Department of Energy
Washington, DC 20585

April 29, 1999

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

Dear Dr. Cohon:

This letter transmits the Department of Energy's response to the Nuclear Waste Technical Review Board's *Report to the U.S. Congress and the Secretary of Energy,* issued in November 1998. The Department appreciates the Board's recognition of the considerable progress we have made in characterizing the Yucca Mountain site and developing a comprehensive repository safety strategy. We also appreciate the Board's views on the specific scientific and technical activities undertaken by the program and its suggestions to improve them. Our detailed responses to the conclusions in the Board's report are found in the enclosure.

On December 18, 1998, shortly after issuance of the Board's report, the Department submitted the *Viability Assessment of a Repository at Yucca Mountain* to the President and Congress. Based on the viability assessment, the Department believes that there are no show stoppers and that the ongoing work should proceed as planned. The Department agrees with the Board that key scientific and technical uncertainties related to repository performance can be further reduced over the next several years. Accordingly, we have implemented a work plan focused on reducing these key uncertainties. We believe that this plan is generally consistent with the objectives and priorities suggested in Board's report.

We agree with the conclusion in the Board's report that site characterization cannot resolve all uncertainties and provide absolute proof of repository performance. We also agree that the acceptable level of uncertainty for decision making is ultimately a policy question. Our experience has shown that the significance of uncertainties, as they relate to our understanding of natural and engineered processes, cannot be determined in the abstract. These uncertainties are best evaluated within the context provided by a specific geologic setting, a coherent repository design, and a comprehensive assessment of its performance. Our work in the past and over the next several years will supply this context. Only then can we ascertain the significance of the uncertainties and provide that information for policymakers.

The Board's report highlighted the need to investigate alternative repository and waste package designs, particularly designs that could significantly reduce uncertainty in repository performance. In response to these and previous recommendations of the Board, we are undertaking an evaluation of design alternatives. This process is enabling us to look individually and collectively at previously identified design features with a new perspective. The Department encourages the Board to follow closely the evaluation of design alternatives. It is our intent to complete a fair and objective evaluation of alternatives with the insights gained from site characterization before we select the appropriate reference design for the site recommendation evaluation and license application.

The input provided by the Board over the previous year contributed to the quality of the viability assessment. We look forward to the Board's feedback, including the Board's forthcoming views on the viability assessment, as we proceed with the additional work required to support national decisions on geologic disposal at Yucca Mountain. If you have any questions, please contact me at (202) 586-6842.

Sincerely,

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

Enclosure

Department of Energy's Response to the Conclusions in the Nuclear Waste Technical Review Board's November 1998 Report to the U.S. Congress and the Secretary of Energy

Unsaturated Zone (UZ)

The UZ of Yucca Mountain is potentially an important component of the defense-in-depth repository design.

The effects of repository heat on thermohydrologic conditions near the repository are not well understood, but tests have been initiated at Yucca Mountain to improve understanding and reduce uncertainties, (page 23)

Response:

The Department agrees with the Board and recognizes the significance of transient conditions near the repository as a result of waste-generated heat. We are addressing this issue at both the drift scale and the site scale, with both modeling and testing. Results from the drift scale heater test over the next few years will be particularly important in confirming our understanding of thermally-driven changes in the rock mass and fractures.

At the site scale, the effects of repository heat are being studied through coupled thermal-hydrologic-chemical modeling. The goal of these studies is to estimate the changes in rock properties or mineralogy that may alter the UZ flow field. The effects of heat on the ambient flow field are being evaluated, as well as coupled geochemical changes involving over 20 minerals. For example, some model results indicate that during the thermal pulse, it is possible that silica will be mobilized in the boiling zone and then precipitated in the vapor condensation zone. These changes could have the effect of restricting some flow pathways and reducing the porosity of the fractures. The changes to rock matrix will also be evaluated, but are expected to be much less than the effects in the fractures. These changes are sometimes conceptually referred to as a “precipitation cap" and may be significant for estimating post-closure performance. Other potential effects on the UZ flow field include those caused by the formation of zeolite and clay minerals during the thermal pulse. Although the modeling results are useful, they will always be compared to test results and natural analogs as a check.

Seepage flux under ambient conditions can be better estimated through the proposed in situ experiments, by analog studies at the Nevada Test Site, and by numerical simulations. Seepage after the thermal period has not been addressed in the past, but planned experiments may produce relevant data. To the Board's knowledge, the effects of near-field changes (e.g., tunnel collapse) are not being addressed (page 23)

Response:

Studies are underway or planned to address seepage flux for ambient conditions and the thermal period. In addition to these studies, evaluations have been added to address effects of alternative drift geometry, such as those caused by tunnel collapse. Specifically, the partial collapse of the drift is being evaluated to estimate the effects on seepage. A partial roof collapse could create large-scale asperities that increase dripping.

Despite recent progress in reevaluating the solubility of Np, significant uncertainties (possibly as much as five orders of magnitude) remain. Because the long-range dose potential of ^{237}Np is so significant, additional efforts are needed to narrow these large uncertainties, (page 24)

Response:

The Department agrees that additional work should be done to better estimate the solubility of neptunium (Np). Experiments and analyses are underway to address this issue. The Board raised three questions regarding the Department's reevaluation, in connection with the total system performance assessment for the viability assessment, of the expected value of the solubility of Np, which are addressed below.

Does the new evaluation use the proper conceptual model?

The goals of the reevaluation were to synthesize the relevant experimental and modeling work on dissolved Np concentrations and to assess the applicability of the data on Np solubility-limits for Yucca Mountain, rather than to select and use a particular conceptual model. These data were obtained from studies using water, like that from well J-13 near Yucca Mountain, that was oversaturated with respect to Np. The reevaluation concluded that the phases observed from oversaturation are metastable relative to NpO_2. Because solubility limits are intended to refer to the thermodynamically stable phase for an element, NpO_2 appears to be the appropriate phase with which to constrain Np concentrations over geologic time. Future work should be focused on delineating and evaluating the magnitude of any kinetic barrier to NpO_2 formation over geologic time.

Has the role of secondary mineral precipitates been evaluated adequately?

The Department agrees that precipitation of secondary minerals, particularly uranium phases that could incorporate Np or other radionuclides, should be characterized in more detail. Identification of the specific mechanisms that pull Np out of solution, including the effects of secondary mineralization, has begun. One example of such effects is incorporation of Np into schoepite, a secondary uranium phase. This observed alteration of the spent fuel is analogous to observations of oxidized uranium deposits and should be accounted for in more robust models of waste form evolution. The Department agrees with the Board that the constraints on dissolved Np concentrations from its incorporation into secondary uranium phases would represent more realistic constraints while these processes exert such controls. In addition, the effects on dissolved radionuclide concentrations from the nonequilibrium processes during alteration of the spent fuel can be addressed in work on waste form evolution.

Have the starting Np-bearing solid phases in the spent nuclear fuel been evaluated adequately?

The reevaluation discussed the possible Np-bearing solid phases and concluded that NpO_2 is the stable Np phase in this system based on the existing data sets. However, the reevaluation did not assume that the Np is in this form as a starting phase in the spent nuclear fuel, rather it discussed the possibility of NpO2 dissolved in the UO2 and the implications this would have for interpreting observed experimental data. For example, metallic Np, another potential starting phase, is highly metastable in the J-13-like-water experiments and would not be expected to be a stable phase under any conditions that are not highly reducing.

More data and better models are needed to demonstrate whether radionuclide travel times though the UZ could be significant (thousands of years), allowing the UZ to serve as a substantive natural component of a multi-barrier repository design, (page 24)

Response:

The Department is acquiring more data and developing better models to address radionuclide travel time in the UZ. Three areas where we are trying to reduce uncertainties in our models are in the effects of perched water, fracture-matrix interaction, and colloids.

The shorter travel times that are predicted with the current model, compared with previous models, are primarily a result of using much higher net infiltration rates than previously considered. The higher infiltration rates crossed the threshold from a condition in which the total percolation flux could potentially be transmitted through the matrix of the less permeable welded and zeolitic rock units to one in which fracture flow in these units is required. With a substantial portion of the flow in the fractures, the radionuclide travel times are much shorter, particularly for nonsorbing radionuclides.

However, there are several elements of UZ flow that remain uncertain and require additional study. These include the transport pathways in areas of perched water, fracture-matrix interaction in the more permeable Calico Hills nonwelded vitric rock unit, and colloid-facilitated radionuclide transport. The first of these elements is discussed below and the second two, in the following response.

The current model predicts that transport pathways are laterally diverted around perched water zones, resulting in very rapid radionuclide transport to the water table. An alternative model is being investigated for which transport pathways, in whole or in part, pass vertically through the perched water zone. Predictions of chemical and isotopic water compositions using this perched water conceptual model will be compared against observations.

The testing at Busted Butte is being conducted to assess the transport of colloids and other aqueous species through the UZ below the repository and should provide enough information to reduce uncertainty, (page 24)

Response:

Testing at Busted Butte is underway to address uncertainties in the UZ flow through the Calico Hills formation, which is a potential barrier below the repository.

The current flow model, discussed in the proceeding response, predicts that flow in the matrix is dominant in the more permeable Calico Hills nonwelded vitric rock unit compared to the fracture flow in the other rock units between the repository and the water table. Travel times, particularly for nonsorbing radionuclides, are primarily a result of travel time through this unit, due to the rapid transport in fractures through the other rock units. The field testing being conducted at Busted Butte will be used to help support or refute this conceptual model.

Concerning colloid-facilitated radionuclide transport, the current model will be linked more directly to laboratory testing and field investigations at Busted Butte and the Nevada Test Site (NTS).

Engineered Barrier System

The engineered barrier system, ..., performs a vital role in the operational and postclosure performance of the geologic repository.

Evaluations of alternative concepts for underground facility design are needed, especially of concepts that may provide the same level of performance, but with less uncertainty than provided by the current underground facility design. For example, a ventilated repository design with lower peak temperatures could reduce current uncertainties about the heat-induced hydrologic, mechanical, and chemical changes in the rock surrounding tunnels and could reduce the rates of waste package corrosion and radionuclide mobilization from the waste, (page 37)

Response:

The Department agrees that the repository design should not be prematurely fixed and potential design enhancements should not be foreclosed. Our design approach balances the need to develop and maintain a coherent working concept with the recognition that such a design concept will invariably change over time. In response to the suggestions of the Board, we are undertaking an evaluation of design alternatives known as the License Application Design Selection activity. This process is enabling us to look individually and collectively at previously identified design features with a new perspective. It is essential that we complete a fair and objective evaluation of alternatives with the insights gained from site characterization before we select the appropriate reference design for the site recommendation evaluation and license application. The reference design is envisioned to continue to evolve throughout site recommendation, licensing, and construction.

Predicting the performance of a waste package design is a matter of predicting the external (tunnel) environment of the waste package, how the waste package and its environment would interact to modify the environment, and how the materials used in the waste package would degrade (corrode) in response to the environment. High confidence in performance predictions for the nickel-alloy inner wall of the current design is needed because of its importance to waste package longevity. Research could determine if the present package design could easily generate, beneath the remains of the carbon-steel outer wall, an environment aggressive enough to deteriorate the corrosion-resistant alloy quickly. Research also is needed to confirm long-term predictions (e.g., corrosion rates, phase stability over tens of thousands of years). These predictions are based on knowledge gained during only the past several decades for materials that rely on passive films for corrosion protection and on data gained only during the pastyear or so for Alloy 22 under Yucca Mountain conditions, (page 37)

Response:

The Department agrees with the Board's statement regarding the importance of understanding waste package environment and how the package would degrade in that environment, with an emphasis on understanding the performance of the corrosion-resistant inner barrier (Alloy 22) material. Testing is underway to address the Board’s concerns on corrosion of Alloy 22.

The tests include studies of changes in water chemistry in the crevice between the outer and inner barrier; short term tests are underway to better characterize that environment and the alloy's ability to maintain a passive film. Other tests include use of an atomic force microscope to characterize the changes to the passive film as corrosion progresses.

Long-term tests to address predictions of corrosion began two years ago to assess a variety of conditions expected at Yucca Mountain. In regard to the thermal phase stability of Alloy 22, the phases present as a result of welding and/or aging are being characterized. This work includes the evaluation of welds taken from the full-diameter prototype and samples provided by suppliers that have been exposed for tens of thousands of hours at elevated temperature. Samples of the aged material will be subjected to corrosion testing to determine the impact that aging has on corrosion resistance.

Several alternative waste package concepts include outer walls of high-performance materials, such as titanium alloys or Alloy 22. These alternatives offer the promise of lasting tens of thousands of years or longer, given the range of environmental conditions and the spatial and temporal distribution of dripping that may be found within the undergroundfacility. Adoption of one of these concepts could substantially reduce part of the uncertainty associated with the current waste package design. Research still would be needed, however, to confirm the viability of the alternatives, (page 37)

Response:

The Department agrees that high-performance materials could provide enhance system performance and reduce uncertainty. The suggested alternatives are being evaluated as part of the License Application Design Selection activity, and research is underway to support design decisions.

The alternatives being evaluated include waste packages made of Alloy 22 over carbon steel, two corrosion-resistant materials consisting of Alloy 22 over a titanium alloy, a design of two corrosion-resistant materials with an intermediate structural stainless steel member, designs with ceramic coatings, and others. To support the selection, data are being generated from both long-term and short-term tests. The latter focus on water chemistry, crevice corrosion, stress corrosion cracking, and, particularly for titanium alloys, hydrogen attack.

Saturated Zone (SZ)

The Board believes that the SZ is an essential natural component of a defense-in-depth repository design for Yucca Mountain.

Groundwater appears to move through the SZ from Yucca Mountain to the accessible environment 20 to 30 km away in less than the likely regulatory period of 10,000 years. Although retardation in fractured rocks may be ineffective because highly transmissive regions within the SZ may allow dissolved radionuclides to bypass sorptive minerals, retardation in the alluvium near Amargosa Valley may be greater. If so, the SZ could significantly delay transport of radionuclides between the repository and the accessible environment, (page 45)

Response:

The Department agrees that transport of radionuclides between the repository and the accessible environment could be significantly delayed, especially in the alluvial part of the SZ. Reactive tracer tests in the Amargosa Valley could address this issue.

Sorption, and therefore retardation, may be significantly greater in the alluvium than in the volcanic tuffs, because of the slower groundwater velocity in the alluvium, its mineralogical character, and its more homogeneous nature. The alluvium seepage velocity is lower than that of the volcanic tuff because of the higher effective porosity in the alluvium. The average porosity values for the alluvium and volcanic tuffs used for the viability assessment are 0.2 and 0.01, respectively.

We are exploring the option of conducting a series of reactive tracer tests in an alluvial well complex in the Amargosa Valley similar to those conducted at the C-wells complex. Using reactive tracers may allow quantitative evaluation of the sorptive characteristics of the alluvium. This work would be done in cooperation with Nye County.

Parts of the SZ may be a chemically reducing environment where some of the very-long-lived radionuclides, including Np and uranium, would precipitate, permanently removing them from the groundwater and reducing predicted radiation doses at the biosphere, (page 45)

Response:

Evidence of reducing conditions would include the presence of dissolved methane, H_2S, and Fe^{++} in groundwater; the absence of dissolved oxygen; and measured Eh of less than 100 pEV. Work is underway to evaluate these and other geochemical conditions in the SZ in wells of the Nye County Early Warning Drilling Program, as well as in selected existing wells at and around Yucca Mountain.

Work is planned to evaluate SZ geochemical conditions, including the possible occurrence and significance of a reducing environment, below the potential repository at Yucca Mountain and along the path of potential radionuclide migration. Additionally, the SZ site-scale flow and transport model, which will be used to estimate radionuclide concentrations at the accessible environment, will have the capability to simulate any concentration reduction that could occur through permanent removal of radionuclides by precipitation along the flow path.

Following this work, the sorption parameter values used in transport modeling will be adjusted to reflect the oxidation potential conditions observed in the SZ.

More data are required to support modeling of the SZ, especially for the regional flow system between the repository and the accessible environment 20 to 30 km away. Key geologic, hydrologic, and geochemical data, including information about long-range colloid transport, have the potential to answer specific questions, such as the role of stratigraphy and structure, recharge and discharge locations, and possible ages of water. Obtaining these data is likely to improve the understanding of SZ characteristics much more than additional modeling efforts will. (page 45)

Response:

The Department will acquire data to support SZ modeling in cooperation with Nye County. Data from the planned Nye County wells will help to increase our knowledge of the SZ flow system down gradient from the repository in an area where we have little data.

The Nye County wells should help locate the transition in the SZ flow system where the water table goes from the volcanic tuffs to the alluvium, which is particularly important to potential sorption of radionuclides. If wells are sufficiently deep at this transition, tests of flow and transport in the transition would be possible, as well as tests exclusively in the alluvium or in the volcanics.

Tracer tests in Nye County wells at scales larger than those of the C-wells complex (100 meters) will be completed in the alluvium. The tests will help characterize important SZ transport parameters. Specifically, they will provide dispersivity, flow porosity, storage porosity, matrix diffusion parameters, sorption-retardation parameters, and colloid transport parameters, along with transmissivity and storativity values of the volcanic-to-alluvium transition region.

In the future, planned Nye County drilling and testing could provide data on hydraulic and colloid transport parameters for faults. If the “length scale of interest” for fault effects is more than about 500 m, then cross-hole tracer testing will be impractical. This issue could then be addressed by (1) point dilution tests, (2) very long-term cross-hole natural gradient tests, or (3) a series of drift-pumpback tests (i.e., measuring the amount of drift during shut-in and comparing responses of different tracers during the pumpback).

Other relevant testing at the C-wells complex includes ongoing experiments of colloid-facilitated transport using microspheres and comparison of colloid transport to conservative tracer transport. Also, field and laboratory transport tests are being carried out to test desorption of radionuclides from colloids. In addition, long-range colloid transport measurements were completed at the NTS.

Lastly, geologic mapping has been extended to cover the southern part of the SZ model domain. The mapping has been incorporated into the hydrogeologic framework model and into the numerical site-scale flow and transport model.

Current estimates of SZ dilution eventually may prove to be conservative, but supporting a larger dilution factor will be difficult unless new data are obtained to support the estimates produced by numerical models. The wells and experiments planned by Nye County should provide valuable information about the part of the SZ downgradient of Yucca Mountain. However, these wells may not provide sufficient data, and additional testing at other sites closer to Yucca Mountain may be needed (page 45)

Response:

The Department recognizes the importance of the SZ dilution factors in performance assessment and may use additional testing in the Nye County wells and the C-well complex to support the dilution factors to be used for modeling.

Different tests can be designed to address each of the three distinct dilution processes occurring in the SZ that may act to reduce radionuclide concentrations at the accessible environment. These three processes are (1) dilution due to mixing at the UZ-SZ interface; (2) dilution due to dispersion, sorption, and matrix diffusion in the SZ; and (3) dilution due to mixing in the pumping well.

To assess dilution due to mixing at the UZ-SZ interface, point-dilution testing and testing that provides estimates of vertical transverse dispersivity need to be part of the objectives of future SZ tracer testing. In addition, recent geochemical analyses, which indicate that increased dilution results from climate changes that cause increased recharge in the region down gradient from the repository, will be considered in models.

To assess the dilution due to dispersion in the SZ, transverse dispersion can be estimated using long-term natural gradient tracer tests. Sorption, as discussed earlier, is being addressed with tests in the Nye County wells. Also, field and laboratory measurements of matrix diffusion will support values used in models.

To assess dilution due to mixing at the pumping well, relevant factors include pumping rate, well location and screen depth and interval with respect to the radionuclide plume, and transient nature of the pumping (i.e., the on and off pumping cycle). Currently, performance assessment models do not take credit for well-head dilution, but this decision and the need for additional supporting data could be reevaluated.