the Board has developed procedures for interacting with the DOE that enhance the Board's ability to conduct its independent review and communicate its findings and recommendations in a timely and effective way to Congress, the Secretary, DOE program managers, and the public. Written DOE responses to Board recommendations are transmitted to the Board and included in Board reports to Congress and the Secretary. If the DOE does not accept a Board recommendation, the Board's recourse is to advise Congress or reiterate its recommendation to the DOE, or both.

- **Legislation could affect nuclear waste policy.** Although nuclear waste legislation was not passed by the 105th Congress, it may be taken up again in 1999. The effects of such legislation on the program or the Board's role are not currently known.

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.

Program Evaluation

The Board will conduct an annual review of its actions in achieving its performance goals from the previous year. In evaluating its performance, the Board will consider (1) whether the reviews, evaluations, and other activities included in its performance goals have been completed, (2) whether the results of reviews, evaluations, and other activities undertaken under the auspices of program goals have been communicated in a timely, understandable, and appropriate way to the Secretary of Energy and Congress, and (3) whether the recommendations made by the Board had a positive effect on the program.

The Board believes that it is important to evaluate its effectiveness on the basis of programmatic results as opposed to "output" (e.g., reports, letters, recommendations). It should be noted, however, that because the Board has no implementing authority, it cannot compel the DOE to comply with its recommendations. Therefore, the judgment of whether a specific recommendation had a positive outcome may, in some cases, be somewhat subjective. To help balance the evaluation, the Board will seek comments from Congress, the Secretary of Energy, and the public on the effectiveness of its recommendations.

The Board will use its evaluation of its own performance from the current year, together with its assessment of current or potential key issues of concern related to the civilian radioactive waste management program, to establish its annual performance goals and develop its budget request for the next fiscal year. The results of the Board's performance evaluation, together with the Board's findings and recommendations related to the civilian radioactive waste management program, will be used to evaluate and, if necessary, to revise the Board's overall goals and objectives and will be included in the Board's annual summary report to Congress and the Secretary of Energy.

Congressional and Stakeholder Consultations

In developing its strategic plan for 1998-2003, the Board consulted with the Office of Management and Budget, the DOE, congressional staff, and members of the public. The Board solicited public comment and presented its strategic plan at a session held expressly for this purpose during its meeting in Armagosa Valley, Nevada, on January 20, 1998. In addition, the Board made a copy of the plan available on its Web site. A copy of the plan also has been provided to the NRC and to representatives of state and local governments. The Board plans to continue the consultation process throughout fiscal year 1998 and, on the basis of comments received, will submit a revised strategic plan by September 30, 1998.

Appendix E
U.S. Nuclear Waste Technical Review Board FY 1999 Performance Plan

FISCAL YEAR 1999 PERFORMANCE OBJECTIVES

As stated in the Board's 1998 - 2003 strategic plan, the overarching goal established by Congress for national radioactive waste management is to ensure that civilian spent nuclear fuel and high-level radioactive waste are safely packaged, transported to, and disposed of in a permanent repository at a suitable site. The Board's general goals are to (1) help ensure that site-characterization activities undertaken at Yucca Mountain, Nevada, provide a sound technical basis for an eventual decision concerning the suitability and licensability of a permanent repository for the disposal of commercial spent fuel and high-level radioactive waste and (2) to convey effectively and in a timely manner technical and scientific findings and recommendations that can be used to inform decision-making related to the management of spent fuel and high-level radioactive waste.

The Board developed its fiscal year 1999 performance objectives based on the general objectives in the strategic plan for site characterization and transportation and packaging. The aim is to ensure that the activities undertaken by the Board in fiscal year 1999 completely support the Board's long-term goals and objectives.

Site Characterization Performance Objectives

- Determine what the DOE's viability assessment can and cannot tell us about further activities needed to determine the suitability of the Yucca Mountain site, and ascertain the extent to which the repository and engineered barrier designs at the time of the viability assessment are likely to support decisions about the suitability of the site.

- Determine the strengths and weaknesses of TSPA-VA, and how they could influence the conclusions to be drawn from the viability assessment.

- Identify and evaluate the technical issues required to make a technically-supportable site-suitability decision. Increase the Board's understanding of the natural processes at work at the Yucca Mountain site by recommending additional studies needed, with particular attention to estimates of infiltration rates and identification of fast pathways for water flow.

- Explore the relationship between science and engineering in the DOE program, especially the way results from site-characterization studies do or do not influence design of the engineered barrier system.

- Monitor the results of ongoing thermal tests, and evaluate DOE plans for using the test results to support models of the thermally disturbed region near a repository.

- Evaluate the DOE's use of risk assessment and quantification of uncertainty and determine whether it is being used appropriately.

- Review the technical basis for the environmental impact statement being prepared for the Yucca Mountain site, issues to be addressed, and the validity of the data used to project potential environmental effects. Advise the DOE and Congress of any weaknesses or short- comings found.

- Monitor progress being made on the environmental radiation protection standards for a Yucca Mountain repository to be developed by the U.S. Environmental Protection Agency and the implementing regulations to be developed by the U.S. Nuclear Regulatory Commission. Advise the DOE and the Congress of the technical implications (e.g., cost, ability to demonstrate compliance of the standards and regulations).

Transportation and Packaging Performance Objectives

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

- Determine how the design of the waste package (for disposal) at the time of the viability assessment is likely to influence decisions about the suitability of the site.

Performance Measurement

In measuring its fiscal year 1999 performance, the Board will consider (1) whether the reviews, evaluations, and other activities included in its performance objectives have been completed, (2) whether the results of reviews, evaluations and other activities undertaken under the auspices of program goals have been communicated in a timely, understandable, and appropriate way to the Secretary of Energy and Congress, and most importantly, (3) whether the recommendations made by the Board had a positive effect on the DOE program.

While the Board believes it is important to measure its effectiveness based on programmatic results or "outcomes" as opposed to "outputs" (e.g., reports, letters, recommendations), it is important to note that because the Board has no implementing authority, it cannot compel the DOE to comply with its recommendations. Therefore, the judgment of whether a specific recommendation had a positive outcome may, in some cases, be somewhat subjective, and makes establishing specific performance measures very difficult.

In addition, the results of many of the Board's recommendations may not be known until the licensing process begins in 2002. To supplement its own evaluation, the Board will seek comments from Congress, the Secretary of Energy, and the public on the timeliness, clarity, and effectiveness of its recommendations and reports.

The Board will use its evaluation of its own performance from the current year, together with its assessment of current or potential key issues of concern related to the civilian radioactive program, to establish its annual performance objectives and develop its budget request for the next fiscal year. The results of the Board's performance evaluation, together with the Board's findings and recommendations related to the civilian radioactive waste management program, will be used to evaluate and, if necessary, to revise the Board's overall goals and objectives and will be included in the Board's annual summary report to Congress and the Secretary.

Board Operations

The Board consists of 11 presidentially-appointed members who serve on a part-time basis, are eminent in a field of science or engineering, including environmental sciences, and are appointed solely on the basis of distinguished service. Because of the comprehensive nature of the program and the part-time availability of the members, Congress authorized the Board to maintain a professional staff of 10 full-time employees. The professional staff support the Board's comprehensive review of the DOE program. In addition to the members and professional staff, the Board maintains a small administrative staff to support its activities.

The full Board meets three or four times each year, and each panel typically meets at least once per year. The Board also gathers information through field trips to the Yucca Mountain site, visits to contractor laboratories and facilities, and informal meetings with individuals working on the project. Based on the information gathered throughout the year, the Board issues its findings in letters and reports.

Resource Allocation for Fiscal Year 1999

The Board's budget request for fiscal year 1999 is $2,950,000. Of that total, $1,925,000 will be allocated for activities related to site characterization. These activities will include the salaries and benefits of the Board's members and professional staff. They will also include the cost of conducting meetings, field trips, and other fact-finding activities, and the production of reports related to these activities. $545,000 will be allocated for transportation and packaging activities, which will include activities similar to those used to evaluate site-characterization efforts. The balance of $480,000 will be allocated for the administrative support of the Board's activities in fiscal year 1999.

The Board has made great progress in reducing its administrative support costs. By implementing teaming, reengineering administrative processes, and using technology wherever possible, the Board has reduced its administrative support staff by 50% (from 10 FTE to 5 FTE) in the last two fiscal years. The Board relocated in 1997 reducing its rent by 35%. The Board will continue to strive to reduce administrative support costs and allocate as many resources as possible toward its activities related to the general goals and objectives in the strategic plan.

Appendix G
Nuclear Waste Technical Review Board Publications

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

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.

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 perspectives on DOE progress, the state of Nevada's role, the project's regulatory framework, the nuclear waste negotiator, other oversight agencies, and the Board's future plans.

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.

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.

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.

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 management program in five countries, specifically those areas that might be applicable to the U.S. program, including program size and cost, utility responsibilities, repository construction schedules, and alternative approaches to licensing. Appendix F provides background on the Finnish and Swiss programs.

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 organization and management. These recommendations should be implemented without slowing the progress of site-characterization activities at Yucca Mountain.

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.

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 Department of Energy'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 Office of Civilian Radioactive Waste Management'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.

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.

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 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.

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 Department of Energy'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 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 Department of Energy 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.

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: January to December 1996. 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.

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).

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.

Review of Material on Hydrothermal Activity. July 24, 1998

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

Report to the U.S. Congress and The Secretary of Energy. 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 Department of Energy (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

Appendix F
Communications Between the Board and the OCRWM

In addition to published reports, the Board periodically writes letters to the Director of the DOE's Office of Civilian Radioactive Waste Management (OCRWM). These letters typically provide the OCRWM with the Board's views on specific technical areas sooner than do Board reports. The letters are posted on the Board's Web site after they have been sent to the OCRWM. For archival purposes, the three letters written during calendar year 1998 are reproduced here

The OCRWM typically responds to the Board's reports and letters, indicating its plans to respond to the Board's recommendations. Included here are the OCRWM's responses received by the Board during calendar year 1998. Inclusion of these responses does not imply the Board's concurrence.

- Letter from Chairman Jared L. Cohon to Lake H. Barrett, Acting Director, OCRWM; January 12, 1998. Subject: Board comments on October 1997 Board meeting and Board panel meetings and field trips held in October, November, and December 1997.

- Letter from Chairman Jared L. Cohon to Lake H. Barrett, Acting Director, OCRWM; April 7, 1998. Subject: Board comments on January 1998 Board meeting.

- Letter from Chairman Jared L. Cohon to Lake H. Barrett, Acting Director, OCRWM; July 30, 1998. Subject: Board comments on June 1998 Board meeting.

- Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; May 11, 1998. Subject: Response to January 12, 1998 Board letter.

- Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; May 19, 1998. Subject: Response to the Board's *Fifteenth Report*.

- Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; June 15, 1998. Subject: Response to April 7, 1998 Board letter.

- Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; September 8, 1998. Subject: Response to the Board's *Report to The U.S. Congress and The Secretary of Energy: 1997 Findings and Recommendations*.

- Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; October 19, 1998. Subject: Response to July 30, 1998 Board letter.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

January 12, 1998

Mr. Lake H. Barrett
Acting Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
RW-2/5A-085
Washington, DC 20585

Dear Mr. Barrett:

The Nuclear Waste Technical Review Board (Board) would like to thank you and your staff and contractors for participating in several Board events during the last three months. During that time, the Board held one full Board meeting, three panel meetings, and one field trip. In my opening remarks at the October Board meeting, I indicated that the Board would provide feedback to the Office of Civilian Radioactive Waste Management (OCRWM) after each of its meetings. The comments below are offered in that context.

Comments from the Board's October Meeting

The Board's fall meeting focused on designs of the repository and the waste package that will be included in the viability assessment (VA) of the Yucca Mountain site.

1. Alternative Designs. The design options discussed at the Board meeting appear to involve "add-ons" (e.g., drip shields) to the existing reference designs. The reference waste package design and the reference repository subsurface design seem to have changed very little over the years, even though data obtained from the exploratory studies facility (ESF) in the last two years indicate that the repository may be "wetter" than originally thought. Although the discovery of possible fast pathways for infiltrating precipitation has triggered examination of other design options, these options have not been incorporated in the reference designs.

In addition to evaluation of design add-ons, we believe the program would benefit from serious study of other repository and waste package designs that represent alternatives to the reference designs. Examples of design concepts that could be explored include some or all of the following: (1) a design in which the boiling fronts do not coalesce between drifts; (2) a design permitting humans wearing typical work clothing to safely enter emplacement drifts containing preclosure or postclosure ventilation or both, based on natural convection, forced convection, or a combination of both; and (5) a waste package design using two corrosion-resistant materials. Each concept for repository design should address all thermal constraints *and* accommodate at least 70,000 metric tons in the current repository footprint.

We realize that these ideas—and many others—are not new to the program. We are not aware, however, that they have received a thorough and objective evaluation that considers new hydrologic data obtained from the site. The Board believes that including alternative repository and waste package designs in the VA is a good idea, although it is clear that alternatives will not be as fully developed as the reference case. In particular, we think it is vital that the VA that is conveyed to Congress includes alternatives that show an array of cost-versus-performance choices.

2. Remote operations and ventilation. We understand that the current design basis assumes that humans will not be allowed in emplacement drifts containing one or more waste packages and that all operations of emplacement, retrieval, monitoring, and maintenance in such drifts will be totally automatic. Although this design basis appears to be unprecedented for underground operations having durations of up to a century, temperatures ranging from ambient to several hundred degrees, and severe radiation fields, it is not technically infeasible. What is clear, however, is that a technical development program will be needed to demonstrate and debug the equipment and the control and communication systems necessary for implementing the design basis for underground operations. The costs of and the potential for problems with these remote systems should be recognized in the VA.

Given the current size and number of exhaust shafts, the rationale for including the north-south exhaust drift that runs underneath the repository is unclear. Assuming that the east, south, west, and north main drifts have the same diameter, it appears that the same amount of ventilation could be accomplished with or without the north-south exhaust drift. Also unclear is why the current design calls for the exhaust drift to be constructed below rather than above the repository. In any case, the repository design should take advantage of the density difference between the warm exhaust air and the cooler intake air to maximize preclosure heat removal by natural convection.

3. Galvanic protection and waste package fabrication. Presentations made at the meeting raise questions about whether the performance assessment and engineering design groups are using the same approach to galvanic protection for the base case of the VA. Specifically, it seems that (1) the performance assessment group intends giving little or no performance credit for galvanic protection in its VA base case and (2) the engineering designers assume that the waste package design for the VA base case *will* provide galvanic protection. Recently, both the Waste Package Expert Elicitation Project and the Total System Performance Assessment (TSPA) Peer Review Panel presented opinions that galvanic protection is likely to provide no more than several hundred years of additional protection. It is unlikely that data will be obtained and analyzed between now and the VA delivery date that will either refute or confirm these opinions with any degree of confidence. Therefore, we believe that a prudent course of action would be to omit galvanic protection entirely for the base case of the VA or to rely on it for no more than a few hundred years. At the same time, we realize that galvanic protection has significant potential, and we encourage continued experimental work in the area and sensitivity studies in VA cases other than the base case.

The Board agrees with information presented at the October Board meeting indicating that shrinkfitting is technically feasible and that it is not a costly operation in itself. However, unless the parts to be mated are machined with a high degree of precision, the residual stresses from the shrinkfitting will be variable. Concerns have been expressed that the residual stresses left from shrinkfitting could exacerbate corrosion of the waste package or cause other unknown stress-related problems. As we understand it, the principal, perhaps the only, justification for shrinkfitting is to promote galvanic protection. Because the additional performance that galvanic protection will provide is considered limited, we question whether shrinkfitting should be included in the VA.

In addition, the Board has long been concerned, as have people within the program, about the inspectability of final closure welds (the welds made after waste has been placed in the package) of both the inner and the outer shells. We believe that this issue is completely resolvable and that its resolution may be postponed to well beyond the delivery date of the VA. However, we think it important to point out that the shrinkfit design makes the final closure welds, particularly those of the inner shells, difficult to inspect.

4. *Independent cost estimate.* The Board was pleased to learn that an independent cost estimate (ICE) of the mined geologic disposal system (MGDS) will be performed for the VA by a major U.S. engineering-construction firm. The Board is particularly interested in techniques, allowances, and contingencies the ICE provider will use to show technology-development costs (e.g., manufacture of prototype waste packages, development and testing of robotics systems for remote emplacement and monitoring) and to accommodate current technical uncertainties (e.g., alignment of emplacement drifts). We also would like to know how the ICE will address potential enhancements to the MGDS that are not part of the base case design. We believe that it is important for the Board to understand the approach being used for the ICE. We would appreciate receiving a copy of the statement of work from the contract with the ICE provider, as well as copies of task orders or other amendments to the statement of work as they are developed.

5. *ECRB and performance confirmation.* We thank you for sending the documentation for the planning effort for the enhanced characterization of the repository block (ECRB). We understand that some data from the ECRB will be available before the VA is delivered. We would like to know how the data could or would be used in the VA. Because data from the ECRB could be critical, we would appreciate your providing future ECRB plans and developments to the Board as they become available.

Comments from Board Panel Meetings and Field Trip

In addition to the Board's fall meeting, held on October 22-23, 1997, the Board sponsored three panel meetings and one field trip in the last 11 weeks. The Board's Panel on the Environment, Regulations, and Quality Assurance held a meeting on October 21 on the DOE's interim performance measure for a Yucca Mountain repository; the Board's Panel on the Waste Management System held a meeting on the safety of spent-fuel transportation on November 19-20; and the Board's Panel on the Repository held a meeting on December 17 on the disposal of highly enriched aluminum-clad spent fuel. On December 3-4, a number of Board members and staff took part in a field trip to Amargosa Valley, during which we were briefed on several biosphere issues and toured the ESF. We are providing some limited feedback from each of these activities.

First, we are concerned about the DOE's exclusion of children from the definition of the critical group in the interim performance measure. If the exclusion is viewed by others as an attempt to bias downward the dose estimates for a Yucca Mountain repository, the DOE's credibility could suffer. The DOE should include in the VA estimates of the likely doses for children as well as adults.

Second, despite the high degree of public concern about transportation of spent fuel and high-level waste, the DOE's recent efforts in the transportation area have been limited essentially to the privatization of much of the transportation function. The Board's view is that there may be difficulties in implementing this approach as it is now envisioned and that developing contingency plans would be prudent.

Third, several members of the Board had the opportunity to look over the drift-scale thermal test facility during their December 4 tour of the ESF. The Board is very pleased that drift-scale thermal testing has begun and considers the planning, design, construction, and start-up of the facility in less than two years a remarkable accomplishment. We share in the hope that the facility will provide valuable data for increasing understanding of the implications of various thermal loads for repository and waste package performance. The Board congratulates all involved on this well-integrated effort.

Finally, the OCRWM should carefully consider its technical bases for accepting highly enriched aluminum-clad spent fuel (essentially all of which is from domestic and foreign research reactors) for disposal in a repository at Yucca Mountain. Compared with commercial spent fuel, highly enriched aluminum-clad spent fuel is a waste form that degrades faster, leading to greater long-term doses on a ton-for-ton basis, and that may heighten concerns about criticality control.

To provide the rapid feedback we promised, we are furnishing the foregoing, which contains preliminary and formative thoughts. Accordingly, it seems inappropriate for the Board to request or expect a written response—although your informal reactions would be welcome. It is reasonable to expect that the views of many Board members and staff over the next few months will reflect the points articulated in this letter.

Thank you for your personal participation in our Board meetings and the participation of your staff and contractors. The Board hopes that this letter is helpful.

Sincerely,

Jared L. Cohon

Jared L. Cohon
Chairman

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
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April 7, 1998

Mr. Lake H. Barrett
Acting Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
1000 Independence Avenue, SW
RW-1
Washington, DC 20585

Dear Mr. Barrett:

On behalf of the Nuclear Waste Technical Review Board, I would like to thank you and your staff and contractors for participating in the Board's January 1998 meeting. In particular, we appreciate your response to the points raised in the Board's recent letter report to Congress and the Secretary of Energy and your effort to make yourself available throughout the entire public-comment session on the first day of the meeting.

This letter provides the Board's comments on the January meeting and reflects our ongoing effort to provide feedback to the Office of Civilian Radioactive Waste Management (OCRWM) after Board meetings. The Board's January meeting focused on site-characterization activities related to the saturated zone (SZ). The OCRWM also presented an overview of the status of the environmental impact statement (EIS) for the proposed repository and provided a brief update on thermal testing activities at the site.

Presentations on Characterization of the Saturated Zone

The Board was particularly interested in SZ site-characterization activities that have been completed and activities that are under way related to the SZ, including the hydraulic and tracer studies at the C-well complex, the geochemical and isotopic age-dating data on the SZ water, the regional studies of discharge areas, the influences of climate and population changes, and the effects of increased groundwater withdrawals. The Board looks forward to receiving updates on the data obtained from these ongoing studies and learning more about the detailed plans for the second C-well-type complex for larger-scale hydraulic and tracer testing of the SZ, the regional geochemical studies, and the proposed well(s) for investigating the large hydraulic gradient north of the proposed repository. (The Board also will be interested in receiving progress reports on the studies of transport in the unsaturated zone being conducted at Busted Butte.) The Board believes that a review of these proposed test plans by an outside technical panel like the one convened for the expert elicitation on the SZ would be beneficial for the project.

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These studies should provide much useful information. However, it is clear that answering questions about the effects of molecular diffusion, hydrodynamic dispersion, and sorption on dilution in the SZ will be difficult. The most direct way to obtain answers to these questions would be to perform large-scale tracer tests. However, such tests may be impractical because it could take many years for the tracers to travel from Yucca Mountain to the monitoring wells. Although some data may be obtained from the proposed SZ well complex, which will be located south of the proposed repository, uncertainties will remain about the dilution that the SZ can provide.

Expert Elicitation on the Saturated Zone

The Board is pleased that the DOE convened an expert panel for quantifying key uncertainties in the SZ studies. Several of the panel members expressed doubt about whether a large amount of dilution could occur in the SZ. Those panel members noted that present modeling of the dilution processes in the total system performance assessment for the viability assessment (TSPA-VA) assumes an optimistic and, indeed, unsubstantiated amount of mixing of waters and thus an unsubstantiated increase in dilution. The Board is deeply concerned that such a high mixing factor and so few data to back up that assumption could raise challenges in the future. The Board believes that the DOE should use dispersion-dilution models in the reference case TSPA-VA that are more in accord with the expert opinions.

The Board is pleased with the program's progress in integrating available data and expert opinions into modeling of the *unsaturated* zone. However, we concluded from the presentations on the SZ modeling that far more model integration and reality checking using data obtained from the site need to occur before these models can be viewed as credible and robust. It appears that the researchers involved in modeling the SZ are using several hydrologic models that may not be consistent with each other and that very few data are available to develop, bound, and validate models of the SZ.

Presentation by the State of Nevada's Contractor

A contractor for the state of Nevada, Linda Lehman, presented an interesting conceptual model of SZ flow. Her model, which is based on temperature data and was developed using uncomplicated modeling techniques, correlates SZ flow with fault zones and other features of the site. The OCRWM should carefully review her findings, if it has not already done so.

The EIS

The Board believes that the session outlining the OCRWM's plans for preparing an EIS provided the opportunity for a useful exchange of views and information. We would like to thank you for ensuring that the Board will have access to all requested information. The Board noted that the EIS presentation did not include essential analyses of alternative designs for the repository and waste package that should normally be part of any National Environmental Policy Act process. Without these analyses, the OCRWM will have difficulty making its case that all "reasonable" alternatives have been examined. The Board believes that ensuring that the EIS is technically defensible and tightly reasoned should remain a high program priority.

Thermal Testing Update

Significant uncertainty persists about the thermo-hydrologic response of Yucca Mountain to high temperatures and the resulting waste package environment during a period of high temperatures. Thus, progress on the thermal tests remains absolutely vital to site characterization. The Board believes that the single-heater and drift-scale heater tests have been well planned and executed and that the results are being analyzed appropriately.

To provide feedback in a time frame that will be useful to the OCRWM, we are furnishing the foregoing preliminary and formative thoughts. Accordingly, it seems inappropriate for the Board to request or expect a written response—although your informal reactions would be welcome. We thank you again for the time you spent at the meeting and for your attention to the comments in this letter.

Sincerely,

Jared L. Cohon

Jared L. Cohon
Chairman

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

July 30, 1998

Mr. Lake Barrett
Acting Director
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
Washington, DC 20585

Dear Mr. Barrett:

I am pleased to forward the Board's comments on the June 1998 meeting, which all the members felt was very productive and stimulating. The Board was pleased that you were able to join us for the field trip to Yucca Mountain and the Nevada Test Site and that you attended the entire meeting. Bob Andrew's presentation was even better than the one he gave to our Panel on Performance Assessment in April. Holly Dockery's demonstration slide show is a promising approach for making total system performance assessment (TSPA) more transparent. Claudia Newbury also deserves special credit for coordinating the Office of Civilian Radioactive Waste Management's (OCRWM) participation and for planning the informative field trip.

We have some specific impressions about the presentations, as well as some thoughts on issues that arose during the meeting.

Total System Performance Assessment. Bob Andrew's latest presentation shows that the OCRWM continues to refine its thinking about the TSPA being developed for the viability assessment. This latest analysis leaves the clear impression that the projected performance of the repository system is highly dependent on the corrosion resistance of the waste package.

Any set of calculations, however, is only as valid as the underlying assumptions, models, and data used. For example, the uncertainty analyses were highly dependent on the *assigned* uncertainty. Important issues, such as cladding performance, did not appear important only because they were assigned a low uncertainty. Also not evident was whether the correlation between parameters, such as infiltration and seepage fraction, had been taken fully into account.

The Board recognizes the need to make judgments in any analysis. However, these judgments and their bases need to be stated explicitly and clearly. In 1997, the Board provided a number of suggestions on how TSPA could meet this and other challenges. These suggestions appear in the Board report on its 1996 activities (March, 1997) and in a letter sent to April Gil (April 15, 1997) in response to the OCRWM's request for comments on proposed revisions to 10 CFR 960. In that report and letter, the Board laid out some suggestions on how to prepare a

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technically persuasive and robust performance assessment. We believe that the OCRWM's assessments should increasingly incorporate those ideas.

License Application Plan. The Board was pleased with Jack Bailey's presentation because it showed the beginnings of a systematic effort to assess technical priorities. He laid the groundwork for a methodology to identify the critical research that needs to be conducted before a site recommendation and the possible submittal of a license application to the Nuclear Regulatory Commission. This information is helpful. The Board believes, however, that the OCRWM needs to define key measures of knowledge, uncertainty, and value more rigorously. It also needs to make its decision-aiding methodology more transparent.

Determination of Importance Evaluation (DIE) on the East-West Crossing. The Board reviewed the latest revision to the DIE. It believes that the OCRWM has not addressed adequately mountain-scale coupled thermal, hydrologic, and mechanical (THM) processes. The Board has not seen any rigorous THM analysis of whether the east-west crossing will affect long-term repository performance or will foreclose repository design alternatives. Nor has the Board seen evidence that efforts are planned in this area. The Board, once again, urges the DOE to carry out a systematic study of the potential effect of the east-west crossing.

Observations from the Field Trip. The Board was impressed with the speed at which the Busted Butte experiment was conceived, designed, and constructed. Data from this effort could reduce some of the significant uncertainties in understanding how radionuclides are transported in the unsaturated zone matrix below the repository horizon. The data also could strengthen the conceptual foundation of the performance assessments. If the project has not already done so, it should examine work on plutonium and colloidal transport that was carried out at Hanford as part of the Basalt Waste Isolation Plant (BWIP).

The Board believes that tunnels at the Nevada Test Site, such as the N-tunnel, could provide information on the percolation flux above the repository horizon in the unsaturated zone under conditions of higher precipitation. The data might be quite useful in modeling repository performance under pluvial conditions.

Environmental Impact Statement. The Board's concerns about the alternatives to be analyzed in the draft environmental impact statement for the repository were not reduced by Wendy Dixon's presentation. Two conclusionary statements were made in the presentation to the effect that the implementing alternatives "bracket" the relevant environmental impacts. No technical basis was given for those statements despite the Board's specific request that all technical analyses dealing with the choice of alternatives be presented. We look forward to being provided with additional information on this issue.

Alternative Repository Designs. Michael Voegele presented a plan for examining alternative configurations before selecting a repository design that the OCRWM will carry forward to site recommendation and license application. The Board is pleased that the OCRWM has made this commitment. The Board is concerned, however, that, according to budget figures available to it and the current level of project activities, this examination may not be as comprehensive as the Board believes it ought to be and that it might not be completed in time to play a meaningful role in the May 1999 design decision. The Board reemphasizes the importance it attaches to a full-scale systems engineering analysis. Such an analysis should evaluate alternative system concepts incorporating various combinations of repository and waste package features, including, but not limited to, restricting peak temperature to below 80° C, long-term ventilation, and the location of the corrosion-resistant layer in the waste package design. Again, if the project has not already done so, it should examine work in this area done at the BWIP.

In closing, I congratulate you and your staff for putting together a meeting containing such a high level of technical content. The exchanges between the Board and project participants were enlightening and significant. Again, I thank you.

Sincerely,

Jared L. Cohon

Jared L. Cohon
Chairman

jlc045a

Department of Energy
Washington, DC 20585
May 11, 1998

MAY 14 1998

Dr. Jared L. Cohon
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, Virginia 22201-3367

Dear Dr. Cohon:

The Department of Energy appreciates the Nuclear Waste Technical Review Board's new initiative in providing preliminary comments following its meetings. This timely feedback will help the Department manage the ongoing work by providing early insights into the Board's perspective on technical issues. To ensure that important issues are being addressed appropriately, the Department would like to provide the Board with responses to its comments. The enclosure is our response to your letter of January 12, 1998, with the Board's comments from the October 1997 meeting, three panel meetings, and one field trip.

We continue to value the Board's feedback as we pursue completion of the viability assessment and the future work beyond. If you have any questions, please contact me at (202) 586-6842.

Sincerely,

Lake H. Barrett, Acting Director
Office of Civilian Radioactive
Waste Management

Enclosure

DOE Response to Comments of the Nuclear Waste Technical Review Board from its October 1997 Meeting

Alternative Designs

As explained at the Board's meeting in Amargosa Valley in January 1998, the Department is preserving flexibility to ensure that design alternatives identified in the viability assessment (VA) for the engineered barriers, as well as those that emerge with advancements in technology, can be accommodated in the repository development process. The Department agrees that the repository and waste package designs should not be prematurely fixed and that other potential alternatives, such as those suggested by the Board, should not be foreclosed. As pointed out by the Board, design alternatives should be reevaluated as relevant new data become available. We expect that design alternatives will continue to be evaluated throughout repository licensing, construction, and operation. As modifications to the reference design and concept of operations are proposed and analyzed, the Department will share those with the Board.

For the VA, the Department is addressing the feasibility of geologic disposal at Yucca Mountain by focusing on a reference design concept which is only one of a number of workable concepts. This reference design and an assessment of its performance provide the frame of reference necessary to evaluate the sufficiency of site characterization data and analyses. The VA will include qualitative analyses of design alternatives and plans for further evaluation of alternatives before submittal of the license application. The VA will not include cost estimates or performance assessments for the design alternatives.

Remote Operations and Ventilation

The Department agrees with the Board on the need to develop and demonstrate systems for remote operations in the repository. However, the detailed designs of these systems are not critical to the VA, because the main components of the subsurface waste transportation and emplacement systems use existing technology. No additional research needs have been identified. The VA design description will contain discussion of the remote systems, including limited information on failure modes and responses. The detailed design work will be undertaken at the appropriate time after the VA and shared with the Board. As suggested by the Board, the estimated costs of such systems, including contingencies for potential problems, will be included in the VA.

The Board questioned the need for and location of the north-south central main exhaust drift and suggested taking advantage of natural convection. In the reference design, air flows from the east and west mains toward the center of the block, enters the central main exhaust drift, and is carried in the exhaust drift to the exhaust shaft. The use of a central exhaust allows both the east and west mains to be used for intake, or fresh air mains. The benefit of the central main exhaust is that it reduces the length of the emplacement drifts that needs to be ventilated by a single intake from a maximum of approximately 1,200 meters to about 600 meters. This reduction in length shortens the maximum travel and communications distance between the remote equipment and the drift entrance, and also enables faster "cooldown" of drifts where wastes have been emplaced, if re-entry is required.

The rationale for the location of the central main exhaust drift is based on post-closure water movement. One design objective is to avoid placing any non-emplacement drift in a position such that, if water enters that drift, it could pass directly through a man-made opening into an waste emplacement area. Other drifts above the emplacement areas, such as performance confirmation drifts, are not directly connected with man-made openings to the underlying emplacement area and are laid out to have a consistent gradient which will promote gravity drainage away from emplacement areas. The central main exhaust drift must, because of its function, be directly connected to the emplacement drifts. For this reason, it was placed below the emplacement area.

Regarding the utilization of natural convection, the location of the central main exhaust above or below the emplacement block will have little impact on the magnitude of natural ventilation pressure developed by the repository system. The dominating factor in the determination of the natural ventilation pressure is the depth of the emplacement exhaust shaft. This shaft is over 400 meters deep, and it is the density of this column of warm air compared to a similar column of air with characteristics of the outside atmosphere which will determine the natural ventilation pressure. Whether the exhaust main is 10 meters below, or 10 meters above, the emplacement block will have no more than about a 5 percent impact on the magnitude of natural ventilation pressure.

Galvanic Protection and Waste Package Fabrication

The Department agrees with the Board that there are unresolved issues with demonstrating the value of galvanic protection. Accordingly, the Department considered the input received from our outside experts along with our testing information to determine the level of credit for galvanic protection defensible for the total system performance assessment (TSPA) for the VA. The decision has been made that credit for galvanic protection is not being included in the TSPA-VA base case calculation.

As the Board has noted, galvanic protection has significant potential. Therefore, the Department has initiated experiments that could provide the results needed to take credit for galvanic protection in the license application, if needed.

In completing TSPA-VA, the performance assessment staff are using a design baseline to ensure that the design assumptions in performance assessment are consistent with the engineering design assumptions. This formally controlled process is structured to avoid disconnects between engineering design and performance assessment.

The concerns expressed by the Board on residual stress from shrink-fitting of the two cylinders constituting the inner and outer waste package barriers are understood and are being investigated. Shrink-fitting is being considered for ensuring that the two cylinders do not move relative to each other, in addition to its potential benefit for providing some galvanic protection of the inner barrier. Preliminary calculations of the additional stress imparted to the waste package barrier system as a result of shrink-fitting have shown that the stress is well below the level that would cause stress corrosion cracking in the inner barrier. Shrink-fitting is being further investigated during Fiscal Year 1998.

The Board's concerns on the inspectability of final closure welds will be fully addressed before selecting the final fabrication and welding processes. The inspection by ultrasonic testing of the inner barrier on the Fiscal Year 1997 waste package mock-up was successfully accomplished. The inspectability of the inner weld by remote ultrasonic testing will be further investigated during Fiscal Year 1998.

Independent Cost Estimate

The Department appreciates the Board's interest in the independent review of the cost estimate of repository construction, operation, and closure. The VA cost estimate is being externally reviewed by Foster Wheeler, a major U.S. engineering-construction company. Foster Wheeler's scope of work is limited to an evaluation of project cost estimating assumptions, methodologies, and bases of estimates associated with the VA base case design. The review includes examination of estimates relating to waste packages, surface and subsurface facilities, and performance confirmation, as well as related project development and evaluation costs. Foster Wheeler will be preparing individual assessments of these cost segments, as well as a summary report. Foster Wheeler initiated its review in October 1997 and is scheduled to complete all cost segment reviews by May 1998. The summary report, expected in June 1998, will address Foster Wheeler's findings on each VA cost estimate segment and its integration into the overall cost summary.

The Department provided the Board with the statement of work for Foster Wheeler on April 8, 1998.

Enhanced Characterization of the Repository Block and Performance Confirmation

We understand the Board's desire to see the data collected from the Enhanced Characterization of the Repository Block (ECRB) initiative included in the VA. Construction of the cross-drift will be completed about the time that the VA will be completed. We expect that observational data collected during the construction of the cross-drift will be included to the extent practicable. This data could include identification of faults that are exposed in the cross-drift and preliminary information on fracture distributions. It is not likely that there will be sufficient time to complete sample collection and analysis or in situ testing in the cross-drift prior to issuing the VA. The results of these investigations will be included in the site recommendation and license application. The Department will keep the Board informed on plans and developments for the ECRB and performance confirmation.

DOE Response to Comments of the Nuclear Waste Technical Review Board from its Panel Meetings and Field Trip

Definition of Critical Group

The Department recognizes the Board's concern regarding dose estimates to children. At this time, there are no Environmental Protection Agency (EPA), Nuclear Regulatory Commission (NRC), or Departmental radiation protection standards that specifically include children. Currently, regulatory practice is to estimate doses using physiological parameters developed by the International Commission on Radiological Protection, collectively known as the Reference Man. The dose conversion factors estimated based on the Reference Man have uncertainties that are comparable in magnitude to the uncertainties in exposure assessments and to the estimates of cancer risks.

For purposes of radiation protection, the Department concurs with EPA's and NRC's positions that the assumptions exemplified by the Reference Man adequately characterize the general public, and a detailed consideration of factors such as age and sex is generally not necessary. As the Board is aware, estimating doses to children and other age-specific groups is a complex task because of factors such as systemic biokinetic models, gastrointestinal uptake factors, organ masses and positions, and food consumption habits, all of which change as a person ages.

The Department will evaluate impacts to children in a technical report. The report will address the impacts to children and other age groups from a repository at Yucca Mountain. To estimate these impacts, the Department will use recently developed national and international guidance.

Contingency Plans for Transportation

The Department recognizes the public's concerns with the transportation of spent fuel. To identify and address potential difficulties in implementing our market-driven approach to transportation, the Department issued for comment a draft request for proposals in December 1996 and a revised draft in November 1997. In addition, the Department interacts regularly with a broad range of stakeholders on issues related to transportation. The Department will consider the input from these forums in developing its strategy for transportation and the need for contingency plans. In the meantime, we would welcome the Board's comments on the revised draft request for proposals.

Drift Scale Thermal Test Facility

The Department thanks the Board for its positive comments on the timely planning, design, and start up of the drift-scale thermal test.

Highly Enriched Aluminum-Clad Spent Fuel

The Department agrees with the Board that the effects on repository performance of accepting highly-enriched aluminum-clad spent fuel need careful consideration. The Department is addressing issues raised in your letter concerning long-term doses and criticality.

Although the aluminum-clad spent fuels degrade faster than zircalloy-clad commercial fuels, the burnup of the aluminum-clad spent fuel is less than the burnup of commercial fuels, leading to a lower source term for the long-term dose. Preliminary evaluations indicate that the relatively small amount of aluminum-clad spent fuel, with its smaller source term compared to the commercial fuel, does not have a significant impact on overall repository performance, even with the higher degradation rate.

The proposed design features and loading limits for the aluminum-clad spent fuel are expected to make criticality control for this fuel no greater a concern than for the commercial spent fuel.

The Department is developing acceptance criteria for disposal of Department-owned spent fuel, including the highly enriched aluminum-clad spent fuel, which will also address these waste form issues. We look forward to your review of these criteria.

Department of Energy

Washington, DC 20585

May 19, 1998

MAY 21 1998

Dr. Jared L. Cohon
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, Virginia 22201-3367

Dear Dr. Cohon:

This letter transmits the Department of Energy's response to the Nuclear Waste Technical Review Board's second report of 1997 to the U.S. Congress and the Secretary of Energy, also referred to as the Board's *Fifteenth Report*, that was issued on December 23, 1997. Our response to the Board's comments on several key issues is found in the enclosure.

The Department appreciates the Board's recognition of the considerable progress we have made in characterizing the Yucca Mountain site and our efforts to improve interactions between the Department and the Board. Additionally, we appreciate the Board's recognition of the well-integrated effort that resulted in the timely completion of the drift scale test facility and the initiation of important thermal tests. We look forward to continuing to receive the Board's evaluations as we pursue completion of the viability assessment. If you have any questions, please contact me at (202) 586-6842.

Sincerely,

Lake H. Barrett, Acting Director
Office of Civilian Radioactive
Waste Management

Enclosure

DOE Response to Comments on Several Key Issues by the Nuclear Waste Technical Review Board in its Second Report of 1997 to the U.S. Congress and the Secretary of Energy, December 1997

Viability Assessment

The Department agrees with the Board that the viability assessment (VA) is an important intermediate milestone on the path to an evaluation of site suitability rather than a decision point and should be kept in the proper context. We expect that the VA will provide information to facilitate intermediate evaluation of the potential Yucca Mountain Monitored Geologic Repository. The independent views of the Board will be important in this evaluation process. From the Department's perspective, the VA components will objectively describe the design, performance, and cost of a Yucca Mountain repository based on the information collected to date. The assessment will also include a proposed path forward for completing site characterization and developing a site recommendation and a license application (LA).

Repository and Waste Package Designs

The Department recognizes the advantages of using a robust engineered barrier system in combination with geologic barriers, as suggested by the Board. Our reference design includes a multi-metallic robust waste package that is projected to contain the waste for thousands of years in the repository environment.

As part of its ongoing design and analysis programs, the Department is developing design alternatives for the repository and the engineered barrier. We are preserving flexibility in the existing design approach to ensure that design alternatives now foreseen, as well as those that may emerge with advancements in technology, can be accommodated in the repository development process, as recommended by the Board. We expect that design alternatives will continue to be evaluated throughout repository licensing, construction, and operation. As modifications to the reference design and concept of operations are proposed and analyzed, the Department will share those with the Board.

A reference design, however, is essential for the VA, and a reference design will be essential for the rational completion of site characterization and the licensing process. Such a reference design and an assessment of its performance provide the frame of reference required to evaluate the sufficiency of site characterization data and analyses. This use of a reference design ensures that the components of the VA, and later key documents, relate to a coherent proposed facility and rely on consistent information. Consideration of significant alternatives to the reference design will continue to be an important part of the design development process. Discussion of alternatives is required for the license application and will be included at a conceptual level in the VA.

Total System Performance Assessment

We recognize the importance of support from the scientific community at large for the Department's technical work. We appreciate the Board's strong support of our efforts to solicit the views of outside experts on the interpretation of data obtained in site characterization and the development of appropriate process models for use in total system performance assessments (TSPA). Expert elicitations in five focused subject areas have been conducted to help define and, where possible, quantify the uncertainties in parameters and models to be used in the TSPA-VA. These elicitation addressed: unsaturated-zone flow; waste package degradation; saturated-zone flow and transport; near-field and altered zone coupled effects; and waste form degradation. These elicitations are intended to supplement data collection and analysis by focusing on uncertainties in the currently available information. In each of these elicitations, the experts were asked to recommend additional data collection and analysis activities that, in their opinion, could lead to a significant reduction in the existing uncertainties. The Department will make full use of the information provided by the experts for evaluating predictive models and as a guide for future testing.

In addition to the focused input we receive from outside experts, we have formed an independent peer review panel to review the entire total system performance assessment process. This review is ongoing. We have received two interim reports from the panel, which are being used to improve our performance assessment process. The panel's final report will follow the VA and will influence how the Department proceeds with the performance assessment for the LA. The Department appreciates the interest that the Board has shown in the TSPA peer review process and encourages your continued participation as observers at the peer review briefings to the Department.

The Department agrees with the Board that expert elicitation is dependent on collected data and can guide additional data collection, but is not a substitute for reasonably obtainable data. We have structured our ongoing expert elicitations to be generally consistent with guidance from the Nuclear Regulatory Commission on the use of expert elicitation, which is also based in part on these premises.

Enhanced Characterization of the Repository Block

We appreciate the significance of hydrologic data that will come from studies in the cross drift that is being constructed as part of the enhanced characterization of the repository block. The construction of the starter tunnel for the cross drift is well under way, and the tunnel boring machine started boring on March 31, 1998, approximately three weeks ahead of schedule. Excavation is expected to be completed later this year.

The testing for the enhanced characterization of the repository block will continue for several years after excavations are completed; however, visual observations and mapping will be performed as excavation proceeds. The Department understands and agrees with the Board's desire to see included in the VA as much as possible of the data collected from the enhanced characterization of the repository block program. We expect that the observational data collected during construction will be included in the VA to the extent practicable. These data could include identification of faults exposed in the cross-drift and preliminary information on fracture distributions. It is not likely that there will be sufficient time to complete sample collection and analysis or in situ testing prior to issuing the VA. The results of these investigations will be included in the LA.

In addition to the cross drift, the Department is constructing an underground facility at Busted Butte in the Calico Hills formation to provide a test site in the same rock unit that exists below the western part of the proposed repository block. This testing is intended to reduce uncertainties in the Yucca Mountain Project's assessment of the potential transport of key radionuclides from the repository area, through the unsaturated zone, to the water table underlying Yucca Mountain. Tests also will address the importance of colloid-facilitated transport of radionuclides in fractured and unfractured rock. Underground construction began in mid-December 1997 and testing will continue through August 1999.

Department of Energy
Washington, DC 20585

June 15, 1998

JUN 17 1998

Dr. Jared L. Cohon
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, Virginia 22201-3367

Dear Dr. Cohon:

The Department of Energy appreciates the Nuclear Waste Technical Review Board's continuing effort to provide preliminary comments following its public meetings. To ensure that important issues are being addressed in a timely manner, the Department would like to provide the Board with preliminary responses to its comments of April 7, 1998, on the Board's January 1998 meeting. This meeting focused on studies of the saturated zone and the environmental impact statement.

Characterization of the Saturated Zone

We share the Board's interest in saturated zone (SZ) studies. Additional field tests are being planned in response to the importance assigned to SZ flow and transport in the repository safety strategy. The intent of these tests is to reduce the uncertainties about radionuclide dilution in the SZ. We will keep the Board informed of the results of ongoing studies and of plans for additional tests in the SZ. As the plans for additional tests are being formulated, we will also consider the Board's suggestion for a review of the plans by an outside technical panel.

Expert Elicitation on the Saturated Zone

The Board suggested that our SZ models assume an optimistic amount of dilution and that the current models need better integration and more supporting data. Based on the expert elicitation and other inputs, we have substantially revised and simplified the SZ model in TSPA-VA from that presented to the Board in January 1998. This has resulted in more realistic dispersion and therefore, much reduced dilution factors. We will include in the viability assessment (VA) a study on the sensitivity of repository performance to variations in the dilution factor. As was discussed earlier, the Department intends to conduct additional testing in the SZ after the VA to provide additional data to support the SZ models.

Presentation by the State of Nevada's Contractor

As suggested by the Board, the SZ flow model presented by the State's contractor is being reviewed as we continue development of SZ models. The Department recognizes the value of considering alternative models for ensuring that the full range of uncertainty is addressed.

The Environmental Impact Statement (EIS)

The Department welcomes the Board's interest in the EIS process and how alternative designs will be considered. Through the EIS, we intend to bound the environmental impacts from a reasonable range of designs, based primarily on a range of thermal loads. The impacts of other reasonable alternative designs should fall within these bounds.

As the Board mentions, the Department must at the appropriate time present a comparative evaluation of design alternatives. We expect that evaluation, which is required by the U.S. Nuclear Regulatory Commission (the Commission), to be initially developed for the VA and then to evolve throughout the prelicensing and licensing periods. The Department intends to use a workable reference design to support the development of a license application. We recognize that technological advances over the decades of repository construction and operation can be expected to influence design changes. Input from the Board, the Commission, and other interested parties will be important in making the design decisions.

Thermal Testing

We agree with the Board on the importance of thermal testing for reducing uncertainties in the thermal-hydrologic response of Yucca Mountain. We appreciate the Board's compliments on the progress in the thermal testing program.

We continue to value the Board's feedback as we pursue completion of the VA and the future work beyond. If you have any questions, please contact me at (202) 586-6842.

Sincerely,

Lake H. Barrett, Acting Director
Office of Civilian Radioactive
Waste Management

Department of Energy

Washington, DC 20585

September 8, 1998

SEP 09 1998

Dr. Jared L. Cohon
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, Virginia 22201-3367

Dear Dr. Cohon:

This letter transmits the Department of Energy's response to the Nuclear Waste Technical Review Board's *Report to the U.S. Congress and the Secretary of Energy: 1997 Findings and Recommendations*, issued in April 1998. Our response to the Board's recommendations are found in the enclosure.

As the Board noted, the Department has been focused on completing the viability assessment (VA) for a repository at Yucca Mountain, as directed by the President and Congress. The VA is a management tool for the Department and an important informational input to the policy process. Its completion this year will culminate a three-year effort by the Department to assemble the information collected during site characterization into a workable repository concept for Yucca Mountain and to focus the Program on the remaining key technical issues. Our plans call for a substantial effort after the VA to complete site characterization, to continue our design activities, and to develop and document the technical bases for a site recommendation and a license application, if the site is found suitable. As the Board has suggested, this effort will include the enhanced characterization of the repository block, long-term corrosion tests, and the drift-scale thermal test.

The Department appreciates the Board's constructive review and recommendations regarding the technical and scientific aspects of the Civilian Radioactive Waste Management Program. We continue to value the Board's feedback as we complete the VA and the additional work for a site recommendation. If you have any questions, please contact me at (202) 586-6842.

Sincerely,

Lake H. Barrett, Acting Director
Office of Civilian Radioactive
Waste Management

Enclosure

Department of Energy's Response to the Recommendations in the Nuclear Waste Technical Review Board's *Report to the U.S. Congress and the Secretary of Energy: 1997 Findings and Recommendations*

Recommendation 1:

The Board views the Department of Energy's (DOE) work on alternatives to the reference design as a vital element in the repository program. Although much of this work will be carried out subsequent to the viability assessment (VA), the DOE should consider including, in the VA, cost estimates of alternative repository design concept and sensitivity studies showing the effects of these alternative design concepts on long-term repository performance. Work on alternative repository designs should be started now, even if it cannot be included in the VA.

Response:

The Department is responding to the Board's interest in studies of alternative repository design concepts by establishing a working group to identify and evaluate major design alternatives. This effort ensures that an appropriately comprehensive evaluation of design features and alternative design concepts, including those suggested by the Board, are examined prior to selecting the reference design to support site recommendation and license application. The VA will describe the current status of the effort to evaluate design features and alternative design concepts. The VA will include sensitivity studies and costs only for a set of design enhancements for the VA reference design. The working group will address performance and cost issues for other major design alternatives after the VA.

As used in the VA, design feature refers to a component of a repository system, and alternative design concept refers to a layout developed specifically to incorporate particular design features. Certain design features are somewhat independent of the actual design layout; generally, they could be implemented in almost any layout. Other design features are more dependent on the design layout. Accordingly, to realize the performance enhancement potential of these design features, a specific layout must be considered.

The VA describes design features and alternative design concepts in sufficient detail to identify the studies needed to support selection of the reference design for site recommendation and license application. This future design could be closely related to the VA reference design or an enhanced version of that design. Also, it could be one of the VA alternative design concepts, or an as yet undeveloped design concept that takes advantage of the performance potential of one or more design features.

The goal of the evaluation is to provide an acceptable repository design for site recommendation and license application. This evaluation is an appropriate precursor to any submittal of a license application, as Nuclear Regulatory Commission (NRC) regulations require comparative evaluation of alternatives to major design features that are important to waste isolation. The

Department expects to interact with the Board during selection of the reference design in the event of site recommendation and license application to ensure that the Board's views are addressed.

Related to the Board's recommendation on alternative designs, the Board's report presented five questions related to the reference underground design, expressed concerns related to the waste package on galvanic protection and waste package fabrication, and suggested reconsideration of several concepts for surface operations. These issues are addressed below:

Underground Facilities Alternative Designs and Reference Designs

1. *Why should the diameters of the emplacement drifts be 5.5 m?*

Selection of the 5.5-m excavated emplacement drift diameter for the reference VA design resulted from the following major considerations. The drift diameter had to:

- accommodate the largest waste package dimension (approximately 2.0-m diameter) as well as the heaviest (154,000 lbs);
- provide an adequate operating envelope for a gantry (waste package carrier) to transport waste packages over the largest emplaced waste package, if necessary;
- provide for ground support systems up to 200-mm-thick and an invert. Even if no full circle lining were planned, any use of steel sets for occasional bad ground would require approximately the same clearance as that needed by the liner;
- meet the thermal goal of 200° C rock wall temperature and 350° C waste package core temperature with waste packages that have initial heat output as high as 18 kW.

Based on these considerations, a minimum of 5.1-m clear envelope was developed. Adding the 200-mm for lining, the excavated diameter is 5.5-m. Recent analysis indicates that the 5.5-m emplacement tunnel may not allow sufficient tolerances and operating envelopes. Providing the needed tolerances may cause a slight increase in diameters (~100 mm). However, the need to carry a waste package over another waste package will be reevaluated in a future analysis, which could change the requirements for drift size.

Since the existing diameter is required primarily by the gantry and largest waste package, any significant reduction in drift diameter could require a significant reduction in the largest waste package size and thermal output, a change in the emplacement mode, and elimination of backfill as an option. Alternate emplacement delivery systems such as railcars, which could allow a smaller diameter, may be employed and will be evaluated. Previous designs which used railcars indicated high costs and perceived difficulties with retrieval for that design.

The option of a small diameter emplacement drift is planned to be evaluated as a part of the design alternatives study. In that evaluation, the issues of drift stability, type of ground control system necessary, ease and cost of construction, compatibility with the waste package dimension and weight, emplacement delivery systems, ventilation and other functional objectives will be evaluated.

> 2. *Has the potential effect of the exhaust drift underneath the repository on the long-term performance of the repository been evaluated?*

No detailed evaluations have been made of the potential thermal and thermomechanical effects on repository performance of the exhaust drift underneath the repository. The location of the exhaust main beneath the center of the emplacement area, and the slight slope of the emplacement drifts from the center down to the edges means that little or no water can drain from the emplacement drifts to the exhaust main. Thus, the exhaust main should not accumulate water from the emplacement drifts nor act as a fast path. While the non-thermally perturbed hydrologic effect of the exhaust shaft seems small, the thermal-hydrologic system has yet to be evaluated. The long term effects of an exhaust main beneath the repository level will be the subject of a future study.

> 3. *Is the value added by the exhaust drift worth its cost and potential effects, if any, on long-term performance?*

A central exhaust main is located below the emplacement drifts, midway between the east and west mains, and connects the mains located at the north and south ends of the repository block. The central exhaust main is used primarily for ventilation of the emplacement drifts and has the following values:

- It effectively reduces the total emplacement drift lengths by one-half, allowing emplacement operations from both east and west mains;
- It provides better logistics for emplacement operations to accommodate the thermal load management requirements, and improves the reliability of waste package transportation within the emplacement drifts by reducing the transportation distance to one-half of the total east-west drift length;
- It allows faster cool-down of any emplacement drifts, if re-entry is needed.

The Department considers that these values, which enhance the operation of the subsurface facilities, make the exhaust main worthwhile.

> 4. *Have the DOE's plans provided for the funds and time that will be needed to develop, demonstrate, and license the equipment, sensors, communication devices, etc., required for remote operations?*

The use of remotely controlled transportation and emplacement equipment significantly reduces worker exposure to radiation. It also reduces shielding needed to meet health and safety requirements. Remote systems are not planned to perform any drift maintenance. If such work is necessary, the drift will be cooled by ventilation, waste packages will be removed from the drift and placed in an empty drift, and work will be performed with personnel access in the drift.

The reference VA design utilizes remote systems that are based on proven technologies, not on technologies to be developed, and are expected to function safely and reliably under the anticipated radiation and thermal conditions in the repository operations area. However, because these technologies will be uniquely applied, designers are striving to keep the applications as simple as possible.

The Project's plans include a mock-up and testing program to demonstrate functions of the remote system. The remote equipment and the communications systems by which it is controlled will both be the subject of a significant test and evaluation program.

The evaluation of alternative designs will include at least one alternative in which the waste packages are emplaceable by on-board human operators and the emplacement drifts remain accessible throughout the pre-closure period.

> *5. Why are the benefits of continuous ventilation of all drifts not being taken advantage of in the current design?*

Repository ventilation studies demonstrate that increased ventilation rates can remove both heat and water vapor from the emplacement drifts. However, there is not yet significant evidence to indicate that a strategy of aggressive continuous ventilation will lead to better long-term performance. The current Project strategy is to maintain high temperatures around the emplacement drifts in order to drive away water and keep the waste packages dry as long as possible. The upcoming design alternatives analysis, which will include performance assessments, will evaluate continuous ventilation at higher levels than currently shown in the reference design.

Galvanic Protection and Waste Package Fabrication

As suggested by the Board, the total system performance assessment (TSPA) for the VA does not take credit for galvanic protection. This is based mostly on the fact that the corrosion-allowance barrier (carbon steel) will degrade principally by general corrosion and not by localized corrosion. In this case, galvanic protection is less effective. The only concern, which is being addressed with ongoing testing, is the potential for high aspect ratio pitting corrosion of the carbon steel by high pH water that results from interaction of groundwater with high pH concrete utilized for the drift liner surrounding the waste package. In this case, galvanic protection may be significant because the throwing power of the galvanic current from the carbon steel would be able to cover the exposed area in the corrosion-resistant material at the base of the pit. Exposure of galvanic couples between carbon steel and corrosion-resistant materials as well as drip tests are underway. These tests should provide information on the nature of the attack and the throwing power of the carbon steel. The results would also indicate whether credit for galvanic protection can be taken for the license application.

On the Board's concern about integration between the performance assessment and engineering groups, the performance assessment staff are using a design baseline in completing TSPA-VA to ensure that the design assumptions for galvanic protection in performance assessment are consistent with the engineering design assumptions for analyses addressing corrosion of the inner barrier. This formally controlled process is structured to avoid disconnects between engineering design and performance assessment.

The concerns expressed by the Board on residual stress from shrink-fitting of the two cylinders constituting the inner and outer waste package barriers are understood and are being investigated. Shrink-fitting is being considered for ensuring that the two cylinders do not move relative to each other, in addition to its potential benefit for providing some galvanic protection of the inner barrier. Shrink-fitting has been demonstrated to be a viable method of assembling two barriers in close mechanical contact. This has been proven by the fabrication of two mock-ups and is being used in industry routinely. It is at this time considered to be the easiest and most cost-effective method to achieve the required mechanical requirements. However, other methods will be evaluated before a final manufacturing method is selected. These evaluations will consider stresses, potential crevices, point loading from shifting centers of gravity, reliability of the fabrication and inspection processes, and cost.

The Board's concerns on the inspectability of final closure welds will be fully addressed before selecting the final fabrication and welding processes. The inspection by ultrasonic testing of the inner barrier on the Fiscal Year 1997 waste package mock-up was successfully accomplished. The inspectability of the inner weld by remote ultrasonic testing will be further investigated during Fiscal Year 1998.

Surface Facility Operations

The Board suggested that the Department reopen studies of multi-purpose canisters and other concepts where preparations at utilities could reduce handling of fuel assemblies and costs. The Department believes that the concept of multi-purpose canisters has merit. While the Department initiated the design and development of a multi-purpose canister system, the private sector has since embraced this activity. The Department does not plan to fund additional studies but will consider multi-purpose canister systems proposed by the private sector in response to our market-driven approach to transportation. The Department will also consider sharing any disposal cost savings from the use of a multi-purpose canister.

The Board also suggested that the Department reexamine the basis for the peak annual emplacement rate based on a concern that the waste handling facilities were being designed for a peak emplacement rate of 4,500 metric tons of uranium (MTU) that is significantly higher than the average rate of 3,300 MTU. The Department understands the concern that the waste handling facilities are cost drivers and the size of these facilities is sensitive to emplacement rate. The current design can annually process about 380 commercial spent nuclear fuel (SNF) waste packages (3000 MTU), 100 glass waste packages (250 MTU), and 70 DOE-owned SNF waste packages (50-150 MTU). This results in a peak annual emplacement rate of 3300-3450 MTU, which is comparable to the average rate of 3300 MTU and is a reasonable basis for design.

Recommendation 2:

The DOE should estimate and disclose the likely variation in doses for alternative candidate critical groups characterized by different locations, ages, and lifestyles. In particular, potential doses to children should be compared with doses to adults within each candidate group.

Response:

The Department recognizes the Board's concern regarding dose estimates to children. At this time, there are no U.S. Environmental Protection Agency (EPA), NRC, or Departmental radiation protection standards that specifically include children. Current regulatory practice is to estimate doses to a hypothetical representative adult, known as the Reference Man, using physiological parameters developed by the International Commission on Radiological Protection. The dose conversion factors estimated based on the Reference Man have uncertainties that are comparable in magnitude to the uncertainties in exposure assessments and to the estimates of cancer risks.

For purposes of radiation protection, the Department agrees with the EPA and the NRC that the assumptions exemplified by the Reference Man adequately characterize the general public, and a detailed consideration of factors, such as age and sex, is generally not necessary. As the Board is aware, estimating doses to children and other age-specific groups is a complex task because of factors such as systemic biokinetic models, gastrointestinal uptake factors, organ masses and positions, and food consumption habits, all of which change as a person ages.

The Department, however, will conduct a preliminary evaluation of the impact to children and other age groups and will report the results of that evaluation in a technical report, recognizing that the development of age-dependent dosimetric and biokinetics models is an ongoing international effort. The report will reflect currently available information, which may not fully address age-specific differences in some biokinetic parameters.

The concern about doses to children should be considered in light of the assumptions used in performance assessment for future populations. We assume, consistent with internationally accepted recommendations, that characteristics of the population tens of thousands of years in the future are similar to those of the current population, because we cannot reasonably forecast changes in characteristics of the population. This assumption has a large uncertainty and means that dose calculations indicate the range of likely performance of a repository for only a hypothetical population. As such, the doses should be viewed only as an indicator or figure of merit for repository performance. This indicator should be viewed in a different perspective from that for potential doses from currently operating facilities, where the characteristics of the population are known.

Recommendation 3:

The DOE should evaluate the need for site-specific data for supporting the biosphere modeling needed for license application, especially soil-to-plant transfer factors. The evaluation should *include an estimate of the length of time over which measurements of such parameters would be needed to produce a reliable data set. Plans for obtaining the necessary data should be developed now.*

Response:

The Department appreciates the Board's conclusion that our approach to biosphere modeling seems appropriate and agrees that generic biosphere data will be adequate for many aspects of the modeling. The Department will continue to examine sources of uncertainty in the modeling, including the use of generic versus site-specific data. As recommended by the Board, an evaluation of using generic soil-to-plant transfer factors, or concentration ratios, has been initiated and is nearing completion.

This evaluation indicates that the values reported in the scientific literature for concentration ratios vary widely for several reasons. As the Board suggests, some of this variation is due to site-specific environmental conditions such as soil composition and texture. However, experimental procedures also contribute to the variation. For example, depth of sampling, sample preparation protocols (e.g., washing, cooking, and plant part versus whole plant analysis), pot versus garden experiments, plant species, and management practices (e.g., fertilizer, irrigation rates, and plowing) all influence experimental results. Therefore, the variation in reported values represents variations in both site-specific environmental conditions and experimental procedures.

The Department has been using generic concentration ratios published by the International Atomic Energy Agency (IAEA), because they were developed based on a critical review of existing scientific literature and data contributions from scientists generally using standardized experimental procedures. Although the use of generic concentration ratios does not appear to be the most important source of uncertainty in the biosphere modeling, the Department will continue its evaluation of generic versus site-specific concentration ratios for Amargosa Valley. In addition, we will continue to evaluate the applicability of the IAEA database to the Amargosa Valley, including the use of subsets of this database, which may be more relevant to the Amargosa Valley.

Recommendation 4:

The DOE should make full and effective use of the expert elicitations, both as direct input to performance assessment and design and for the technical insights provided. The DOE should provide a rationale for the way it intends to aggregate the views of different experts and how the individual views of the experts will be treated in performance assessment. The DOE should also consider developing guidelines on how the results of expert elicitations will be treated in light of new data.

Response:

The Department agrees with the Board on the value of expert elicitations. The application of the elicitations spans a range from direct use of aggregate Probability Distribution Functions to qualitative insights. For instance, the elicitations have provided direct inputs to TSPA by quantifying the range of infiltration rates applied to the surface of Yucca Mountain, the range of degradation rates of the corrosion-resistant inner waste package material C-22, and the range of effective dilution likely to occur in the saturated zone. In other cases, the elicitations have identified conceptual issues that have generally been addressed in sensitivity analyses, such as the range of conceptual models to describe unsaturated zone flow and transport, the range of alternative conceptual models used to determine the seepage into drifts, and the range of cladding degradation conceptual models. In cases where only one or two experts provided an assessment (e.g., microbiologically influenced corrosion), the elicitations usually required specialized knowledge, and the expert's opinion was only used for insight and/or input to sensitivity analyses. Yet another use of the expert elicitations has been to identify types of information that could be used to reduce the uncertainty in key components of TSPA.

The Department has developed quality assurance (QA) requirements and implementing procedures for the conduct of expert elicitations. These QA requirements and procedures for expert elicitations require documentation of the individual expert assessments and the process of aggregating their assessments, if the views of different experts are aggregated, and include guidelines for reevaluating the results of expert elicitations in the light of new data. For example, current Project plans include an activity for each fiscal year to identify new data that are relevant to the volcanic and seismic hazard analyses, such as the recent geodetic data across Yucca Mountain. The effect of these data on the results of the probabilistic volcanic and seismic hazard analyses will be evaluated if analyses, such as sensitivity studies, indicate that the effect may impact the hazard assessments.

The requirements and procedures reflect guidance provided by NRC in its *Branch Technical Position on the Use of Expert Elicitation in the High-level Radioactive Waste Program* (NUREG-1563). In meetings and correspondence, NRC has indicated that the Department's approach is in conformance with the NRC guidance and has closed numerous open items related to the Department's use of expert judgement.

Additional Board Comments

The Board's report raised issues beyond those captured in the four recommendations. Where these issues relate to topics in the recommendations, the Department's responses also address the related issues. Additional issues, concerning the environmental impact statement and transportation, are addressed below.

Environmental Impact Statement (EIS)

The Department welcomes the Board's interest in how the EIS will explore alternative designs and characterize the "no-action" alternative. The Department, as part of its ongoing design activities, is developing design alternatives for the repository and the engineered barrier system. We are preserving flexibility in the existing design approach to ensure that design alternatives now foreseen, as well as those that may emerge with advancements in technology, can be accommodated in the repository development process. We expect that design alternatives will continue to evolve and be evaluated throughout repository licensing, construction, and operation. Input from the Board, the NRC, and other interested parties will be important as design decisions are made.

We agree that the EIS process is an appropriate venue for exploring the potential environmental impacts of design features and alternatives. We believe that the ongoing design activities that will be discussed in the VA will represent a range of reasonable design alternatives, including those alternatives recommended by the Board for consideration. In the EIS, we intend to bound the environmental impacts for the full range of designs by analyzing the impacts from the EIS implementing design alternatives (i.e., three different thermal loads).

To ensure that the impacts from the range of designs are bounded by the thermal load implementing alternatives, a study is being conducted as input to the EIS. If significant environmental impacts are not bounded by the implementing alternatives, additional analysis will be performed. With this approach, we intend to provide sufficient analyses to encompass most design features and alternatives.

The Department recognizes the importance of characterizing the impacts from the "no-action" alternative and currently is considering how best to characterize the scope of the "no action", alternative. In making that decision, we will be mindful of the Nuclear Waste Policy Act's directive that the EIS need not consider alternative sites, the need for and time of availability of a repository, and alternatives to geologic disposal.

Transportation

The Department agrees with the Board that institutional issues related to transportation may require as much or more time to resolve as developing the physical infrastructure. The Office of Civilian Radioactive Waste Management works with other elements of the Department as they address such institutional issues as transportation planning, routing, emergency preparedness and training, and technical assistance for near-term radioactive materials shipments. The Department has been addressing these and other issues in preparation for the operation of the Waste Isolation Pilot Plant and for the foreign spent fuel shipments. These institutional issues have been recognized in our recent interactions with a broad range of stakeholders.

For example, we have issued core planning and policy statements for stakeholder comment. We issued a revised draft policy on April 30, 1998, for Safe Routine Transportation and Emergency Response Training, which defines policies for providing technical and financial assistance to States and Native American Tribes approximately four years prior to the start of shipping. The technical and financial assistance is a Department responsibility under Section 180c of the Nuclear Waste Policy Act. Our market-driven approach to transportation, for which the Department issued a revised draft Request for Proposals in November 1997, addresses the Department's and transportation regional service contractors' institutional responsibilities with regard to planning for emergency response, training, and public information. Institutional coordination with States and Tribes under the market-driven approach is intended to begin three to five years before the start of shipping. Our recent efforts related to Section 180c and the market-driven approach to transportation provide a working foundation for the Department to complete its transportation preparations and resolve remaining issues with affected stakeholders consistent with the planning basis for multi-year development and operation of the radioactive waste management system in 2010.

Concerning the need for full-scale testing of casks, the Department will continue to follow and comment on any related action by the relevant regulatory agencies. The use of dedicated trains, along with other rail safety and operations related issues, are being addressed through the Department's continuing dialog with the Association of American Railroads, the Federal Railroad Administration, and the rail industry for this Program, as well as through other Departmental transportation activities.

We are confident that transportation institutional issues will receive amplified attention and resolved once the decision regarding site recommendation has been made..

Department of Energy
Washington, DC 20585

October 19, 1998

OCT 20 1998

Dr. Jared L. Cohon
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, Virginia 22201-3367

Dear Dr. Cohon:

The Department of Energy has received and reviewed the Nuclear Waste Technical Review Board's letter of July 30, 1998, transmitting comments on its June 1998 meeting. We appreciate your compliments on the high level of technical content in the Department's presentations and on the coordination for the field trip. In an effort to address important issues in a timely manner, the Department would like to respond to the Board's comments. Our responses are provided in the attachment.

We continue to value the Board's feedback as we complete the viability assessment and work toward site recommendation. If you have any questions, please contact me at (202) 586-6842.

Sincerely,

for Ronald A. Milner
Lake H. Barrett, Acting Director
Office of Civilian Radioactive
Waste Management

Attachment

Department of Energy Responses to the
July 30, 1998, Letter of the
Nuclear Waste Technical Review Board

Total System Performance Assessment

The Department agrees with the Board that any set of calculations, including those presented on the status of the TSPA calculations for the VA, are only as valid as the underlying assumptions, models, and data. Time constraints at the June 1998 Board meeting did not permit a thorough presentation of the science underlying the calculations. More exhaustive presentations were made to the Board's Performance Assessment Panel in April 1998. The most complete documentation of the analyses is contained within Volume 3 (TSPA) of the VA and in the accompanying TSPA-VA Technical Basis Document.

The Board questioned how parameter uncertainties were assigned and whether parameters were appropriately correlated. The Department agrees that the parameter uncertainty analyses are dependent on the assigned uncertainty distributions. To address this concern, we also conducted a suite of sensitivity analyses, which provide additional insight into the range of possible behaviors. On the correlation question, the parameters cited in the Board's example, infiltration and seepage fraction, are fully correlated, and this correlation has been included in all analyses. Uncertainty analyses and correlations are presented in Volume 3 of the VA in summary level and in the TSPA-VA Technical Basis Document in detail. We recognize that additional uncertainty analyses and correlations will be required for the site recommendation and license application.

The TSPA team has consistently used comments made by the Board to improve the quality of our analyses. The Board's previous comments on making TSPA technically persuasive, transparent, and traceable, on paying proper attention to uncertainties, on coordinating with the repository safety strategy, on demonstrating validity with natural and engineering analogues, and on using simplified calculations, peer review, and outside expertise are all leading to improvements. We will continue to combine these suggestions with the comments we have received from the Nuclear Regulatory Commission (NRC) and the TSPA Peer Review Panel as we move forward to the TSPA for site recommendation and license application.

License Application Plan

We appreciate the Board's suggestion that the decision methodology be made more transparent and that the key measures of importance be defined more rigorously. The License Application Plan (Volume 4 of the VA) describes the additional technical work needed before the Department's decisions regarding site recommendation and license application can be made. That work includes evaluation of design alternatives and features that might enhance confidence in system performance. The Plan also identifies the work needed to address the remaining issues for postclosure performance and preclosure safety.

The Department's approach to determining the relative importance of the principal factors affecting these issues and the prioritization of the information needed to address them was outlined in the presentation to the Board. A more detailed description of the importance of the various principal factors and the prioritization of those factors are presented in Volume 4 of the VA. This discussion will provide additional information on work done subsequent to the June 1998 meeting that is responsive to the Board's comments on making the methodology more transparent and rigorous. However, uncertainties in characteristics of the system will continue to make the judgements about necessary work somewhat subjective. A completely rigorous assessment of the information needs in the face of these uncertainties is not practicable. Nevertheless, we hope the additional information provided in the VA will help illuminate the judgements that have been made.

Determination of Importance Evaluation on the East-West Crossing

The Board wrote that it "believes that the OCRWM has not addressed adequately mountain-scale coupled thermal, hydrologic and mechanical (THM) processes. The Board has not seen any rigorous THM analysis of whether the east-west crossing will affect long-term repository performance or will foreclose repository design alternatives."

Part of the Department's basis for excavating of the east-west cross-drift was our conclusion that the Determination of Importance Evaluation (DIE), Revision 2, adequately bounds the impact of the cross-drift on repository performance. This conclusion was based in part on these findings:

- An in-depth analysis of coupled thermal-hydraulic processes in the near-field environment demonstrates that the effects of the drift are small, even at the scale of the near-field model, and dampen out over time.

- Lateral gas-phase connectivity within the repository area would not change significantly due to the cross-drift, given the massive connections represented by waste emplacement drifts.

- The cross-drift may participate in thermal convention cells; however, this potential mechanism also exists in undisturbed rock due to natural fractures.

- Although the cross-drift effective conductivity is significantly larger than for fractures, any gas-phase process that connects the waste emplacement drifts with the cross-drift must also pass through fractured rock. Therefore, fracture conductivity will dominate the serially connected pathway.

- The cross-drift overlies only a very small number of waste packages; hence any adverse effects due to condensate drainage from the cross-drift onto waste packages would have a very limited effect.

- Operational controls (such as waste package selection to accommodate thermal mixing) will preclude asymmetric thermal loads.

- Any flux (beyond the nominal fracture connectivity) that could occur between hot and cold drifts in a repository as a result of the presence of the cross-drift could be mitigated by backfilling the drift.

- There is no available technology to perform a rigorous mountain-scale coupled THM analysis. If such analysis is deemed necessary, the methodology could be developed and validated. Mountain-scale models currently in use do not yet take into account the effects of drifts; for example, ventilation models such as the one George Danko, University of Nevada - Reno, presented to the Board are based on drift-scale calculations. While the mountain-scale models do provide boundary and initial conditions for the near-field models (a "nested" approach), they do not provide sufficient resolution to assess the effects of the cross-drift.

The Department maintains that the practical, qualitative approach used for the mountain-scale analysis in the DIE is in accordance with standard geoengineering practice and conforms to the Department's DIE procedure. Standard practice performs appropriate analyses prior to design and construction, but is fully prepared to implement remedial measures, if necessary.

The possible effects on repository design alternatives were an important consideration in the decision where to site the cross-drift. A formal analysis was not included in the DIE, Rev. 2, as it was not required by the DIE procedure.

Revision 3 of the DIE was released on September 4, 1998. This revision includes consideration of expanded infiltration rates, operational controls to preclude asymmetric thermal loads, impacts of temporary storage of the Tunnel Boring Machine at Station 28+23 meters, expanded Quality Assurance controls, and several other features.

The Department has concluded that the DIE is technically adequate, based on available technology; however, we would appreciate your specific suggestions that would improve our THM processes. We look forward to further discussions with the Board on this matter.

Observations from the Field Trip

The Board complimented the Project for the rapid progress on the Busted Butte experiment and suggested examining related colloid transport work done at Hanford. In Fiscal Year 1999, we will collect and evaluate the field colloid information from Busted Butte and the Nevada Test Site. Additional laboratory information will be collected to determine forward and backward sorption/desorption rates based on drip test colloids.

The technical cross-fertilization now in progress with other sites will aid the Project in addressing issues of observed or projected radionuclide migration. The Department has opened a data and knowledge-sharing dialogue with the investigators responsible for characterizing and understanding the migration of radionuclides observed at Hanford, the Idaho National Environmental and Engineering Laboratory, the Los Alamos National Laboratory, and the Nevada Test Site. Preliminary indications are that where migration of actinides has been observed, there was a direct link to the chemistry of the solutions involved, which were typically designed to keep actinides in solution or suspension. It is not appropriate to apply results from these sites directly to Yucca Mountain; however, anthropogenic analogue work will examine the colloid information at Hanford for potential use by the Project.

The Board also suggested that tunnels elsewhere on the Nevada Test Site (NTS) could provide information relevant to percolation during wetter climates at Yucca Mountain. The N-tunnel system was previously examined as part of a scoping exercise to select candidate sites for analogue studies. The tunnel is considered "wet" and has been sealed with a temporary bulkhead. Data are currently being collected for NTS through the bulkhead with remote monitoring equipment. A white paper was prepared several years ago that summarized what is known about the N-tunnel and further work was proposed; however, due to budget constraints the proposed work was not funded.

Environmental Impact Statement

The Board requested additional information on how the thermal load options bracket the environmental impacts from potential repository designs beyond what was presented during the June 24, 1998, meeting. The Department presented the logic for initially selecting a range of thermal loads as the underlying basis for the thermal load options to be evaluated in the Environmental Impact Statement (EIS). The intent of the EIS presentation was to put into context how the Project developed and is using the thermal load options. A report documenting the technical analyses and decisions on the range of potential repository designs is being prepared as an EIS reference, and we will provide you with the additional information.

Departmental staff and National Environmental Policy Act (NEPA) experts made the initial selection of thermal load options in informal planning sessions. That selection, in concert with the transportation options and spent nuclear fuel packaging options, was made in early to mid-1995 for purposes of developing the EIS Notice of Intent, which is the start of the NEPA process. Evaluating a range of thermal loads was considered to be reasonable for purposes of eliciting public input on the potential scope of the EIS during the scoping period for the EIS. This construct was believed to bound the potential environmental impacts of the design alternatives and features that were then being studied by the Project.

We are also conducting additional studies to ensure that the thermal load options adequately bound the environmental impacts of potential repository designs. This work is being conducted in close coordination with the reference design activities presented at the Board meeting. Because the environmental impact analysis is closely integrated with the analysis to determine the reference design to carry forward to site recommendation and license application, it will not be finalized until mid-1999. As the work proceeds, if environmental impacts are potentially not bounded by the current EIS construct, additional analyses will be done and the draft EIS will be revised.

We look forward to sharing the results of our ongoing evaluations with the Board and specifically understanding what potentially significant types of environmental impacts that the Board thinks may not be bounded by the current construct of the EIS thermal load options.

Alternative Repository Designs

The Board was pleased with the Department's commitment to examine design alternatives before selecting a design for site recommendation and license application but questioned whether the examination would be as comprehensive as the Board desires. The scope of the Department's alternative repository design evaluations has been established with the goal of considering any repository design concepts that appear to have potential merit. Potential merit includes pre- and post-closure safety, operating and maintenance characteristics, cost, schedule, licensability, and risk considerations. The VA Reference Design and TSPA–VA will be used for evaluation purposes since there is substantial scientific and technical information available for them and they can be useful as a benchmark in comparing other design concepts. All concepts will receive an equitable consideration.

The Board also suggested that the Program examine relevant work done at the Basalt Waste Isolation Project (BWIP). The Program is taking advantage of experience such as BWIP in conducting its evaluations. Technical exchange visits to BWIP have been conducted. Technical documentation produced for BWIP and other programs is being captured during the compilation and evaluation of previous work that is relevant to our alternate designs and design features.

The work to evaluate alternative designs and design features is planned to be comprehensive and includes examples cited by the Board (i.e., restricted peak temperature, long term ventilation and waste package material layering options) as well as many others. Information on the budget for the alternatives work may not adequately reflect the extent of the effort. There is substantial work in the Fiscal Year 1999 planning, which will benefit the alternative effort although not coded as such (e.g., engineering on facility elements which are building blocks for alternatives). Also, substantial advantage will be taken of previous, well-documented work which has heretofore been presented as topical information, but which can now be applied in integrated design alternatives and design feature evaluations. Previous work will be updated as necessary.

The planning for the alternatives evaluation work has been geared towards meeting the May 1999 design decision. The schedule is challenging and has been identified as one of the top priority items by Project management, both in terms of management attention and support of resources to accomplish the work.