Moving Beyond the Yucca Mountain Viability Assessment

A Report to the U.S. Congress and the Secretary of Energy

U.S. Nuclear Waste Technical Review Board
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Nuclear Waste Technical Review Board

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Introduction

The Nuclear Waste Policy Act, as amended (U.S. Congress, 1987), designated the Yucca Mountain site in Nevada as the sole location to be studied for possible development as a repository for the permanent disposal of spent nuclear fuel and high-level radioactive waste. The act also established the U.S. Nuclear Waste Technical Review Board and charged the Board with evaluating the technical and scientific validity of activities undertaken by the Secretary of Energy, including characterization of the Yucca Mountain site.

The U.S. Department of Energy (DOE) recently published *Viability Assessment of a Repository at Yucca Mountain* (DOE 1998). The purposes of the viability assessment (VA) are to summarize the scientific information that has been collected at the site over the last 15 years, present a conceptual design for the repository and its waste packages, estimate how well such a repository would isolate wastes from the human environment, identify the additional studies (and their costs) needed to evaluate the suitability of the site and prepare a license application, and estimate the overall cost of waste disposal at the site. The VA is an evaluation of progress on site characterization at Yucca Mountain and provides the technical basis for deciding whether to continue studying the site.

The VA is not, and was not intended to be, a determination of whether the Yucca Mountain site is suitable for development as a permanent geologic repository. Additional site studies, repository design work, and analyses of repository system performance will be completed before the DOE makes a suitability determination, currently planned for 2001. So far, neither the Board's review of the VA nor its other reviews of the program have identified any features or processes that would automatically disqualify the site. However, the Board believes that the DOE should give serious consideration to alternatives to the VA reference design, including changing from a high-temperature design to a ventilated low-temperature design (e.g., below the local boiling point of water).

General Views on the VA

The VA is the most significant milestone thus far in the characterization and evaluation of the Yucca Mountain site. Many parts of the VA present cutting-edge scientific analyses in a comprehensible format. The Board commends the DOE for the successful completion of this assessment. In assembling the VA, the DOE integrated large amounts of data and analyses, established a preliminary repository design, and set priorities for work to be completed before decisions are made about site recommendation and licensing. In this report, the Board presents its general views on the site and on the design of a repository for the site, based on its review of the VA.

The process of integration has had the salutary effect of focusing the objectives of the scientific investigations. In particular, the VA highlighted the close connections between the repository design and the priority list of key uncertainties about the natural system. For example, such site characteristics as the movement of water in liquid and vapor forms at temperatures above boiling and the effects of high temperatures on rock stability are important only because of the VA's high-temperature repository design. In a low-temperature design, uncertainties about these phenomena would be less significant and might not need resolving before making a suitability determination.

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The Board concurs with the DOE that the VA is simply a "snapshot" of current knowledge about the Yucca Mountain site that the Congress can use to make an informed decision on whether to continue funding studies of the site. The Board concludes that Yucca Mountain continues to merit study as the candidate site for a permanent geologic repository and that work should proceed to support a decision on whether to recommend the site to the President for repository development. The 2001 date anticipated for this decision is very ambitious, and much work remains to be completed. At a minimum, significant progress in the work identified by the Board in its November 1998 report (NWTRB 1998) and by the DOE in volume 4 of the VA will be required to support a technically defensible decision. The Board supports continuing focused studies of both

natural and engineered barriers at Yucca Mountain to attain a defense-in-depth repository design and to increase confidence in predictions of repository performance.

Uncertainties in Repository Performance

In its November 1998 report, the Board outlined its views on future research needed to address uncertainties about the performance of the repository system, including both the engineered and the natural barriers. The Board concluded in that report that although there are economic and technical limits to reducing uncertainties about the performance of the proposed repository system, some key uncertainties can be reduced further over the next few years through a focused research effort. The Board realizes that there will be uncertainty about the performance of a repository far into the future and that eliminating all uncertainty is not possible or necessary. However, the Board believes that identifying important sources of uncertainty, estimating the magnitude of those uncertainties, reducing critical uncertainties, and evaluating the effects of residual uncertainties on expected repository performance are essential for supporting a technically defensible site-suitability determination and license application.

The Board notes that the VA relies heavily in some cases on formal elicitation of expert opinion. This was necessary and extremely useful, given the lack of field and laboratory data in certain areas and the equivocal nature of some of the data in other areas. However, as the experts themselves pointed out, expert opinion should not be used as a substitute for data that can be obtained directly from site, laboratory, and other investigations.

… additional scientific and engineering work will be needed to increase confidence …

After reviewing the VA, the Board concludes that a significant amount of additional scientific and engineering work will be needed to increase confidence in a site-suitability determination and a license application. The DOE should evaluate alternative repository designs that have the potential to reduce uncertainties in projected repository performance, thereby reducing the scope of additional necessary scientific study. Regardless of the design adopted, long-term scientific studies will be

needed to establish a solid foundation for projecting repository performance thousands of years into the future. The Board's views are discussed in more detail below.

Additional Scientific and Engineering Work

The DOE has spent many years studying the Yucca Mountain site and designing the engineered components of a repository system compatible with the site. These efforts have produced a large amount of information, but significant uncertainties remain about the ability of the VA reference design to safely isolate radioactive waste. In part, this is a problem inherent in extrapolating repository performance for thousands of years from data acquired over a much shorter period (years to decades). Uncertainties also are associated with specific characteristics of the Yucca Mountain site, especially the nature of water movement through the fractured unsaturated rocks of the mountain and the possible entry of water into repository tunnels and its contact with waste packages. Many of these uncertainties likely would be exacerbated by the high temperatures of the reference repository design, which may reduce tunnel stability, increase waste package corrosion, and perturb geochemical reactions and water movement in ways that are difficult to predict.

Predicting the performance of the waste packages, which play a crucial role in the performance of the VA reference repository design, is a critical area that needs more study. Candidate waste package materials rely on the presence of a thin passive layer to protect the underlying metal from the oxidizing environment that will be present in a Yucca Mountain repository. Improving the basic understanding of long-term passivity is essential because, at present, there seem to be no documented natural or man-made analogs that can be used to demonstrate whether this mode of protection would persist over the desired period of time. Research also should be continued on the susceptibility of the passive layer to known modes of corrosion, especially potentially catastrophic failure modes, such as stress-corrosion cracking.

The Board believes that the scientific and engineering work completed to date should be supplemented to improve the technical foundation for evaluating the suitability of the site or preparing a license application. The Board agrees with a DOE-commissioned peer review panel (Whipple et al. 1999) that two types of additional data are needed to improve the credibility of the total system performance assessment part of the VA (TSPA-VA): (1) fundamental data that are essential to the development and implementation of the models and (2) data sets designed to challenge conceptual models and test the coupled models used in the TSPA-VA. The substantial uncertainties about the performance of a repository that is based on the VA reference design can be resolved only by considering alternative repository and waste package designs and by collecting additional scientific data.

In volume 4 of the VA, the DOE has identified and set priorities for a suite of additional studies to produce information that would be needed for repository licensing, if the site is determined suitable for development as a repository. The planned studies include data collection, analysis, and engineering design, as appropriate, for the three major barriers discussed by the Board in its November 1998 report (unsaturated zone, engineered barrier system, and saturated zone). Among the most important are ongoing and proposed geologic, geochemical, and hydrologic studies, including those planned for the east-west cross drift. These studies are aimed at understanding the magnitude and distribution of seepage into the repository under conditions similar to those of today and under conditions like those that existed in the past when the climate was very different. They include systematic analysis of the rock samples being collected, especially for chlorine-36 and other indicator isotopes; flow and seepage tests at different locations along the drift; moisture-monitoring activities; tests in the lower lithophysal zones that would host the majority of waste packages; and studies of the Solitario Canyon fault, the active fault bounding the repository on the west. Of equal importance are studies for supporting projections of the performance of the engineered barrier system, which, in the VA reference design, plays a critical role in isolating radioactive wastes for tens of thousands of years.

The studies identified by the DOE in volume 4 of the VA appear to be appropriate in the sense that they are technically feasible and are likely to produce useful information that will improve the understanding of long-term repository performance. Of course, there is no guarantee that completion of these studies will lead to successful development of a repository at the site. The studies could show the site to be unsuitable, or they could raise new questions about potential repository performance. On the basis of current information, however, the Board is pleased that volume 4 identifies an appropriate suite of studies to be pursued in the years ahead.

The Board is concerned that some of the planned studies identified in volume 4 of the VA may be deferred because funds are not available to carry them out in a timely manner. Deferring scientific and engineering studies will delay the assembly of a more credible technical basis to support the site suitability determination anticipated in 2001 and, if the site is found suitable, a license application in 2002. For the current VA repository design, a credible basis does not yet exist.

Alternative Repository Designs

… designs with lower waste package surface temperatures … have the potential to reduce uncertainty … and make licensing easier.

High temperatures in the VA repository design cause large uncertainties about how the site would behave both before and after repository closure. The Board believes that repository designs with lower waste package surface temperatures merit further detailed analyses. Such designs have the potential to reduce uncertainty, simplify the analytical bases required for site recommendation, and make licensing easier. Combined with improved waste package shielding, such designs also could simplify preclosure performance confirmation by enhancing access to the tunnels, thus reducing or eliminating the need for separate performance-confirmation drifts, and by permitting direct access to performance-confirmation instrumentation near the waste packages.

The following factors influenced the Board's thinking on repository design.

- Lower temperatures would significantly reduce the uncertainty associated with coupled thermal-hydrologic and thermal-geochemical processes. Maintaining near-field temperatures below the boiling point of water after repository closure, by ventilation or through aging, could reduce uncertainties about the movement of water and associated geochemical processes in the repository's natural barriers. This could increase confidence in the analyses of repository performance required for a site-suitability determination.

- For a given environment, the chances of degradation of corrosion-resistant waste package materials would be reduced significantly if peak waste package surface temperatures were reduced.

- High repository temperatures are expected to increase the mechanical degradation of repository rocks. There is little, if any, relevant experience to draw on for predicting the long-term effects of repository heating and subsequent cooling on drift stability.

The DOE is evaluating alternative repository designs that might be appropriate as the basis for a license application, and the reference repository design presented in the VA is expected to change as the alternatives are considered. The Board strongly urges that serious consideration be given to alternatives that keep waste package surface temperatures below the boiling point of water.

Long-Term Scientific Studies

If Yucca Mountain is found suitable and construction of a repository is authorized, the Board believes that a long-term science program will be needed to improve understanding and reduce uncertainties about the performance of engineered barriers and the interactions between the repository and natural processes. An important goal of these studies should be identification of currently unknown long-term failure modes or unexpected

evolution of natural processes that could adversely affect the performance of the major barriers of the repository. Thus, the studies may be more extensive than the performance confirmation activities now anticipated for a repository. For example, if the waste package design continues to rely strongly on corrosion-resistant metals protected from corrosion by a passive layer, long-term scientific studies need to be carried out to improve the basic understanding of the processes that could affect the passive layer and the susceptibility of the passive layer to known modes of corrosion, especially potentially catastrophic failure modes, such as stress-corrosion cracking.

Long-term studies of the natural barriers also will be needed, primarily to verify projections of water movement within the unsaturated and saturated zones near the repository. For a high-temperature repository design, fundamental studies of coupled thermal-hydrologic and thermal-geochemical processes will be needed. For a low-temperature design, a less extensive program of studies of coupled thermal-hydrologic and thermal-geochemical processes may be adequate because of the much lower degree of coupling. Whether the long-term scientific studies are a decade-long program or much longer will depend in part on how the repository design evolves. There is no doubt, however, that a program of some sort will be needed to increase confidence in estimates of long-term repository performance.

Postclosure Safety Case

The ultimate goal of the studies at Yucca Mountain is to demonstrate that a repository at the site can safely isolate wastes from the human environment. As discussed in Chapter 4 of the VA, the DOE proposes to demonstrate safe waste isolation through a five-part postclosure safety case consisting of the following:

- assessment of expected postclosure performance (i.e., TSPA)
- design margin and defense-in-depth

- consideration of disruptive processes and events
- insights from natural and man-made analogs
- a performance-confirmation plan.

The Board believes that this proposed strategy is an appropriate way to evaluate a Yucca Mountain repository, although each component, especially defense-in-depth and the performance-confirmation plan, requires significant additional development. Multiple lines of evidence will provide a more convincing demonstration of repository safety than will any individual component of the safety case. TSPA, including sensitivity and uncertainty analyses, is the appropriate core analytical tool of the safety case. TSPA is the analytical technique that pulls together relevant information about the performance of the repository system, determines which features or parameters could strongly influence performance, and estimates the uncertainties in projections of performance. TSPA has its limits, however, and the DOE will need to aggressively pursue the other four components of the safety case.

Judging the realism of the "bottom-line" TSPA estimates of repository performance in the VA is difficult because some of the underlying assumptions may be overly conservative and others may be nonconservative. This is due, in large part, to a general lack of data that support many critical assumptions in the mathematical models. Numerous examples of this are presented in the recent report of the TSPA-VA peer review panel (Whipple et al. 1999).

The DOE has acknowledged the limits of the TSPA-VA. In fact, a DOE presentation to the Board (Van Luik 1999) stated that the VA's performance assessment (TSPA-VA) cannot now be used to do the following:

- Assess compliance with regulatory criteria.
- Show defense-in-depth for the design of the repository system.

- Assess the importance of small design changes.
- Determine the suitability of the overall repository system.

The DOE intends to improve future versions of TSPA so that these objectives can be accomplished.

Assessing the realism (or, at least, verifying the conservatism) of TSPA projections of repository performance is an important goal of the additional studies identified by the Board. The Board doubts, however, that relying solely on TSPA to demonstrate repository safety will ever be possible. For that reason, the other four components of the postclosure safety strategy should be developed aggressively as complements to TSPA. A sixth component of the safety strategy also should be considered: designing the waste packages and the repository to minimize uncertainties in projected repository performance.

Conclusion

The VA concludes, "… Yucca Mountain remains a promising site for a geologic repository and … work should proceed to support a decision in 2001 on whether to recommend the site to the President for development as a repository" (DOE 1998, Vol. 1). The Board agrees that Yucca Mountain continues to merit study as the candidate site for a permanent geologic repository and that work should proceed to support a decision on whether to recommend the site to the President for development. The 2001 date anticipated for this decision is very ambitious, and much work remains to be completed. At a minimum, progress on the work identified by the Board in its November 1998 report and by the DOE in volume 4 of the VA will be required to support a technically defensible decision. The Board supports continuing focused studies of both natural and engineered barriers at Yucca Mountain to attain a defense-in-depth repository design and to increase confidence in predictions of repository performance.

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