UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD

2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

September 20, 2000

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

Dear Dr. Itkin:

On behalf of the Nuclear Waste Technical Review Board, I extend our appreciation for the presentations made by your staff and contractors at the Board's meeting last month in Carson City, Nevada. We were especially pleased that you were again able to attend the meeting and address the Board. The main focus of the meeting was total system performance assessment for site recommendation (TSPA/SR), and we appreciate your staff's willingness to present and discuss the preliminary results of the calculations that are the bases for estimates of repository performance in models being developed for the TSPA/SR. The presenters were very responsive to the Board's requests for information and helped make this one of the most informative meetings the Board has held over the last few years. We would like to single out Claudia Newbury of your staff for her contributions to this meeting and other DOE-Board interactions.

The comments enclosed with this letter provide the DOE with the Board's views on the status of the program at a time when changes can be made that will strengthen the technical and scientific bases for a DOE decision, scheduled for July 2001, on whether to recommend the Yucca Mountain site. The Board notes that most of the key issues discussed in the letter (extrapolation of corrosion rates, modeling coupled processes, analyzing alternative repository designs, developing multiple lines of evidence, quantifying uncertainty) have been raised by the Board in previous letters and reports to the DOE. The Board also notes that in several areas the DOE has made significant progress since the 1998 viability assessment—e.g., substantial improvements have been made in performance assessment capability, integration has increased significantly, new and better models have been developed, and new and important data are being collected.

There remain many areas where improvements are needed, however. The Board is not convinced that the range of experiments and analyses carried out by the DOE is broad enough to describe, or even bound, all relevant coupled processes in the near-field environment affecting the engineered barrier system. Furthermore, because the understanding of fundamental corrosion processes is limited, extrapolation of corrosion rates determined from short-term (several years) experiments to predict waste package performance over tens of thousands of years is a subject of concern. Extrapolations based on assumptions about the fundamental long-term mechanisms that affect the passive layer critical to the corrosion resistance of Alloy 22 may be suspect. Although the Nye County Early Warning Drilling Program has yielded improved hydrogeological information, substantial uncertainties persist. Furthermore, it is not clear to the Board how the program plans to incorporate or reflect new data and analyses that are obtained in the next year or so in its site recommendation.

In its March 20, 2000, letter to you, the Board discussed the importance of proper treatment and estimation of uncertainties. Several suggestions were made to assist the DOE in this task. We are encouraged by the efforts made thus far and presented at the meeting, but we also offer the caution that additional efforts are needed before a case can be made that uncertainties are estimated in a technically credible manner. The Board believes that the quantification, analysis, integration, and communication of uncertainty need to be addressed in a more rigorous manner than shown in the presentations at the Board meeting. Any projection of repository performance will be incomplete unless the DOE also provides a description and a meaningful quantification of the level of uncertainty associated with its predictions.

The Board has strongly endorsed the DOE's efforts in developing multiple lines of evidence to construct a "safety case" for the proposed repository. However, the Board believes that the evolving *Repository Safety Strategy (RSS)* does not yet substantially increase confidence that a repository at Yucca Mountain will perform as anticipated, because a majority of the components of the *RSS* are all dependent on performance assessment. In the Board's view, multiple lines of evidence that are not subject to the same limitations of performance assessment are needed to increase confidence in performance projections.

Recently, the Board answered questions from Representative Joe Barton following the Board's June 23, 2000, testimony before Mr. Barton's Subcommittee on Energy and Power. In its answers, which also are enclosed, the Board noted that, on the basis of information it has reviewed to date, the Board believes that the technical basis for current long-term projections of repository performance has critical weaknesses. These projections and their associated weaknesses reflect in part the DOE's "base case" (above-boiling) repository design. Although the site may merit a positive recommendation, the DOE has not yet demonstrated—for the base-case design—a firm technical basis for such a conclusion. As the Board pointed out in its July 1999 letter to Lake Barrett, who was at that time Acting Director of the program, some of the current large uncertainties about waste package and repository performance are directly or indirectly related to the high (i.e., above-boiling) repository temperatures associated with the current base-case design. Other uncertainties are related to a lack of fundamental understanding about physical processes that will occur over thousands of years; realistic predictions are therefore very difficult to make.

The Board reiterates its observation that there have been substantial improvements in performance assessment since the viability assessment. We particularly appreciate the DOE's willingness to discuss its preliminary calculations in an open and thoughtful manner. Addressing the concerns we have discussed in this letter will help to make the TSPA/SR and the proposed *Repository Safety Strategy* more useful and understandable to the scientific community and to the decision-makers involved in deciding whether to recommend development of a repository at Yucca Mountain.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

Attachments:
"Comments of Nuclear Waste Technical Review Board
on Meeting of August 1 and 2, 2000, in Carson City, Nevada"
"Nuclear Waste Technical Review Board Responses to
Questions for the Record from Mr. Barton, August 31, 2000"

Comments of Nuclear Waste Technical Review Board on Meeting of August 1 and 2, 2000, in Carson City, Nevada

Total System Performance Assessment

The Board notes with satisfaction the substantial improvements made in performance assessment capabilities since the last iteration in 1998 for the viability assessment (TSPA/VA). Integration has increased substantially, and new and better models have been developed, including the site-scale saturated zone flow-and-transport model and the model relating the presence or absence of water on the surface of the waste package to relative humidity at high temperatures. New and important field data are being collected, for example, in the Exploratory Studies Facility (ESF), the east-west cross drift, the Nye County Early Warning Drilling Program, and the Busted Butte facility. Laboratory data also are being collected, for example, in the long-term-corrosion testing facility at Lawrence Livermore National Laboratory (LLNL).

In the following paragraphs, we provide detailed comments on TSPA and its specific components. Carrying out a performance assessment for the proposed exceedingly long-lived repository at Yucca Mountain, including taking into account highly complex interactions between the natural and engineered systems, is an extremely difficult undertaking. As might be expected for such a challenging project, our comments tend to highlight areas where improvement is needed. They should not be interpreted as diminishing the significant progress made in the last few years.

TSPA: General Comments

Efforts were made in the TSPA/VA and in the most recent performance assessment to increase transparency, but additional work is needed. For example, the most recent performance assessment and the latest version of *Repository Safety Strategy* contain sensitivity studies that show the effect of "neutralized" and "degraded" barriers. The differences between neutralized and degraded barriers should be stated clearly and justified. In addition, a clear explanation is needed to justify why some neutralization analyses assume the complete removal of a barrier while others, such as waste package neutralization, assume only partial removal of a barrier. Differences between the "nominal" and the "igneous activity" scenarios also need to be clarified, and the rationale for separating these scenarios should be clearly stated and justified. "Nominal" may be a poor name for what usually has been referred to as the "base case." In addition, presenting only the probability-weighted igneous scenario is confusing. It would be much clearer if the conditional results of the igneous scenario were presented and discussed both with and without probability weighting.

The Board is concerned about the lack of formal peer review for the TSPA/SR. The peer review panel convened for the TSPA/VA provided very useful comments and insights on that analysis. Several of their suggestions were implemented in the TSPA/VA and in the current version of the TSPA/SR. Areas where peer review would be particularly useful for site recommendation are statistics and uncertainty estimation. Evaluation of the statistical techniques used to estimate parameter ranges and the overall treatment of uncertainty could increase the credibility of the conclusions drawn. At the meeting, the Board was told that a peer review (by an international body) would be completed for license application. Unfortunately, important national decisions, whose technical components will rest in large part on the TSPA/SR, must be made for site recommendation.

TSPA: Comments on Specific Components

Program integration has improved, but problems still exist. Several models were presented that address coupled processes, including the mountain-scale thermal-hydrological (TH) model, the thermal-hydrological-chemical (THC) model, and the thermal-hydrological multiscale model. Determining how these coupled-process models interact with each other and with other TSPA models is difficult. For example, the input to the isothermal seepage model is somewhat arbitrarily taken to be the fluxes predicted by the TH multiscale model 5 meters above the drifts. Because a large amount of thermally mobilized water is predicted to be present at this location at the time of peak waste package and drift-wall temperatures, seepage into the drifts is predicted. This is contrary to the conceptual model that to a large degree provides major justification for an above-boiling repository design showing that heat would move water away from the emplacement drifts when drift-wall and waste package temperatures are high. The credibility of these analyses would be improved by a coherent narrative description of the interrelationships of the various process models and their abstraction for TSPA.

The THC model predicts that coupled THC processes will have no significant effect on flow in the unsaturated zone. The TSPA/VA peer review panel, on the other hand, observed that a precipitate cap could be formed by thermally induced mineral deposits above the repository. Formation of such a cap would be important in determining how the repository environment would change with time and how that would affect the distribution and quantity of water flowing through the repository. At the Board meeting, Yucca Mountain scientists stated that the assumption of minimal THC effects on flow may be optimisitic—that is, nonconservative. The validity of the assumption that there are no THC effects on flow in the unsaturated zone should be demonstrated in a scientifically sound and defensible manner.

The DOE stated that radionuclide transport in the unsaturated zone is not affected significantly by large changes in fracture aperture. The Board is puzzled by this statement, given the known sensitivity of permeability to fracture aperture and the known sensitivity of radionuclide transport to permeability. The DOE should examine the justification for this assumption more closely. In addition, some assumed rock properties are supported by little or no data. Examples are the dearth of information at the appropriate measurement scale on intrinsic permeability, variability of permeability (including anisotropy), and input parameters needed for the models of active fractures and saturated zone diffusion.

According to DOE sensitivity studies, an important assumption affecting repository performance is the value assigned to the coefficient for diffusion of radionuclides through the invert to the rock immediately below the waste package. The DOE should evaluate whether the currently assigned diffusion coefficient may be too high (conservative). If so, justification for a different diffusion coefficient not only would improve predicted repository performance but also would allow a more robust estimation of barrier performance.

The environment affecting the engineered barrier system (EBS) is critical to determining the interactions between the natural and engineered components of the repository. Of particular importance to the corrosion of the drip shield and the waste packages is the chemistry of water and gases in the drifts. The Board is not convinced that the range of experiments and analyses carried out by the DOE is broad enough to describe, or even bound, all relevant coupled processes in the near-field environment affecting the EBS. For example, the work done at LLNL in the last few years to determine the changes in composition and boiling point of synthetic J-13 water as it becomes more concentrated via evaporation represents a major advancement in knowledge. However, the Board is unaware of any work—theoretical or experimental—for determining whether there are plausible fractionation mechanisms that could result in brines that are disproportionately enriched in trace elements or that show significant composition differences other than those anticipated to result from simple evaporation. Given the importance of the EBS environment, the DOE should examine and evaluate all pertinent and important chemical interactions.

Because sensitivity and neutralization studies indicate that the waste package may be the most important barrier for containing and isolating radioactive waste, the data, models, and assumptions pertaining to the waste package deserve special scrutiny. There have been significant improvements in waste package data and models since the TSPA/VA. For example, a major advancement is the model relating the presence or absence of water on the outer surface of the waste package to relative humidity at temperatures above the boiling point. Similarly, LLNL's long-term-corrosion testing facility (LTCTF) has improved the data set from which corrosion rates are estimated.

Still, there are important gaps in understanding waste package performance. For instance, the current TSPA model for generalized corrosion of Alloy 22 is based almost entirely on corrosion data from the LTCTF. These data were developed using Alloy 22 samples in comparatively dilute J-13-derived brines at temperatures no higher than 90°C. However, recent experimental and theoretical work carried out principally at LLNL shows that concentrated brines could be present on waste packages at temperatures up to 120°C. The DOE must establish that the water that will contact waste packages is similar to (or bounded by) J-13-derived water and ensure that the basis for predicting generalized corrosion rates at 90°-120°C is adequate.

The work for determining the temperatures and compositions at which water (with dissolved components) could exist on waste package surfaces has been under way for only a few years. Although progress has been made, the work should continue and broaden. For example, work comparing J-13 water and pore water from the repository horizon raises the issue of whether they are sufficiently similar so that J-13-derived water can be used as a reasonable surrogate for water that will contact waste packages. This issue needs to be resolved.

Extrapolation of corrosion rates determined from short-term (several years) experiments to predict waste package performance over tens of thousand of years is a subject of great concern to the Board. Long-term extrapolations may be suspect if they are made with little or no understanding of the fundamental mechanisms that either preserve or dissolve the passive layer critical to the corrosion resistance of Alloy 22. Such understanding should be accompanied by examples of long-term (archeological-geological) protection by passive layers in aggressive environments. Currently "unknown" processes that could affect the long-term viability of the passive layer include the following:

- passive layer defect accumulation—that is, the passive layer encounters microscopic defects as it sweeps into metal
- passive layer debris accumulation—that is, the long-term effects of corrosion products on the passive layer
- quasitranspassive dissolution—that is, if the open-circuit potential creeps up over time, transpassive regimes may be approached, promoted by the high molybdenum content of Alloy 22.

Several groups, including those at VTT (Finland), the Center for Nuclear Waste Regulatory Analyses, and The Pennsylvania State University, are investigating mechanisms that could affect the long-term behavior of passive layers. The DOE should familiarize itself with this work to improve the credibility of the extrapolation of long-term performance from short-term data.

The waste form consists of the radioactive waste itself, cladding, and any encapsulating or stabilizing matrix. Models of waste form degradation take into account several important considerations, including the radionuclide inventory, degradation of spent nuclear fuel and high-level defense waste, cladding, radionuclide solubilities, and formation of colloids. Waste form degradation determines the availability of radionuclides for transport out of the EBS and into the natural system after a waste package is breached. As in other areas, there have been substantial improvements since the TSPA/VA. Such improvements include better models for the perforation and unzipping of Zircaloy cladding, radionuclide solubilities, and in-package chemistry. In-package chemistry (for example, pH, carbonate content, ionic strength, and fluoride concentration) is particularly important because it will have a large effect on waste form degradation. Low pH in the first thousand years after waste package breach would result in a relatively high solubility for neptunium, which is the prime contributor to long-term dose.

The model that simulates colloid-facilitated transport of radionuclides seems reasonable but lacks sufficient data. Colloids are microscopic particles and other solids that can, and do, move rapidly through groundwater systems. Colloids can be man-made, resulting from corrosion of the waste package or the waste form itself, or they can be naturally occurring. Examples of natural colloids include organic humic substances, microbes, and inorganic materials, such as clays, iron and manganese oxides, and some silicates. Colloids are important in unsaturated and saturated zone transport because several important radionuclides, including plutonium and americium, can attach (sorb) themselves onto these microscopic solids. Recent studies, such as those at the Nevada Test Site, have shown that colloids are present in larger amounts than previously assumed. Data presented thus far are not adequate to form a technical basis for simulating colloidal transport. Recent performance assessments apparently assumed that colloid concentrations leaving the waste form are determined by the availability and stability of iron oxide. However, other studies have shown that sorbed plutonium is associated with manganese oxide and smectite (a form of clay) rather than iron oxide. Basing colloidal-transport coefficients on site-specific studies that consider the appropriate colloidal forms is needed for a technically defensible prediction of radionuclide transport.

Flow and transport in the saturated zone determine the timing and rate at which radionuclides reaching the water table beneath Yucca Mountain travel to the accessible environment, currently defined as 20 km from the repository. This is an area where there have been particularly important changes since the TSPA/VA. For example, in TSPA/VA, the DOE relied on an extremely simple flow-tube model to characterize flow and transport in the saturated zone. The current approach makes use of a three-dimensional site-scale flow-and-transport model for most radionuclides. Other changes include simulation of matrix diffusion and sorption in the alluvium.

The Nye County Early Warning Drilling Program has yielded improved hydrogeological information; continuation of that program will produce very valuable data in the future. Unfortunately, substantial hydrogeological uncertainties persist at present. Rock and fault permeabilities (including anisotropy) remain to be measured at the appropriate scale for numerical model predictions. The vertical distance between zones of fracture concentration that conduct fluid flow is a critical parameter for fracture-matrix diffusion calculations. This parameter has been quantified only in the 3 C-Well boreholes, located outside of the likely flow paths from the repository footprint to the proposed compliance points downgradient. The extent of the alluvial zone, a potentially important contributor to repository performance because of its ability to retard radionuclides, still has not been defined adequately by field investigations. The areal extent and magnitude of the upward gradient from the deep regional carbonate aquifer remain defined by only a single data point. The use of the same dispersivity values for all rock formations is better suited to homogeneous rocks than to the rocks near Yucca Mountain. The Board anticipates that the Nye County program can help to fill in many of these data gaps.

Biosphere models in the TSPA determine how the plant and animal communities take up radionuclides that reach the accessible environment. A major change has occurred at the interface between the saturated zone and the biosphere. In the TSPA/VA, radionuclide concentrations in water were determined by calculating the concentration in water wells penetrating specific locations in the saturated zone. The current approach simply assumes that all the radionuclides crossing a boundary 20 km from the repository are diluted by the amount of water used by a hypothetical agricultural community. This approach lessens the need to determine specific flow paths unless they change the time it takes for transported radionuclides to reach the 20-km boundary. The Board notes, however, that this approach may be inconsistent with the "representative volume" concept used by the U.S. Environmental Protection Agency (EPA) in its proposed standards for a Yucca Mountain repository, 10 CFR Part 197. Consistent with the EPA's proposal, the current approach assumes that future populations will be similar to present populations. This eliminates the need to predict changes in the communities surrounding Yucca Mountain thousand of years into the future, predictions that are impossible to make reliably.

One of the most interesting results from the current performance assessment is the conclusion that igneous activity is the only contributor to estimated dose during the 10,000-year regulatory period. This is due to increased efforts in modeling the consequences of igneous activity and to the assumption that, absent igneous activity, waste packages will not be breached during the first 10,000 years. Modeling the consequences of igneous activity includes two igneous release scenarios: (1) eruption through the repository and (2) disruption of the waste packages in the emplacement drifts, allowing greatly increased exposure of waste to water seeping into the drifts. These scenarios involve many assumptions about the nature of igneous activity, the extent of waste package disruption, the transport of radionuclides through the atmosphere, and dose-conversion factors for atmospherically transported radionuclides. Future technical interactions between the DOE and the Nuclear Regulatory Commission on igneous activity will, in large part, be devoted to examining the assumptions made by the DOE in its consequence models. The Board will be examining the basis for the assumptions.

TSPA: Treatment of Uncertainty

In its March 20, 2000, letter to you, the Board discussed the importance of proper treatment and estimation of uncertainties. Several suggestions were made to assist the DOE in this task. We are encouraged by the efforts made thus far and presented at the meeting, but we also offer the caution that additional efforts are needed before a case can be made that uncertainties were estimated in a technically credible manner. The Board believes that the quantification, analysis, integration, and communication of uncertainty need to be addressed in a more rigorous manner than shown in the presentations at the Board meeting. Any projection of repository performance will be incomplete unless the DOE also provides a description and a meaningful quantification of the level of uncertainty associated with its predictions.

The Board believes that meaningful quantification of the uncertainties associated with performance, clearly and understandably presented, is essential to provide policy-makers who are deciding on a site recommendation with critical information on trade-offs between projected performance and uncertainty in those projections. The Board realizes that projecting long-term performance of a potential repository at Yucca Mountain, or anywhere else for that matter, is inherently associated with uncertainty. Eliminating all the uncertainties will never be possible (although they can be reduced). In fact, the Board has noted that a decision on whether to recommend the site can be made at any time, depending in part on how much uncertainty policy-makers are prepared to accept. The timing of the site recommendation, of course, is clearly beyond the Board's charge.

At the Board meeting, we noted several issues that need further attention. For example, the ranges of chosen parameters need further justification. The use of performance assessment to set these ranges by determining what "really counts" may be of limited value because of the dependence of this method on the specific models used. Sound evidence is needed to justify the parameter range chosen. The number of "realizations" to be used for uncertainty analyses appears to have been determined somewhat arbitrarily. A more rigorous determination of the optimal number of realizations would make the uncertainty analyses more defensible. We heard at our meeting the preliminary results of sensitivity studies aimed at defining the effect of changes in assumptions about models and input parameters. In some cases, it was difficult to determine whether results were insensitive to some parameters because of the underlying physics and chemistry in the process models or because of simplifying assumptions used in the abstractions. We realize that many of these studies were so new that the presenters did not have sufficient time to evaluate them. Analysts and project scientists need to make the effort to do so and, as appropriate, modify them accordingly. Otherwise, they will be of limited use to reviewers.

Analysis and integration of uncertainties are other topics of Board interest. The Board is puzzled by the sharp decrease in uncertainty, as defined by the bandwidth of the Monte Carlo simulations after 100,000 years. Uncertainty typically increases over time, but in the performance assessment analyses, this measure of uncertainty decreases. If, as some maintain, the decrease is due to the assumed failure of most of the waste packages by that time, an effort should be made to demonstrate convincingly that this is so. As indicated previously, a clear analysis of the contribution of uncertainty to the overall results is needed.

Another issue requiring further thought is the adoption of a mix of conservative, realistic, and optimistic assumptions in models and parameters: for example, the "conservative" estimates of diffusion through the invert and the "optimistic" estimate of the extent of THC coupling. Determining the overall level of conservatism for a mix of conservative, realistic, and optimistic assumptions will be very difficult. If the DOE wants to argue that the TSPA is conservative, an effort must be made to provide a defensible estimate of the overall level of conservatism.

Finally, even if a technically credible performance assessment is carried out, poor communication can hurt the perception of credibility. An example of this is the potential confusion generated by the differences between the nominal scenario and the igneous scenario, as discussed above. In contrast to the nominal scenario, the igneous scenario is heavily influenced by the very low probability of the occurrence of igneous activity affecting the proposed repository. This probability is about one chance in 100,000,000 per year. Much of this confusion can be prevented if the differences between the two scenarios and the rationale behind probability weighting are clearly explained along with a presentation and discussion of igneous activity scenarios without probability weighting.

Ongoing Scientific Studies

Results of ongoing scientific investigations at Yucca Mountain were presented at the August Board meeting. Much significance was attached to certain observations in the lower lithophysal rock in the cross drift. These observations appear to show greater capillary suction and fracture permeability and therefore lower seepage in the lower lithophysal unit than in the middle nonlithophysal unit in the ESF. According to present plans, the lower lithophysal units will house more than 70 percent of the waste packages. Based on other observations, a new mechanism explaining the mineral deposits found in lithophysal cavities also was proposed. Both these observations and the related hypotheses are important in determining the ability of water to seep into the drift. They need to be evaluated carefully.

Access to the lower lithophysal unit is providing very useful information to the project. We understand that some tests, including the thermal test in the cross drift, are being deferred. The Board urges the DOE to continue and complete ongoing studies, such as the crossover-drift test, and start deferred tests in a timely manner. To finalize a repository design and conduct a convincing performance assessment, the DOE needs to know as much as reasonably possible about the actual rocks within which the waste will be placed.

Finally, at the May 1, 2000, meeting in Pahrump, Nevada, an independent study was presented that apparently contradicted results from the original study of chlorine-36 in the ESF and the cross drift. The differences may be due in large part to differences in sample processing. No new results were presented at the August meeting. We understand that an effort is under way to address the processing differences, and we look forward to resolution of the issue.

Repository Safety Strategy

At its August meeting, the Board heard a presentation on the latest version of *Repository Safety Strategy (RSS)*. Although demonstrating, in the conventional sense, how a repository will behave thousands of years into the future may not be possible, steps can be taken to increase confidence in estimates of future performance. The Board has strongly endorsed the DOE's efforts in developing multiple lines of evidence to construct a "safety case" for the proposed repository. The DOE develops such a case in the *RSS*, now being revised. The DOE's safety case rests on six elements, or "pillars": performance-assessment calculations, safety margins, defense-in-depth, explicit consideration of potentially disruptive events, insights from natural analogs, and performance confirmation.

In the Board's view, the pillars of the *RSS* do not yet satisfy the goal of providing multiple lines of evidence and do not substantially increase confidence that a repository at Yucca Mountain will perform as anticipated. Four of the pillars—performance-assessment calculations, safety margins, defense-in-depth, and analyses of disruptive events—as currently presented are not independent of each other. They are all dependent on performance assessment. Thus, if one lacks confidence in the DOE's performance assessment, one is not likely to have much confidence in any of the four pillars. The last two pillars of the repository safety case—natural analogs and performance confirmation—*are* independent of performance-assessment calculations. However, the DOE's evaluation of natural analogs so far has been minimal, and performance confirmation is simply a plan of activities that will be subject to future budget and time constraints.

The Board has endorsed the DOE's use of performance assessment-calculations, but it has noted the limits of those calculations and has expressed doubt that relying solely on them to demonstrate repository safety will ever be possible. Multiple lines of evidence that are not subject to the same limitations of performance assessment can increase confidence in performance projections. The DOE's safety case has not yet accomplished those important ends.

Finally, as part of its approach to demonstrating defense-in-depth, the DOE conducted neutralization analyses. The analyses show the effect on the calculated dose of neutralizing or removing different barriers. We point out above the need to clarify this effort. We also note that a useful supplement to this approach would be to see the incremental effect on dose of adding individual barriers. In other words, the analysis would start off by estimating the dose, assuming that the radioactive waste was lying exposed at the surface. Individual elements of the geologic and engineered system then would be added, and resulting dose estimates would be calculated until the repository system reached its proposed form. Such an analysis could give interested parties a clearer picture of how much each individual element adds to repository performance.

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

August 31, 2000

Honorable Joe Barton
Chairman
Subcommittee on Energy and Power
Committee on Commerce
U.S. House of Representatives
Room 2125, Rayburn House Office Building
Washington, DC 20515-6115

Dear Mr. Barton:

Enclosed are responses to the questions posed in your letter of July 20, 2000, to Dr. Debra Knopman following her appearance before the Subcommittee on Energy and Power on June 23, 2000. The Board provides independent advice on the technical issues associated with the management of the country's commercial spent nuclear fuel and defense high-level radioactive waste. The Board offers its technical views to help inform the larger consideration of issues that faces the Department of Energy and the Congress in their evaluation of the suitability of the Yucca Mountain candidate repository site.

The Board is keenly aware that many of the issues that must be considered in making decisions in this policy area are technical ones, but others are not. Regarding site suitability, we believe that Congress and the Secretary will find it useful to have our views on the adequacy of current information to technically support a possible site recommendation. As noted in our responses, a site recommendation can be made at any time, depending in part on how much uncertainty policy-makers are prepared to accept.

Please let me or the Board's staff know if we can provide you or your staff with any additional information on the enclosed responses.

Sincerely,

{Signed by}

Jared L. Cohon
Chairman

Enclosure

NUCLEAR WASTE TECHNICAL REVIEW BOARD RESPONSES TO QUESTIONS FOR THE RECORD FROM MR. BARTON AUGUST 31, 2000

1. Is the Technical Review Board concerned that funding constraints are causing DOE to postpone or skip critical technical analyses necessary to support the site recommendation and licensing decisions? If so, please identify the specific areas that are not being addressed adequately by DOE.

The Board's congressional mandate is statutorily limited to reviewing the technical and scientific validity of Department of Energy (DOE) activities. Therefore, the Board has not examined the details of DOE's budget for Yucca Mountain research or its funding allocations for program operation, management, procurement, and contracting. Consequently, the Board cannot judge the extent to which the Yucca Mountain site characterization and repository design activities have been or will be constrained by budget limitations. What is clear, however, is that the Board's present understanding of a potential repository located at Yucca Mountain is affected by many policy-related factors, including congressional appropriations, DOE's research and program priorities, and statutory and administrative deadlines, as well as the significant challenge of undertaking a first-of-a-kind activity.

Because less than a year remains before the scheduled site-recommendation decision in July 2001, the amount of additional scientific and technical work that can be completed by that date is very limited. Thus, the information available in July 2001 for a site recommendation will in all likelihood not be appreciably affected by whatever budget Congress passes for FY 2001. However, funding constraints in DOE's budget for FY 2001 and beyond could limit ongoing and new work that might support a DOE license application for repository construction.

The Board reviews the scientific and technical program as it is and makes its technical judgments accordingly. On the basis of information it has reviewed to date, the Board believes that the technical basis for DOE's current long-term projections of repository performance has critical weaknesses. These projections and their associated weaknesses reflect in part the DOE's "base-case" (above-boiling) repository design. Although the site may, in fact, merit a positive site recommendation, DOE has not yet demonstrated—for the base-case design—a firm technical basis for that conclusion.

Some of the current large uncertainties about waste package and repository performance are directly or indirectly related to the high (i.e., above-boiling) repository temperatures associated with DOE's current base-case design. High temperatures increase the level, extent, and significance of the combined, or "coupled," effects of thermal, hydrologic, mechanical, and chemical processes. Furthermore, the waste packages may be more vulnerable to corrosion at higher temperatures if water is present. The Board believes that it will be very difficult for the DOE to improve substantially its current understanding of these high-temperature effects during the next year or two. However, it may be possible over the next several months to reduce some uncertainties, for example, by developing a defensible technical basis for a lower-temperature repository design.

In addition to the effects of high temperatures, some uncertainties are related to a lack of fundamental understanding about physical processes that will extend over thousands of years; realistic predictions are therefore very difficult to make. For example, the performance of the waste packages over thousands of years has been extrapolated from a few years of corrosion data and too limited an understanding of fundamental corrosion processes. Finally, the characterization of the hydrogeology below the repository horizon, although supported by some data, continues to rest largely on inadequately supported hypotheses. As a result, for example, the flow and transport of radionuclides in the unsaturated and saturated zones from the repository to the accessible environment are poorly understood.

The Board believes that significantly improving the fundamental understanding of these natural features and engineered barriers during the next year or two will be very difficult. However, the Board believes that work in these areas is important and should continue. Because of the complexity of the Yucca Mountain site and the challenges involved in extrapolating data over long time periods, gaining such an understanding of these basic processes will take time. Continued adequate funding of these long-term studies will be important.

2. Is it correct that the Technical Review Board is concerned that DOE is not paying enough attention to the uncertainties inherent in the repository's long-term performance, especially with respect to the "hot" repository design?

The persistence of substantial uncertainties has led the Board over the last few years to recommend strongly that DOE develop a more technically defensible basis for making design, site-recommendation, and licensing decisions. In particular, the Board has recommended initiation of fundamental studies on long-term corrosion, evaluation of alternative repository designs, improved characterization of rock formations in the vicinity of Yucca Mountain, examination of radionuclide retardation in the unsaturated and saturated zones below the repository horizon, evaluation of colloidal transport, and investigation of the effect of structures and heterogeneities on water movement above and below the water table. DOE has responded to many of the Board's suggestions, but it has not yet completed all of those studies. Although the Board is encouraged by the level of attention DOE is now giving to the quantification and characterization of uncertainty in estimating repository system performance, the Board also continues to have concerns in this area.

The Board realizes that projecting long-term performance of a potential repository at Yucca Mountain, or anywhere else for that matter, is inherently associated with uncertainty. Eliminating all the uncertainties will never be possible (although they can be reduced). In fact, the Board has noted that a site recommendation can be made at any time, depending in part on how much uncertainty policy-makers are prepared to accept. The timing of the site recommendation, of course, is clearly beyond the Board's charge.

As noted in the answer to question #1, on the basis of information reviewed to date, the Board believes that the technical basis for DOE's current long-term projections of repository performance has critical weaknesses. These projections and their associated weaknesses reflect in part the DOE's base-case (above-boiling) repository design. The Board explicitly raised this concern about above-boiling repository designs in a July 9, 1999, letter to DOE's Office of Civilian Radioactive Waste Management. Although the site may, in fact, merit a positive site recommendation, DOE has not yet demonstrated—for the base-case design—a firm technical basis for that conclusion.

Adopting a lower-temperature repository design for commercial spent fuel might mitigate some of the weaknesses associated with projections of long-term repository performance, such as problems associated with coupled processes. A lower-temperature repository design could make projections of performance less dependent on areas where scientific understanding is incomplete. Therefore, DOE should augment its current design evaluations with a rigorous and persuasive evaluation of the performance of, and trade-offs associated with, alternative repository designs, including assessing the effects of the following factors on performance and uncertainty: age of waste at emplacement, spacing between waste packages, ventilation rates and efficiencies, and time before repository closure. It is possible, but not certain, that a cooler, drier, and simpler design than the current base-case design would lower the technical hurdles that DOE now faces in projecting long-term waste package and repository performance.

DOE, however, has not yet carried out a sufficiently thorough evaluation of low-temperature repository designs. By carrying out such an evaluation, DOE would develop a much better understanding of how the thermal characteristics of different designs may affect critical uncertainties (e.g., those associated with coupled processes, the stability of the passive layer of Alloy 22, and the waste package environment). But the magnitude of other uncertainties, such as those associated with the saturated zone under the repository, are very likely to be independent of the facility's design.

3. How would the Board suggest that DOE should take these uncertainties into account ¾ is this a matter of DOE actually changing its repository design, or merely a matter of presenting this uncertainty information to the decision-makers?

DOE intends to base its site-recommendation decision primarily on the results of a total system performance assessment (TSPA), a complex computer model that estimates repository performance many thousands of years into the future. The technical soundness of DOE's site-recommendation decision will therefore depend to a large extent on the technical validity of its TSPA. Put another way, policy-makers' confidence in performance assessment reflects in many ways the level of uncertainty associated with estimates of performance: the greater the uncertainty, the lower the confidence in repository performance may be.

There are several internationally recognized strategies for managing or reducing uncertainties. One strategy involves using "conservative" assumptions and parameters throughout the performance assessment. Thus, if the assessment is in error, the long-term performance of the repository is underestimated, not overestimated. A second strategy involves using multiple lines of evidence independent of performance assessment in developing a "repository safety case." A third strategy involves making repository design choices that minimize uncertainties.

DOE has made progress in implementing each of these three strategies, but it can—and should—do more. For example, it is difficult to know whether the assumptions and parameters used in DOE's performance assessments are truly conservative or how the combination of conservative, optimistic, and realistic estimates affects overall dose calculations and the uncertainties associated with those calculations. As noted in the response to question #6, DOE has not yet completed the evaluation of independent lines of evidence—an evaluation that is needed to increase confidence in the conclusions of its safety case derived from performance assessment. Finally, as noted in the answer to question #2, DOE has not yet performed a rigorous and persuasive analysis of how uncertainty in repository performance varies with repository design.

Regardless of what strategies are used to manage or reduce uncertainty, the Board believes that DOE's projections of repository performance will be incomplete unless DOE also provides a description and a meaningful quantification of the level of uncertainty associated with its predictions. DOE then will be in a better position to make important decisions, including choosing waste package and repository designs having acceptable predictions of performance, and decision-makers will be able to make technically informed choices related to the DOE's work at Yucca Mountain.

4. When does the decision on hot versus cool repository design have to be made? Can DOE leave this decision open into the licensing phase?

For DOE to make a positive site recommendation, the Board believes that DOE would need to make a technically defensible argument that at least one repository design concept, including firm operational assumptions, will perform satisfactorily for thousands of years. Such an argument would presumably consider the associated levels of uncertainty in repository performance. Therefore, the Board assumes that DOE would describe for the site recommendation at least one design concept and a set of operational assumptions with sufficient specificity so that sound and complete assessments of performance can be developed.

The Nuclear Regulatory Commission, of course, will determine whether the particular detailed design or designs used in DOE's license application will, in fact, provide reasonable assurance of satisfactory performance to warrant constructing a facility.

5. A recent GAO report on radiation standards suggested that the cooler repository design favored by the Board could add $2 billion to the cost of the repository. What is the basis for that statement by GAO, and is that estimate correct?

The statements in the GAO report are misleading in two respects. First, although the Board noted in July 1999 that the technical basis supporting any above-boiling repository design was, in its opinion, not strong enough, the Board is not in a position to *recommend* a specific design alternative. In fact, in its June 23, 2000, testimony before the Subcommittee, the Board explicitly stated, "… more thorough analysis is needed before any judgment is made about the optimal thermal conditions for repository operation."

Second, at the Board's meeting in May 2000, DOE presented some preliminary results and cost estimates related to alternative thermal designs. That analysis suggested that the incremental discounted cost of implementing a below-boiling (as opposed to an above-boiling) design may be as low as $600 million. If, for example, different assumptions were adopted about the distance between repository tunnels, the incremental cost might be reduced even more. This type of result, stimulated by a Board recommendation, is likely to help DOE understand better the technical and economic trade-offs associated with alternative repository designs. Such an understanding is essential for making a sound decision, regardless of what regulatory standard is ultimately established.

6. Please identify any other outstanding technical issues with the repository design that, in the Board's view, are not being addressed adequately by DOE. Explain these concerns fully, and make recommendations on actions that DOE and the Congress should take to resolve these issues.

Unfortunately, DOE's models are not well enough developed or supported by sufficient data to differentiate between the performance of below-boiling and above-boiling repository designs over the next several thousand years. To develop the tools necessary for evaluating these differences, DOE would have to increase substantially its understanding of the coupled thermal, hydrologic, mechanical, and geochemical processes taking place within the repository; the mechanisms and paths by which radionuclides could be transported from the repository tunnels into the unsaturated and saturated zones below; and the data and fundamental knowledge used to project the long-term corrosion susceptibility of waste packages.

Although the Board has endorsed the use of TSPA, in an April 1999 report the Board noted the limits of TSPA calculations and expressed doubt that relying "solely on [performance assessment] to demonstrate repository safety" will ever be possible. Therefore, the Board recommended in this report that DOE develop multiple lines of evidence that can supplement performance assessment.

DOE is working on a repository safety case that is designed to increase confidence that a repository at Yucca Mountain is likely to perform as predicted. The strategy currently rests on six "pillars": performance-assessment calculations, safety margins, analysis of disruptive events, defense-in-depth, natural analogs, and performance confirmation during and after waste emplacement. On the surface, these pillars may appear to satisfy the Board's recommendation that DOE develop multiple lines of evidence that can supplement performance assessment. A closer look suggests otherwise.

To begin with, four of the pillars—performance-assessment calculations, safety margins, defense-in-depth, and analysis of disruptive events—as currently presented are not independent of each other. They are all dependent on performance assessment. Thus, if one lacks confidence in DOE's performance assessment, one is not likely to have much confidence in any of the four pillars. The last two pillars of the repository safety case—natural analogs and performance confirmation—*are* independent of performance-assessment calculations. However, DOE's evaluation of natural analogs so far has been minimal, and performance confirmation is simply a plan of activities that will be subject to future budget and time constraints.