U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

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

January 1, 2001, to January 31, 2002

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
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April 2002

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

The Honorable Robert C. Byrd
President Pro Tempore
United States Senate
Washington, D.C. 20510

The Honorable E. Spencer Abraham
Secretary
U.S. Department of Energy
Washington, D.C. 20585

Dear Speaker Hastert, Senator Byrd, and Secretary Abraham:

The Nuclear Waste Technical Review Board submits this *Report to the U.S. Congress and The Secretary of Energy* in accordance with provisions of the Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203, which requires the Board to report its findings and recommendations to Congress and the Secretary of Energy at least 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 that is related to the design of the repository and to the packaging and transport of spent nuclear fuel and high-level radioactive waste. In this report, the Board summarizes its major activities between February 1, 2001, and January 31, 2002.

During that period, the Board focused on evaluating the technical basis of the DOE's work related to a site recommendation, including the DOE's characterization of the Yucca Mountain site, the DOE's design of the repository and waste package, and the DOE's estimates of how a repository system developed at the site might perform. The Board's review culminated in a January 24, 2002, letter report to Congress and the Secretary of Energy. The major points of that letter and a description of activities undertaken by the Board in developing its evaluation are included in the enclosed summary report.

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We believe that the information in the Board's report will be useful to policy-makers faced with important decisions on the management of the nation's spent nuclear fuel and high-level radioactive waste.

We thank you for this opportunity to present the Board's views.

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 U. S. Department of Energy's (DOE) efforts to develop a system 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 activities undertaken by the Board between January 1, 2001, and January 31, 2002.

Four full Board meetings, three panel meetings, and an extended Board business meeting were held during this period. The meetings were designed to develop the basis for the Board's views on the work related to the DOE's characterization of the Yucca Mountain site, on its design of the repository and waste package, and on its estimates of how a repository system, if developed at the site, might perform. The Board's review and evaluation culminated in a January 24, 2002, letter report to the Speaker of the House of Representatives, Dennis Hastert; the President Pro Tempore of the Senate, Robert Byrd; and the Secretary of Energy, Spencer Abraham. The Board made the following key points.

- In evaluating the DOE's technical and scientific work related to individual natural and engineered components of the proposed repository system, the Board finds varying degrees of strength and weakness. Such variability is not surprising, given that the Yucca Mountain project is in many respects a first-of-a-kind, complex undertaking. When the DOE's technical and scientific work is taken as a whole, the Board's view is that the technical basis for the DOE's repository performance estimates is weak to moderate at this time.

- The Board makes no judgment on the question of whether the Yucca Mountain site should be recommended or approved for repository development. Those judgments, which involve a number of public policy considerations as well as an assessment of how much technical certainty is necessary at various decision points, go beyond the Board's congressionally established mandate.

- The DOE uses a complex integrated performance assessment model to project repository system performance. Performance assessment is a useful tool because it assesses how well the repository system as a whole, not just the site or the engineered components, might perform. However, gaps in data and basic understanding cause important uncertainties in the concepts and assumptions on which the DOE's performance estimates are now based. Because of these uncertainties, the Board has limited confidence in current performance estimates generated by the DOE's performance assessment model.

- This limited confidence is not an assessment of the Board's level of confidence in the Yucca Mountain site. At this point, no individual technical or scientific factor has been identified that would automatically eliminate Yucca Mountain from consideration as the site of a permanent repository.

- An international consensus is emerging that a fundamental understanding of the potential behavior of a proposed repository system is of importance comparable to the importance of showing

compliance with regulations. The Board agrees that such basic understanding is very important.

- Confidence in waste package and repository performance potentially could increase if the DOE adopts a low-temperature repository design. However, a full and objective comparison of high- and low-temperature repository designs should be completed before the DOE selects a final repository design concept.

- The DOE can increase confidence in its performance estimates by, among other things, developing multiple lines of evidence and strengthening its arguments about defense-in-depth. It also can work to ensure better integration of new data and analyses, monitor repository performance, develop a strategy for modifying or stopping repository construction and waste emplacement if unforeseen circumstances are encountered, and continue external review of its technical and scientific activities.

In addition to this significant evaluation in advance of the President's site recommendation decision, the Board focused on many specific issues during 2001. Those issues included multiple lines of evidence, corrosion processes, hydrothermal upwelling, and potential consequences of igneous activity at the Yucca Mountain site. The remainder of this report describes those issues and other activities in more detail.

Board Activities

The U. S. Nuclear Waste Technical Review Board (Board) is charged in the Nuclear Waste Policy Amendments Act (NWPAA) (Congress 1987) with evaluating the technical and scientific validity of the work undertaken by the U. S. Department of Energy (DOE) to develop a mined geologic repository system for disposing permanently of the high-level radioactive waste (HLW) and spent nuclear fuel (SNF) produced by the nation's nuclear defense complex and commercial nuclear power plants. Between January 1, 2001, and January 31, 2002, the period covered by this report, several important milestones were reached, not only by the DOE but also by the two agencies that would regulate any repository that is developed, the U. S. Environmental Protection Agency (EPA) and the U. S. Nuclear Regulatory Commission (NRC). This report begins with a brief description of these milestones and then summarizes the Board's activities.

I. Program and Regulatory Milestones

For more than two decades, the DOE has been characterizing Yucca Mountain in Nevada to evaluate the suitability of the site for constructing a mined geologic repository for the permanent disposal of HLW and SNF. The DOE also has been preparing designs of the package that would contain the waste for disposal and of the subsurface repository facilities. On May 7, 2001, the DOE released a summary of its technical work, *Yucca Mountain Science and Engineering Report, Revision 0* (*S&ER*) (DOE 2001a), and a supplement to the draft environmental impact statement (EIS) for the proposed Yucca Mountain repository (DOE 2001b). At the same time, the DOE solicited public comments on whether the Secretary of Energy should recommend to the President that a repository be developed at the site.

On June 13, 2001, the EPA published its final environmental standard for a Yucca Mountain repository, 40 CFR 197 (EPA 2001). In that standard, the EPA established preclosure performance criteria for the repository. Of particular interest to the Board, the EPA also set the rules under which the postclosure behavior of a Yucca Mountain repository would be judged. The EPA required the DOE to use a complex modeling methodology, called "total system performance assessment" (TSPA), to project the ability of a repository system to isolate and contain HLW and SNF. For a repository system to be approved, the DOE would have to show, using TSPA, that there is a "reasonable expectation" that the system would satisfy three standards for at least 10,000 years.

- The repository would have to limit the individual total effective dose equivalent (TEDE) from released radionuclides so that it would be no higher than 15 millirems (mrem)/year using a scenario that combines nominal repository performance as well as performance under disruptive conditions, such as igneous activity.

- The repository would have to be sufficiently robust so that a dose no higher than 15 mrem/year would be received in the case of a stylized human intrusion scenario.

- Radionuclide contamination of groundwater in the vicinity of Yucca Mountain would not exceed

the permissible levels specified in existing drinking water regulations.

The EPA set the compliance point for the three standards at 18 kilometers south (the putative direction of groundwater flow) of the footprint of the proposed repository.

In July 2001, the DOE authorized the release of *FY 01 Supplemental Science and Performance Analyses* (*SSPA*) (BSC 2001). The DOE requested this document partly in response to concerns that the Board had raised in an August 2000 letter to Representative Joseph Barton (Cohon 2000) and in Board Chairman Jared Cohon's comments at a January 2001 meeting in Amargosa Valley, Nevada (NWTRB 2001a). On August 21, 2001, the DOE released *Yucca Mountain Preliminary Site Suitability Evaluation* (*PSSE*) (DOE 2001c). The Secretary also sought public comment on this document.

On November 2, 2001, the NRC published its final licensing rule for a Yucca Mountain repository, 10 CFR 63 (NRC 2001). The rule incorporated the provisions in the EPA's environmental standard. It also specified the details of the licensing process and described the information that the DOE must submit to receive approval for constructing a repository.

The DOE promulgated its final site-suitability guidelines, 10 CFR 963 (DOE 2001d), on November 14, 2001. Under the guidelines, the DOE may determine that the site is suitable if it meets the EPA's preclosure and postclosure requirements. The DOE would use safety analyses to show that the preclosure criteria are met. The DOE would use TSPA to show that the postclosure criteria have been met for 10,000 years.

On January 10, 2002, Secretary of Energy Spencer Abraham notified the State of Nevada's governor that he intended to recommend to President George W. Bush that Yucca Mountain be approved as the site of a geologic repository for HLW and SNF (Abraham 2002a). The Secretary officially recommended the site to President Bush (Abraham 2002b, DOE 2002a) on February 14, 2002. At the same time, the DOE published the final environmental impact statement for Yucca Mountain (DOE 2002b); *Yucca Mountain Science and Engineering Report, Revision 1* (DOE 2002c); *Yucca Mountain Site Suitability Evaluation* (DOE 2002d); and a document compiling the DOE's responses to public and agency comments on previously released reports (DOE 2002e). On February 15, 2002, President Bush informed Congress that he had accepted the Secretary's recommendation (Bush 2002).

II. Board Findings and Recommendations

January 30-31, 2001, Winter Board Meeting in Amargosa Valley, Nevada (NWTRB 2001a)

At this meeting, the Board described its four priorities, which it termed "essential elements of any DOE site recommendation." (See NWTRB 2001b for a fuller discussion of the priorities.) These priorities are as follow:

1. Meaningful quantification of conservatisms and uncertainties in the DOE's performance assessments

2. Progress in understanding the underlying fundamental processes involved in predicting the rate of waste package corrosion

3. An evaluation and a comparison of the base-case repository design with a low-temperature design

4. Development of multiple lines of evidence to support the safety case of the proposed repository. The lines of evidence should be derived independently of performance assessment [TSPA] and thus not be subject to the limitations of performance assessment [TSPA].

In addition to these overarching priorities, the Board made a number of suggestions about other investigations and studies that can support, complement, and supplement these four areas. Those investigations and studies include research on the unsaturated and saturated zones.

Later on in the meeting, the DOE answered five specific questions dealing with its analyses of

waste package corrosion, flow and transport of radionuclides in the unsaturated and saturated zones, the importance of the waste package in isolating and containing radionuclides, and the criteria the DOE might use to select a repository design. The DOE discussed its ongoing efforts to evaluate uncertainties in the latest iteration of TSPA, its revision of *Repository Safety Strategy* (CRWMS 2000), and its ability to learn from experience and new information.

In a March 30, 2001, letter to the DOE (Cohon 2001a), the Board commented on the DOE's studies for addressing the four priorities. The Board observed that it was "pleased with the efforts made so far to quantify better the uncertainties and conservatisms" in TSPA. The Board noted, however, that the DOE had not yet considered possible differences that may evolve over time between the performance of the engineered barrier systems as they have been designed and their performance as they actually might be built. The Board commended the DOE for developing a set of investigations that could lead to improved understanding of fundamental waste package corrosion processes. The Board also recognized that work had begun in evaluating and comparing repository designs. Finally, the Board noted that additional effort is needed to develop multiple lines of evidence derived independently of TSPA. In other matters, the Board restated its concern that the DOE has not yet reconciled the conflicting findings of its National Laboratory contractors on the possible presence of bomb-pulse chlorine-36 at the repository horizon. Moreover, the Board commented that questions remain about the compositions and corrosion effects of electrolytes that may form on waste package surfaces.

April 13, 2001, Ad Hoc Panel Meeting in Washington, D.C. (NWTRB 2001c)

This meeting focused on how the DOE might develop multiple lines of evidence derived independently of performance assessment. The meeting included a roundtable discussion involving six Board members, five members of the DOE and its contractor team, and three independent researchers identified by the Board. These participants addressed how natural and engineered analogues and simplified calculations might add confidence to the conclusions generated by performance assessment, the reasons that developing multiple lines of evidence might be important, and the relationship between traditional notions of defense-in-depth and the use of multiple lines of evidence.

In a June 11, 2001, letter to the DOE (Cohon 2001b), the Board reiterated its view that developing multiple lines of evidence is an essential element in any site recommendation decision that the DOE might make. The Board observed that although multiple lines of evidence might support some performance assessment conclusions, other conclusions might not be supported. It would be important for the DOE to investigate both possibilities. The Board also urged the DOE to use multiple lines of evidence to gain insight into phenomena whose uncertainty significantly affects estimates of repository performance. Finally, the Board was encouraged to hear from DOE representatives that a case for multiple barriers and defense-in-depth might be advanced using lines of evidence other than performance assessment.

May 8-9, 2001, Spring Board Meeting in Arlington, Virginia (NWTRB 2001d)

At this meeting, the Board heard presentations dealing with each of its four priorities. In addition, the DOE addressed several specific questions about its latest TSPA analyses. Finally, participants in the joint State of Nevada-DOE study of fluid inclusions reported on how they interpreted the latest round of findings.

In a July 17, 2001, letter to the DOE (Cohon 2001d), the Board observed that it continued to be encouraged by the work undertaken to quantify uncertainties and conservatisms in TSPA. The Board, however, expressed two concerns. First, the DOE may be dismissing some sources of uncertainty prematurely simply because they seem to have very minor effects on the performance of a particular barrier or component. Second, even if uncertainty in a single component or barrier does not have a large effect on final dose calculations, it may, together with other "minor" uncertainties, have a nonnegligible cumulative effect. The Board cautioned the DOE that although obtaining corrosion

data to better specify model parameters had obvious short-term appeal, investigations also need to focus on improving the validity of the underlying models. The Board withheld judgment on the appropriateness of the DOE's approach of taking a single general repository design and comparing its performance and associated uncertainties when operated in a high-temperature mode and in a selected low-temperature mode. The Board looked forward to reviewing the additional analyses that the DOE promised would address this priority area. Finally, the Board urged the DOE to give priority to the study of natural and engineering analogues, such as Peña Blanca and josephinite.

June 20-21, 2001, Joint Panel Meeting in Las Vegas (NWTRB 2001e)

This meeting was devoted to a draft of *SSPA*, which sought to quantify uncertainties and conservatisms, provide additional system and subsystem analyses, and evaluate the performance of low- and high-temperature operating modes for a fixed design concept. The primary vehicle for these analyses was an updated and more realistic TSPA than the December 2000 *Total System Performance Assessment for Site Recommendation* (*TSPA-SR*) (DOE 2000).

All the important components of the draft *SSPA* were discussed at the meeting. The Board noted that a great deal of work had been carried out and that the DOE appeared to have been responsive in addressing the Board's four priority areas. Subsequently, the Board reviewed the final version of *SSPA* (BSC 2001), issued in July 2001. The Board found that *SSPA* represents a considerable improvement over *TSPA-SR*. (Improvement is defined here as reflecting a more accurate representation of reality, the state of knowledge, and uncertainties. See NWTRB 2002a.) The improvement was most substantial in the portrayal of the engineered components of the repository system and less so for the natural barrier system. Problematic areas still remain, however, such as the fact that the performance estimates exhibit instability, changing significantly with each iteration of TSPA.

September 10-12, 2001, Fall Board Meeting in Las Vegas, Nevada (NWTRB 2001g)

At this meeting, the DOE discussed *SSPA* and *PSSE*. The Board also heard from representatives of the State of Nevada and the NRC's Center for Nuclear Waste Regulatory Analysis (CNWRA) about their work on waste package corrosion. In addition, the work of the DOE-sponsored peer review on waste package materials was described. Finally, the DOE and a representative of CNWRA presented their models of the consequences of igneous activity.

In an October 17, 2001, letter to the DOE (Cohon 2001e), the Board observed that, on the basis of its preliminary review of *SSPA*, "progress has been made." The Board's main message in the letter, however, was that its upcoming evaluation of the status of the DOE's program, including progress in addressing the Board's four priority areas, has been made more difficult because of gaps in data and analyses. The Board specifically pointed to the following:

1. Incomplete comparison of high- and low-temperature repository designs

2. Unanswered questions about the contributions of natural and engineered barriers to the repository system's capacity to isolate and contain radionuclides

3. Lack of a rationale for going forward to a possible site-recommendation decision in the face of unresolved issues relating to the consequences of igneous activity.

The Board asked the DOE to forward any additional information or letter reports that relate to these gaps in time to be considered at the Board's business meeting at the end of November 2001.

November 27-29, 2001, Board Business Meeting in San Diego, California

The Board held a three-day business meeting to review and evaluate the DOE's Yucca Mountain site-characterization work and its efforts related to the designs of the repository and the waste package.

In addition, the Board considered the DOE's analyses of how a potential repository for disposing of HLW and SNF might perform if developed at the site. The Board closely examined the DOE's documented investigations and analyses of 10 natural and engineered components of the repository system as well as the disruptive-event scenarios. In carrying out the examination, the Board posed 10 questions. The Board also considered the degree to which the DOE had addressed each of the Board's priority areas. Finally, the Board held an extended discussion of how to integrate the Board's evaluation of various elements of the work conducted by the DOE. Individual Board members and the Board collectively arrived at an overall assessment of the DOE's scientific and technical work, particularly its estimates of repository performance, using a three-point scale: "weak," "moderate," and "strong."

In a January 24, 2002, letter to the Speaker of the House of Representatives, Dennis Hastert; the President Pro Tempore of the Senate, Robert Byrd; and the Secretary of Energy, Spencer Abraham, the Board made the following key points (NWTRB 2002a).

- In evaluating the DOE's technical and scientific work related to individual natural and engineered components of the proposed repository system, the Board finds varying degrees of strength and weakness. Such variability is not surprising, given that the Yucca Mountain project is in many respects a first-of-a-kind, complex undertaking. When the DOE's technical and scientific work is taken as a whole, the Board's view is that the technical basis for the DOE's repository performance estimates is weak to moderate at this time.

- The Board makes no judgment on the question of whether the Yucca Mountain site should be recommended or approved for repository development. Those judgments, which involve a number of public policy considerations as well as an assessment of how much technical certainty is necessary at various decision points, go beyond the Board's congressionally established mandate.

- The DOE uses a complex integrated performance assessment model to project repository system performance. Performance assessment is a useful tool because it assesses how well the repository system as a whole, not just the site or the engineered components, might perform. However, gaps in data and basic understanding cause important uncertainties in the concepts and assumptions on which the DOE's performance estimates are now based. Because of these uncertainties, the Board has limited confidence in current performance estimates generated by the DOE's performance assessment model.

- This limited confidence is not an assessment of the Board's level of confidence in the Yucca Mountain site. At this point, no individual technical or scientific factor has been identified that would automatically eliminate Yucca Mountain from consideration as the site of a permanent repository.

- An international consensus is emerging that a fundamental understanding of the potential behavior of a proposed repository system is of importance comparable to the importance of showing compliance with regulations. The Board agrees that such basic understanding is very important.

- Confidence in waste package and repository performance potentially could increase if the DOE adopts a low-temperature repository design. However, a full and objective comparison of high- and low-temperature repository designs should be completed before the DOE selects a final repository design concept.

- The DOE can increase confidence in its performance estimates by, among other things, developing multiple lines of evidence and strengthening its arguments about defense-in-depth. It also can work to ensure better integration of new data and analyses, monitor repository performance, develop a strategy for modifying or stopping repository construction and waste emplacement if unforeseen circumstances are encountered, and continue external review of its technical and scientific activities.

January 29-30, 2002, Winter Board Meeting in Pahrump, Nevada (NWTRB 2002b)

At this meeting, the Board heard presentations on several recent external reviews of the DOE's estimates of projected repository performance. The Board also was briefed on recent regulatory developments at the NRC. The latest work on modeling fluid flow and transport of radionuclides in the unsaturated and saturated zones was presented. Finally, the DOE described to the Board its efforts to portray and communicate the uncertainties associated with TSPA.

III. Board Reviews and Investigations

Field Trips

Field excursions to Yucca Mountain and to other geologically relevant places are an important component of Board activities. In addition to making multiple trips to Yucca Mountain, Board members and professional staff visited Amargosa Valley, Nevada; Death Valley, California; and Peña Blanca, Mexico, in 2001. What follows is a description of the last field trip.

In May 2001, Board members and staff, along with representatives of the DOE's Yucca Mountain Project team, made a geological field excursion to Peña Blanca, a potential analogue site to Yucca Mountain, Nevada. A former CNRWA scientist led the trip. Located in Chihuahua, Mexico, Peña Blanca is the site of an approximately 8-million-year-old hydrothermal deposit of uranium ore.

As noted above, the Board believes that the DOE may be able to use analogues to develop multiple independent lines of evidence for evaluating and informing predictive process models. By possibly reducing admissible ranges of uncertainty in features or processes or possibly invalidating alternative conceptual models, analogues can contribute to increasing confidence in TSPA projections. As an analogue, Peña Blanca has the following features in common with Yucca Mountain: unsaturated fractured silicic volcanic rocks, arid climate, oxidizing geochemical environment, and an underlying carbonate aquifer.

Uranophane, an oxidized secondary mineral incorporating uranium, was observed in the field. A variety of uranium-bearing minerals was sorbed onto iron oxide surfaces coating fractures at the site. Although uranium and ferrous minerals are not present now either at Yucca Mountain or in the groundwater beneath it, they will be introduced if waste is emplaced there. Because each of them can substantially slow radionuclide migration, secondary mineralization and sorption have potentially significant implications for radionuclide transport from a nuclear waste repository at Yucca Mountain. Even after millions of years, natural hydrogeologic transport processes had removed no more that 20 percent of the initial uranium-bearing mineral mass at Peña Blanca. Board members were favorably impressed with the potential of Peña Blanca as an analogue site.

Board Comments on the DOE's Supplement to the Draft Environmental Impact Statement

The DOE issued a draft EIS for the proposed Yucca Mountain repository in July 1999 (DOE 1999). After publication of the document, the repository design evolved, incorporating possible design options and operating modes. The current design, referred to as the "flexible design," is documented in *S&ER* (DOE 2001a). According to the DOE, this design can be operated in a range of higher and lower temperatures and associated humidity conditions. In *higher-temperature* operating modes, parts of the emplacement-drift rock walls would have maximum temperatures above the boiling point of water; *lower-temperature* operating modes would keep the maximum temperatures of all emplacement-drift rock walls below boiling. The supplement to the draft EIS (DOE 2001b) evaluated potential environmental impacts that could occur for the range of possible operating modes of the flexible design and compares the impacts to those presented in the draft EIS.

In comments on the supplement to the draft EIS (Cohon 2001c), the Board reiterated its belief that the technical basis for projecting the long-term performance of a higher-temperature design has

weaknesses. The Board urged the DOE to justify using the design operated in a low-temperature mode as a surrogate for a true low-temperature design to project environmental effects, especially long-term releases of radionuclides to the environment. The Board recommended that the DOE revise its performance assessment models to capture the effects of temperature more accurately, allowing an improved assessment of the merits of higher-temperature versus lower-temperature repository designs.

Workshop on Long-Term Extrapolation of Passive Behavior (NWTRB 2001f)

The 2-centimeter-thick Alloy 22 outer shell of the waste package is a very important barrier for the 10,000-year repository regulatory period and beyond. Alloy 22, a very corrosion-resistant alloy consisting principally of nickel, chromium, molybdenum, tungsten, and iron, belongs to a class of metals and alloys that owe their corrosion resistance to a nearly impervious, very tenacious passive layer only nanometers thick. Generally, such passive layers form spontaneously on exposure to ambient conditions and consist of oxides of one or more metals of the underlying material. Because engineering experience with *any* corrosion-resistant metal or alloy that depends on a passive layer for its corrosion resistance spans little more than a century, there are questions about the technical basis for extrapolating the behavior of the passive layer for 10,000 years.

To address these questions, the Board decided to conduct a workshop on issues related to predicting corrosion behavior for periods of unprecedented duration. The Workshop on Long-Term Extrapolation of Passive Behavior was held on July 19 and 20, 2001, in Arlington, Virginia. Fourteen international experts from a spectrum of corrosion disciplines were invited to participate. To ensure that broad, diverse, and independent views were obtained, most of the participants were selected from among those with little or no direct recent involvement in the Yucca Mountain Project.

The Board's Web site, www.nwtrb.gov, contains thorough documentation of the workshop, including the agenda, a complete transcript, and a compendium of short papers submitted by the invited experts after the workshop. The documentation describes the ideas furnished by the participants regarding mechanisms that could create or aggravate corrosion over long periods of time but that may remain unobserved in the relatively short-term tests conducted to date. The participants also suggested research that could be conducted to evaluate the likelihood of those processes occurring.

Hydrothermal Upwelling

In a July 24, 1998, letter to the DOE (NWTRB 1998), the Board presented the results of its review of material submitted by Jerzy Szymanski to the Board at its January 1997 meeting in Pahrump, Nevada. The Board concluded, "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." However, there was some evidence from fluid inclusions in secondary mineral deposits of the past presence of fluids at elevated temperatures (at least 72° C) in the vicinity of the proposed repository. The critical question is the age of these fluid inclusions. Are the inclusions relatively recent? If so, they might be viewed as evidence of ongoing hydrothermal activity. Are the inclusions millions of years old? If so, they might be related to other processes, such as the original formation of Yucca Mountain 10 to 13 million years ago, and thus would have no bearing on the hypothesis of ongoing hydrothermal activity. The Board recommended that a joint State of Nevada-DOE program be initiated to study fluid inclusions at Yucca Mountain and determine their ages.

The DOE sponsored such a study, which was coordinated by scientists at the University of Nevada, Las Vegas (UNLV). U. S. Geological Survey (USGS), State of Nevada, and UNLV scientists presented the results of the study at the May 2001 meeting of the Board in Washington, D. C. The Board was impressed by the studies, particularly by the systematic approach taken by UNLV scientists in which fluid inclusions were found to be at least 2 or more million years old. The UNLV scientists also

concluded, "This study demonstrates that the hypothesis of geologically recent upwelling hydrothermal fluids is untenable and should not disqualify Yucca Mountain as a potential nuclear waste storage site." These conclusions were supported by independent studies carried out by USGS scientists but were not supported by State of Nevada scientists.

The DOE discussed its overall conclusions in a January 24, 2002, letter to the Board (Dyer 2002) and in a presentation at the Board's January 2002 meeting. The DOE concluded that upwelling waters or seismic pumping hypotheses have been "adequately addressed and may be discounted." The Board concurs with the conclusions of the UNLV, USGS, and DOE scientists and considers this issue resolved. The Board also fully supports the DOE's stated commitment to continuing to examine secondary minerals in conjunction with infiltration, flux rate, thermal effects, waste package geochemistry, paleohydrology, and other studies and to continuing ongoing studies of the thermal history of younger fluid inclusions.

Potential Consequences of Igneous Activity at the Yucca Mountain Site

In an October 17, 2001, letter to the DOE (Cohon 2001e), the Board expressed concern about disagreements arising from different igneous consequence models proposed by the DOE on the one hand and by CNWRA on the other. The conflicting models were discussed at the Board's September meeting in Las Vegas. Because of the events of September 11, 2001, invited Board consultants on igneous consequence models were not able to travel to the Las Vegas meeting. On November 8, 2001, several Board members and professional staff met with the consultants at the Board offices in Arlington, Virginia. A former Board member, Dr. Clarence Allen, also participated in the discussions. When the reports by the consultants were received, they were made available on the Board's Web site.

On the basis of the meeting with the consultants and their reports, the Board believes that the model proposed by the NRC-sponsored CNWRA may be a conservative end-member model, and, consequently, the Board's concern over this issue has lessened. However, additional work on, and a better understanding of, igneous consequences is needed, particularly in light of performance-assessment calculations that show that igneous activity is the largest contributor by far to radioactive dose during the first 10,000 years. The Board's understanding is that both the DOE and the NRC are supporting additional studies in this area.

The Board, however, has one specific recommendation on igneous issues and their presentation. The DOE needs to devote thought and effort to better portraying the nature of igneous activity to decision-makers and the public. Although the use of probability-weighted calculations may be computationally correct, it fails to convey the unique nature of igneous activity as being a high-consequence, low-probability event.

International Activities

Since its first meeting in 1989, the Board has sought to increase its knowledge and understanding of the problems shared by other nations as they try to find safe ways to dispose of HLW and SNF. In 2001, the Board made two international trips.

In July, a small delegation from the Board traveled to Switzerland to meet with representatives of the National Cooperative for the Disposal of Radioactive Waste (NAGRA). The purpose of the visit was to meet and discuss NAGRA's approach to developing and implementing a research and development (R&D) plan for investigating opalinus clay as a potential geology for a permanent repository for Switzerland's high-level radioactive waste. Topics of mutual interest that were discussed included development of a repository safety case, characterization of uncertainty, setting priorities in the R&D program and integrating the work, and the Swiss approach to conducting performance assessment. Sites visited included Mont Terri Underground Rock Laboratory (opalinus clay), Grimsel Underground Laboratory (granite), and ZWILAG facility (interim storage of high-level radioactive waste).

At the conclusion of the trip, Board representatives spent part of a day in Berlin in a meeting with members of Arbeitskreis Auswahlverfahren Endlagerstandorte. This committee of 15 experts,

appointed by Germany's Federal Minister for the Environment, is responsible for recommending procedures on the selection of sites for disposing of radioactive waste in Germany.

In October, a delegation from the Board traveled to Japan to meet with representatives of the following organizations: Ministry of Economy, Trade and Industry; Nuclear Safety Commission; Nuclear Waste Management Organization; Radioactive Waste Management Funding and Research Center; Japan Nuclear Cycle Development Institute (Tokai Works and Tono Geoscience Center); Japan Nuclear Fuel Limited (Rokkosho-mura); and the City of Mizunami. The purpose of the visit was to meet with those involved in organizing, managing, conducting R&D, setting regulations, or potentially hosting R&D sites since the 1998-2000 reorganization of the country's program. Included were site visits to R&D, HLW vitrification, and storage facilities.

IV. Evaluation of the Board's Performance During 2001

The Board believes that measuring its effectiveness by directly correlating improvements in the DOE program with Board actions and recommendations would be ideal. However, the Board has no implementing authority, so it cannot compel the DOE to comply with its recommendations. Consequently, a judgment about whether a specific recommendation had a positive outcome for the DOE program is, in most cases, (1) subjective and (2) an imprecise indicator of the Board's performance because implementation of Board recommendations by the DOE is outside the Board's direct control. Therefore, to measure its performance in a given year, the Board has developed performance measures. For each annual performance goal, the Board considers the following:

1. Were the reviews, evaluations, and other activities undertaken under the auspices of the goal completed?

2. Were the results of the reviews, evaluations, and other activities communicated in a timely, understandable, and appropriate way to Congress and the Secretary of Energy?

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

During 2001, the Board identified four priority areas and a number of other issues that it believed should be addressed as part of any site recommendation, and it communicated this information to the DOE and Congress. Throughout the year, the Board was involved in an intensive and comprehensive review of DOE activities related to a secretarial decision on whether to recommend the Yucca Mountain site. On the basis of these activities and consistent with performance measures described above, the Board's performance for 2001 related to site investigations and other activities undertaken by the Secretary in preparation for a decision on site recommendation was judged effective. However, because of the focus on site investigations, the Secretary's activities related to transportation and packaging of spent fuel and high-level radioactive waste were extremely limited during the last year. The Board therefore deferred its performance goals related to the waste management system until such time as the Secretary undertakes technical and scientific work in this area. A more detailed evaluation of the Board's performance in 2001 is included in Appendix H.

Abbreviations and Acronyms

BSC	Bechtel SAIC Company, LLC
CFR	*Code of Federal Regulations*
CNWRA	Center for Nuclear Waste Regulatory Analysis
DOE	U. S. Department of Energy
EIS	environmental impact statement
EPA	U. S. Environmental Protection Agency
HLW	high-level radioactive waste
mrem	millirem
NAGRA	National Cooperative for the Disposal of Radioactive Waste
NRC	U. S. Nuclear Regulatory Commission
NWPAA	Nuclear Waste Policy Amendments Act of 1987
NWTRB	U. S. Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
PSSE	*Preliminary Site Suitability Evaluation*
R&D	research and development
S&ER	*Science and Engineering Report*
SNF	spent nuclear fuel
SSPA	*Supplemental Science and Performance Analyses*
TEDE	total effective dose equivalent
TSPA	total system performance assessment
TSPA-SR	total system performance assessment—site recommendation
UNLV	University of Nevada, Las Vegas
USGS	U.S. Geological Survey

Glossary

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

analogue Phenomena or materials that can provide information on or add understanding to aspects of repository performance. Analogues are of two types: natural and anthropogenic. Natural analogues may arise from natural phenomena or from materials that have been naturally formed. Anthropogenic analogues result from human activity. An "archaeological analogue" is an anthropogenic analogue resulting from the activities of ancient cultures.

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

container A receptacle used to hold radioactive material.

defense high-level waste High-level waste generated by defense programs, as distinguished from waste generated by commercial and research facilities.

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. Defense-in-depth is greatest when the barriers are fully redundant.

disposal The isolation of radioactive materials from the accessible environment with no intent of recovering them.

engineered barrier system The constructed components of a disposal system designed to retard or prevent the release of radionuclides from the underground facility. They can include the waste forms, fillers, waste containers, shielding, material placed over and around such containers, and backfill materials.

environmental impact statement (EIS) A detailed written statement to support a decision whether to proceed with major actions affecting the quality of the human environment. Required by the National Environmental Policy Act, the environmental impact statement describes the environmental impact of the proposed action; any adverse environmental effects that cannot be avoided if the proposal is implemented; alternatives to the proposed action; the relationship between local, short-term uses of humankind's environment and the maintenance and enhancement of long-term productivity; and any irreversible and irretrievable commitments of resources that would be involved in the proposed action if it is implemented.

fluid inclusion A tiny (100 micron in diameter) cavity containing liquid or gas, or both, formed by the entrapment of liquid in crystal irregularities.

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

high-level radioactive waste Highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing or any solid material derived from such liquid waste; and any other highly radioactive material that the U.S. Nuclear Regulatory Commission, consistent with existing law, determines requires permanent isolation by disposal in a geologic repository.

high-temperature operating mode Allowing the temperature of the waste package surface to exceed the boiling point of water for a significant period of time.

igneous Formed by volcanic activity.

license application A document submitted to the U.S. 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.

low-temperature operating mode Keeping the temperature of the waste package surface significantly below the boiling point of water.

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

natural analogue See **analogue**.

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

preclosure The time before the repository is closed.

postclosure The time after the repository is closed.

radioactivity The spontaneous emission of radiation from the nucleus of an atom. Radioisotopes of elements lose particles and energy through radioactive decay. Radioactivity is measured in terms of the number of nuclear disintegrations occurring in a unit of time. Units of radioactivity are the curie (Ci) and the becquerel (Bq).

radionuclide A radioactive isotope, as specified by its atomic number, atomic mass, and energy state.

radionuclide transport The movement of radionuclides, generally in liquid or gas forms, through a rock formation.

repository system The combination of natural features and engineered barriers that together isolate and contain radioactive waste.

retrievability The ability to remove waste packages from the repository.

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

site recommendation The President's recommendation to Congress that a site be developed as a repository. The site recommendation process is set forth in the Nuclear Waste Policy Act.

site suitability A determination by the U.S. Department of Energy that if a repository were developed at a particular site, it would likely meet the environmental standards established by the U.S. Environmental Protection Agency.

siting guidelines Guidelines set forth in 10 CFR 963, that are to be used by the U.S. Department of Energy in assessing the suitability of the site.

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.

thermal-loading strategies Placing waste in a repository so that the heat produced by it will cause specific effects on repository performance. The strategies are based on whether it is desirable for the repository to be at a temperature below or above the boiling point of water and the effect that different temperature ranges will have on long-lived waste packages.

total system performance assessment (TSPA) Analyses undertaken by the U.S. Department of Energy to assess the ability of a potential repository at Yucca Mountain to provide long-term waste isolation and containment.

unsaturated rock A rock in which some or all of the connected interstices or voids are filled with air.

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

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

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