Appendix H
Communications Between the Board and the OCRWM

In addition to published reports, the Board periodically writes letters to the Director of the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM). The letters typically provide the OCRWM with the Board's views on specific technical areas earlier than do Board reports. The letters are posted on the Board's Web site after they have been sent to the OCRWM. For archival purposes, the four letters written during calendar year 1999 are reproduced here

The OCRWM typically responds to the Board's reports and letters, indicating its plans to respond to the Board's recommendations. Included here are the OCRWM's responses received by the Board during calendar year 1999. Inclusion of these responses does not imply the Board's concurrence.

Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; April 29, 1999.
Subject: The DOE's response to the Board's *Report to the U.S. Congress and the Secretary of Energy, November 1998.*

Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; September 20, 1999.
Subject: The DOE's response to the Board's *Report to The U.S. Congress and The Secretary of Energy, Moving Beyond Yucca Mountain Viability Assessment.* April 1999

Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; September 20, 1999.
Subject: The DOE's response to the Board's *Report to the U.S. Congress and the Secretary of Energy, April 1999, summarizing the Board's 1998 activities.*

Letter from Chairman Jared L. Cohon to Lake H. Barrett, Acting Director, OCRWM; March 3, 1999.
Subject: Comments on repository design, site investigations, and Nye county drilling program.

Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; June 15, 1999.
Subject: The DOE's response to March 3, 1999, Board letter.

Letter from Chairman Jared L. Cohon to Lake H. Barrett, Acting Director, OCRWM; July 9, 1999.
Subject: Comments on the DOE's process for selecting a repository design and on the recommended repository design.

Letter from Lake H. Barrett, Acting Director, OCRWM, to Chairman Jared L. Cohon; September 10, 1999.
Subject: The DOE's response to July 9, 1999, Board letter.

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.

NS

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

96

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 preceeding 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 past year 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 underground facility. 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 μEV. 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.

Department of Energy
Washington, DC 20585

September 20, 1999

SEP 23 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 *A Report to the U.S. Congress and the Secretary of Energy, Moving Beyond the Yucca Mountain Viability Assessment,* issued in April 1999. Our detailed responses to the Board's report are found in the enclosure.

I thank you for commending the Department on our successful and timely completion of the viability assessment (VA). The Department agrees that the VA was a useful management tool for integrating our work and setting priorities. We also agree that the VA is not the same as a suitability evaluation; in fact, the VA identified the additional work to evaluate suitability and prepare a license application. We are pleased that the Board has found that the testing and research plans described in the VA are generally consistent with those identified by the Board.

The Board's report supports continuing focused studies at Yucca Mountain and emphasizes the importance of reducing uncertainties in repository performance. The Department is currently reevaluating our science and engineering activities, taking into account potential budget reductions and advances in the reference repository and waste package designs. We share the Board's concern that budget reductions could cause deferral of planned studies. We are prioritizing the activities most important for supporting the site recommendation decision. We will be emphasizing those activities that reduce the level of uncertainty in the performance of the repository.

In this report the Board noted the merits of a lower thermal loading in reducing uncertainties in repository performance. In response to these and previous recommendations of the Board, we have undertaken an evaluation of alternative designs, as was described at the Board's January and June meetings of this year, for the next phase in the continuing evolution of design concepts. We are considering the recommendation of our Management and Operating (M&O) contractor for a design with a lower thermal loading than the VA reference design, in part for its merits in reducing uncertainties in performance.

87

The input provided by the Board contributed to the quality of the viability assessment. We value the Board's feedback as we continue with the additional work to support a decision for the Nation on geologic disposal at Yucca Mountain. If you have any questions, please contact me at (202) 586-6850.

Sincerely,

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

Enclosure

88

Department of Energy
Washington, DC 20585

September 20, 1999

SEP 24 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 *A Report to the U.S. Congress and the Secretary of Energy*, issued in April 1999, summarizing the Board's 1998 activities. The Department is pleased with the Board's finding that the viability assessment (VA) was a useful management tool for integrating our work and setting priorities. We agree that the VA is not the same as a suitability evaluation; in fact, the VA identified the additional work to evaluate suitability and prepare a license application for the viability assessment reference design.

The Department is also pleased that the Board agrees in general with the research needs described in the VA. The enclosure addresses the particular research needs emphasized by the Board: water seepage into repository drifts, retardation of radionuclides in the unsaturated zone, long-term corrosion rates of waste package materials, and flow and transport properties in the saturated zone.

The enclosure also addresses the Board's comments on the defensibility of taking credit for cladding in performance assessment and the Board's suggestions regarding development of our transportation program.

The other major topics discussed in the report have been addressed in previous correspondence. Characterization of the saturated and unsaturated zones and design of the repository and waste package were addressed in our April 29, 1999, response to the Board's November 1998 report, as well as our June 15, 1999, response to the Board's letter of March 3, 1999. Total system performance assessment was addressed in our October 19, 1998, response to your letter of July 30, 1998.

89

The Department values the input provided by the Board in 1998 as we completed the VA. We look forward to the Board's feedback as we proceed with the additional work to support a decision for the Nation on geologic disposal at Yucca Mountain. If you have any questions, please contact me at (202) 586-6850.

Sincerely,

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

Enclosure

Department of Energy's Response to the
Nuclear Waste Technical Review Board's April 1999
Report to the U.S. Congress and the Secretary of Energy
Summarizing the Board's 1998 Activities

Research Needs

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

> *How much water seeps into repository drifts under ambient conditions as well as during the first 1,000 years after waste emplacement, when the rock surrounding the facility is heated?*

Response:

We appreciate the Board's support for our assessment that seepage into drifts under ambient and thermally perturbed conditions is considered one of the most important areas for further characterization and modeling. Seepage testing in the Exploratory Studies Facility niches and in Alcove 1 has suggested that a minimum "seepage-threshold" percolation flux of between 8 and 100 mm/yr must be present in the rock mass surrounding an excavated opening in order to induce seepage into the opening. Substantiating the existence of and determining the applicable bounds on a "seepage-threshold" flux could provide substantial benefit to overall potential repository system performance.

Current planning calls for testing of seepage parameters in Niche 5 in the East-West Cross-Drift. This information will significantly extend our knowledge of seepage parameters and reduce uncertainty in seepage predictions. Modeling studies will incorporate this and other recent information and include a more representative drift geometry that incorporates partial drift collapse and asperities on the drift wall. Additionally, the ongoing Drift Scale Test will provide data to support modeling not only of the effects of thermal perturbations on seepage, but also the effects of coupled thermal, hydrologic, and chemical processes in the drift environment.

> *Can the zeolitic formations beneath the repository retard the migration of radionuclides to the environment?*

Response:

We appreciate the Board's support for our assessment that the capability of zeolitic minerals beneath the potential repository to retard radionuclides remains an area of priority. Both vitric and zeolitic units, which contain zeolites in differing abundances, can retard the migration of radionuclides. Zeolites have a high sorptive capacity for radioactive alkali and alkaline-earth

cations (Sr, Cs) and a much lower sorptive capacity for transuranic elements (Pu, Np). Retardation of radionuclides in units containing zeolites depends on the amount of matrix activated by the migration front and by the abundance of zeolites at that location.

Currently, performance assessment analyses incorporate some retardation of radionuclides by zeolites in total system performance assessment (TSPA) models; however, data on perched-water occurrences and results from the Busted Butte Field Transport test are indicating that more credit may be taken for this retardation process.

What are the long-term corrosion rates of waste package materials, such as Alloy 22?

Response:

We appreciate the Board's support for our assessment that the long-term corrosion rates of waste package materials is an area of investigation that requires additional work to increase confidence in the predictive models. Samples of key materials have been exposed in the Long Term Corrosion Test Facility for over two years. In addition, literature data on long-term exposures have been collected to augment the available database. Also, similar materials have been considered, such as the performance of Alloy C, a precursor alloy to Alloy 22, to further expand the database. Models for performance prediction will be developed from qualified data. Other data will be utilized to corroborate the predictions developed.

What are the flow-and-transport properties of the groundwater that lies approximately 200 meters beneath the repository horizon?

Response:

We appreciate the Board's support for our assessment that the definition of groundwater flow and radionuclide transport within the saturated zone (SZ) from beneath the potential repository to the compliance point is an important priority. Current Project activities are focusing on the development of a 3-D SZ flow and transport model to support TSPA evaluations of potential repository system performance. The model is based on an updated hydrogeologic framework, includes recent data from hydraulic and tracer testing at the C-Wells Complex, and is incorporating new data from the Nye County Early Warning Drilling Program as these data become available.

Although currently supported by relatively sparse data down-gradient from the immediate site area, the model is expected to provide an improved basis for evaluating flow and transport from the potential repository to the compliance point relative to the representation used in TSPA for the viability assessment. In developing the model, the following specific priorities have been identified:

Definition of the ground-water flow and transport pathways down-gradient from the site;
Determination of the advective flow velocity along these pathways;
Determination of the sorptive properties of the alluvial materials (especially with regard to ^{129}I); and
Quantification of matrix diffusion in the fractured volcanic-rocks aquifers.

Cladding Credit

The final report from the waste form expert elicitation provided little support for taking a significant amount of cladding credit. One expert even indicated that cladding credit probably could never be taken because of the large uncertainties in the environmental conditions surrounding the cladding. Despite these objections, the DOE took full cladding credit in the TSPA-VA. The Board is concerned that the DOE seemingly ignored the judgments of its own experts on this issue. (page 10)

Response:

In general, the expert elicitation panel members concluded there is insufficient information to support significant credit for cladding. However, many of the experts felt that credit for cladding could be taken if some of the concerns regarding the potential for degradation of the cladding as a result of crevice corrosion or delayed hydrogen cracking could be resolved. Other experts outside of the expert elicitation panel felt that there was a need for better understanding of the initial condition of the cladding.

As a first step in resolving the cladding performance issue, a detailed literature review has been undertaken which has involved internationally known and respected experts in cladding performance. These experts have provided insight as to the likely mechanisms that will be active under expected Yucca Mountain conditions, particularly later in the long expected lifetime of the alternative waste package designs being considered. In addition, several kinds of cladding integrity tests are already underway at Argonne National Laboratory. Crevice corrosion testing will be initiated shortly.

These test results, coupled with a detailed evaluation based on a review of the literature, will determine under what conditions credit cladding performance can justifiably be included in the overall performance of the spent fuel waste form. The Department will continue to examine the performance of a multi-barrier system with and without cladding credit.

Transportation

In developing its transportation program, the DOE might learn much from experiences in Europe and Japan, where there is already large-scale transportation activity. In those countries, there is an antinuclear element that the industry must deal with.

The DOE also might learn some lessons from what is taking place in Europe and should make every effort to build trust and a good working relationship with the groups, especially in Nevada, that will be affected by a large-scale shipping campaign. One possible approach to maximizing safety and to preventing undue burdens on the nationwide railroad network could be the use of dedicated trains for transporting spent nuclear fuel. The Board also feels that the design of the transportation cask should be integrated with that of the rail car. An integrated design concept would be a way to increase safety and performance. (page 23)

Response:

The Department appreciates the suggestions on the transportation program from the Board. The Department continues to follow with interest the international transportation and cask development activities along with the other various related issues as they emerge. It appears that every country, including the United States, has or will have, an antinuclear element as mentioned by the Board. The Department is continuing to work with stakeholder groups, including those in Nevada, toward a productive working environment.

In regard to the dedicated train and integrated rail car design, the Department agrees with both suggestions and believes that the current draft Request for Proposals for Waste Acceptance and Transportation Services (RFP) is compatible with the suggestions. The RFP calls for...*maximum use of special train service and advanced rail equipment features where this type of service or equipment can be demonstrated to enhance operating efficiency, dependability, cost effectiveness or lessen the potential of adverse railroad equipment incidents.*

In addition, the RFP requires the testing and operational demonstration of a *Transportation Cask System,* which is defined to include *the transportation cask, or transportation overpack (as applicable), the rail car (for rail-mounted casks), the trailer (for truck-mounted casks), and all other integral (i.e., shipped with/or on the rail car or trailer) transportation-related items including, but not limited to, transport skid, lifting trunnions, removable shielding (if needed), and applicable tie-down mechanisms*. While the rail equipment has not yet been built to support the next generation of rail casks being licensed by the U.S. Nuclear Regulatory Commission, the Department believes that the procurements resulting from this RFP will result in integrated designs.

In summary, the Department believes that we have developed an initial plan and acquisition approach that is consistent with the Board's suggestions. There may be several different, but acceptable solutions to general safety concerns, and the Department expects that there will be additional modifications to the requirements and approach described in the draft RFP prior to its final release.

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

March 3, 1999

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

Dear Mr. Barrett:

On behalf of the Nuclear Waste Technical Review Board, I thank you and your staff for your hard work in preparing for the panel meeting on the repository license application and design selection (LADS) process held on January 25 and the full Board meeting held on January 26 and 27, 1999. The Board members felt that the full Board meeting was among the best we have had, in large part because of the quality and responsiveness of the DOE presentations. We were especially pleased that you were able to participate in the entire session devoted to the viability assessment (VA).

The panel meeting also was very productive and informative. The presentations for both meetings were well prepared, and several effective speakers were involved who had not previously participated in Board meetings. Claudia Newbury deserves special recognition for the excellent job that she did in coordinating the OCRWM's participation and helping ensure the success of the meetings.

Specific comments arising out of the presentations made at the Board and panel meetings follow.

The Viability Assessment (VA). The Board regards the DOE's completion of the VA as a significant accomplishment. The Board agrees with the DOE that the VA was not meant to be and is not a determination of the suitability of the site. However, the VA does integrate the data collected and the analyses performed for the Yucca Mountain Project thus far. It also establishes priorities for future investigations and analyses. The Board is pleased that, in general, the testing and research priorities in the VA are consistent with those identified by the Board in its November 1998 *Report to The U.S Congress and The U.S. Secretary of Energy.* As I indicated at the meeting, Board comments about the VA will be issued in the next few weeks, after we complete our evaluation. The information provided during the Board and panel meetings will be very helpful in our review.

95

Telephone: 703-235-4473 Fax: 703-235-4495

Repository Design. The Board members were very pleased that the first LADS workshop encouraged the advocacy teams for competing designs to think well beyond the bounds of previous repository design concepts. The Board believes that the selection criteria and weighting must be clearly defined and that the transparency of the process should be improved. We look forward to receiving a list of the selection criteria as soon as they are finalized.

As you noted at the Board meeting, the VA reference design will undergo evolutionary change as a result of the LADS process. However, the Board reiterates that an analysis of alternative repository designs should not be simply an evaluation of "enhancements" to the reference design. In particular, high temperatures in the VA reference design lead to large uncertainties about how the site would behave both before and after closure. *Therefore, the Board believes that the DOE should give serious consideration to true alternatives to the reference design, including changing from a high-temperature to a ventilated low-temperature design.*

The Board believes that a repository design based on lower waste package surface temperatures could significantly reduce uncertainty, enhance licensability, and simplify the analytical bases required for site recommendation. Combined with improved shielding, such a design also could simplify preclosure performance confirmation by enhancing access to the tunnels, thus reducing or eliminating the need for separate performance confirmation drifts and permitting direct access to performance confirmation instrumentation near the waste packages.

Some of the factors that have influenced the Board's thinking on repository design follow.

- *Corrosion severity would be significantly reduced by lowering waste package temperatures.* For a given environment, chances for degradation of corrosion-resistant waste package materials would be significantly reduced if peak waste package surface temperatures were reduced (for example, limiting peak temperatures to below the local boiling point of water, 96°C). For defense-in-depth, the use of multiple corrosion-resistant barriers, such as Alloy 22 and Ti, may significantly enhance waste package performance.

- *There would be degradation of tunnel stability because of the thermal pulse.* Professor Tor Brekke, the chair of the DOE's Panel on Drift Stability, pointed out at the Board meeting that high repository temperatures would increase rock degradation. He also stated that the effects of such high temperatures on the different rock units within the repository block at Yucca Mountain are not known.

- *There would be significant reduction of coupled thermal-hydrologic and thermal-geochemical processes at lower temperatures.* Maintaining postclosure near-field temperatures below the boiling point of water—for example, by ventilation or aging—could reduce uncertainties about the movement of water and about associated geochemical processes in the near and far fields. This would simplify the analyses required for a site-suitability determination.

96

The Board recommends that a more complete quantitative analysis of a low-temperature repository design be undertaken before the completion of the LADS process. For example, preliminary calculations could be performed in the next several months to quantify the removal of heat and water from continuously ventilated repository tunnels. Such an evaluation also should include an analysis of the long-term stability of the tunnels.

Site Investigations. The Board was encouraged to hear about progress in a number of site investigations such as the tests being conducted at the Busted Butte facility. If these tests indicate a significant potential for sorption of radionuclides in the unsaturated zone (UZ), they could increase the credibility of the natural features at the site as contributors to repository performance.

However, the Board is concerned about the deferral, at best, of critically important geologic, geochemical, and hydrologic studies in the east-west cross-drift that are aimed at understanding the magnitude and distribution of seepage into the repository under present ambient conditions, as well as under conditions existing in the past, when climates were very different. Technically defensible arguments about the repository's hydrologic environment, which is the single most important natural feature affecting repository performance, will be difficult to make without this information. The studies include (1) the systematic analysis of the rock samples being collected, in particular with respect to chlorine-36 and other indicator isotopes; (2) flow and seepage tests at different locations along the drift, perhaps even closing off part of the drift for these studies; (3) tests in the lithophysal zones, where the majority of waste packages may be emplaced; and (4) studies of the Solitario Canyon fault, the active fault bounding the repository that also may serve as a main conduit for percolating water.

The Board also is concerned about the apparent premature cessation of surface-based drilling at WT-24, the borehole that was meant to shed light on the origin of the large hydraulic gradient located just north of the proposed repository.

Nye County Early Warning Drilling Program (EWDP). The EWDP gives the DOE a unique opportunity to obtain data from the saturated zone (SZ) that may help address significant uncertainties about flow and transport in the SZ. In particular, the Board will be very interested in the substantiation and interpretation of initial results from the EWDP indicating the existence of warm water at depth in some locations. The Board was pleased to see that some initial problems with coordination between the EWDP and DOE-sponsored investigations appear to have been overcome.

Summary. Although the Board believes that completion of the DOE's VA is a significant accomplishment, viability is not suitability. The 2001 date anticipated for the suitability decision is very ambitious, and much work remains to be completed. The Board supports continuing focused studies of both natural and engineered barriers at Yucca Mountain to attain a defense-in-depth repository design. Testing under way in the UZ at Busted Butte and drilling under the auspices of Nye County in the SZ may provide important data about water flow and potential radionuclide transport. In addition, the Board is concerned about the deferral of critical geologic, geochemical, and hydrologic studies in the east-west cross drift.

97

The Board reiterates that a repository design based on lower waste package surface temperatures has the potential to reduce uncertainty, enhance licensability, and simplify the analytical bases required for site recommendation. Through additional analysis and clear selection criteria, this potential alternative could be reasonably compared with the VA reference design or other variations of the VA design.

Finally, the Board is concerned that if cutbacks in science and engineering occur during the next two years, then the chances of accomplishing these needed activities also will decrease.

Thanks again to you and your team for helping make the Board and panel meetings successful.

Sincerely,

Jared L. Cohon

Jared L. Cohon
Chairman

98

Department of Energy
Washington, DC 20585

June 15, 1999

JUN 16 1999

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

Dear Dr. Cohon:

The Department of Energy appreciates the Nuclear Waste Technical Review Board's letter of March 3, 1999, regarding your observations and comments on the Department's presentations at the panel meeting on January 25 and Full Board meeting on January 26-27. In particular, we are pleased that the testing and research plans in the viability assessment (VA) are generally consistent with those identified by the Board. The Department's responses to your specific comments on repository design and site investigations are enclosed.

As discussed at the panel meeting, the Department is evaluating repository and waste package design alternatives beyond the design options considered in the VA. This evaluation furthers the evolution of our repository and waste package design and will provide the basis for selecting an appropriate design for site recommendation (SR) and license application (LA). Our early conceptual waste package design, with thin-walled canisters, changed to larger, more robust waste packages. The reference design then evolved to a high temperature design, as used in the VA, intended to keep water away from the waste packages for long periods of time. However, higher water flux through the repository than previously thought, together with the desirability of reducing uncertainty in repository performance, now makes re-evaluation of the design appropriate.

This evaluation has covered a wide variety of repository and waste package designs, including designs suggested by the Board. The evaluation followed a consensus decision process, which is appropriate for an ongoing design process in which the alternatives are continually being refined. The Department is pleased that the Board has chosen to closely follow the design selection process.

The Program's Management and Operating contractor completed its evaluation process and recommended a repository design with a lower thermal impact than the reference design for the VA. This design is flexible and permits modification toward higher or lower temperatures. It also reduces uncertainty in repository performance estimates. The recommended waste package design also includes an outer corrosion-resistant barrier, as suggested by the Board. The Department plans to make a design decision subsequent to the Board's meeting on June 29-30, during which the alternative design evaluation will be discussed.

99

Regarding your concern on cutbacks in science and engineering, we intend to prioritize in our planning the activities most important to site recommendation. The periodic re-evaluation of the priorities of Project activities has special significance because of the likely change in the reference repository and waste package designs.

We continue to value the Board's feedback on our program as we work toward a decision on site recommendation. If you have any questions, please contact me at (202) 586-6842.

Sincerely,

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

Enclosure

100

Department of Energy Responses to the March 3, 1999, Letter of the Nuclear Waste Technical Review Board

Repository Design

The Board believes that the selection criteria and weighting must be clearly defined and that transparency of the process should be improved. We look forward to receiving a list of the selection criteria as soon as they are finalized.

Response:

The Department agrees that the selection process and criteria should be clearly defined and that the implementation of the process used to evaluate design alternatives should be transparent, structured and defensible. The design selection process includes an independent review panel to help ensure that the process is transparent and defensible. The goal of the design selection process is to select a conceptual design for the initiation of the site recommendation (SR) and license application (LA) process.

The set of criteria used in phase I of the process and presented at the January meeting was revised for the evaluation of the enhanced design alternatives (EDA) in phase II. The revised set included a screening criterion reflective of possible release standards and four general criteria for which the alternatives were ranked in paired comparisons: licensing probability, construction/operation/maintenance issues, flexibility to accommodate design changes, and cost/schedule.

Rather than giving each criterion a specific weight in the selection process, the participants followed a consensus decision process. We believe that this consensus process was most appropriate for an ongoing design process in which the alternatives were continually being refined. The participants looked for designs that appeared to rank well across multiple criteria while having no low ranking for any criterion. The participants considered qualitatively their individual evaluations of the relative significance of the criteria in selecting a design, although no quantitative weights were explicitly assigned to the criteria.

The Board believes that the DOE should give serious consideration to true alternatives to the reference design, including changing from a high-temperature to a ventilated low-temperature design.

Response:

The Department is giving serious consideration to true alternatives to the viability assessment (VA) reference design in the license application design selection (LADS) process, including diversity in waste package design, engineered barrier system (EBS) features, and thermal management features. These alternatives are all ventilated and include two concepts that have

time-temperature profiles that are significantly lower than that for VA, two concepts that have time-temperature profiles that are comparable to VA, and one concept that has a time-temperature profile that is significantly higher than that for VA.

The Board believes that a repository design based on lower waste package surface temperatures could significantly reduce uncertainty, enhance licensability, and simplify the analytical bases required for site recommendation. Combined with improved shielding, such a design could also simplify preclosure performance confirmation by enhancing access to the tunnels, thus reducing or eliminating the need for separate performance confirmation drifts and permitting direct access to performance confirmation instrumentation near the waste packages.

Factors that have influenced the Board's thinking on repository design include:

- *Corrosion severity would be significantly reduced by lowering waste package temperatures.*
- *There would be degradation of tunnel stability because of the thermal pulse.*
- *There would be significant reduction of coupled thermal-hydrologic and thermal-geochemical processes at lower temperatures.*

Response:

The lower temperature concepts are being considered for precisely the reasons identified in the Board's letter. Furthermore, the Department recognizes that the lower temperature concepts carry the potential to decrease the complexity of the performance confirmation system.

The objectives of the LADS activity are to select a reference design that satisfies the appropriate regulatory performance objectives for the preclosure and postclosure time frames, limits cost, limits licensing risk, and limits management risk (e.g., increases confidence and flexibility). Alternatives under consideration have included self-shielded waste packages that allow human accessibility for off-normal events.

The potential for providing shielded waste packages and continuous ventilation to allow unrestricted access to emplacement drifts has been evaluated. This evaluation identified serious concerns with respect to the increased thermal resistance of the waste package (thereby increasing the fuel temperature and potentially degrading the fuel cladding), the operational impacts of handling heavier, shielded packages, and the increased cost of the waste packages. Additionally, the increased size of the waste packages could require larger emplacement drifts. Finally, the current concept of not allowing routine personnel access should allow the facility to operate with lower overall personnel exposures than a concept involving such access.

Upon evaluation of the benefits and impacts, self-shielded waste packages were not carried forward as part of any of the alternatives. In the event that human access would be required to evaluate and respond to an off-normal event, cooling and radiation shielding requirements could be met by blast cooling a normally ventilated drift and by using portable shielding. Recognizing that repeated blast cooling could lead to instabilities in the drift walls, the need to do this would

be thoroughly evaluated before action was taken. These concepts are included in all of the EDAs being considered.

The Board recommends that a more complete quantitative analysis of a low-temperature repository design be undertaken before the completion of the LADS process. For example, preliminary calculations could be performed in the next several months to quantify the removal of heat and water from continuously ventilated repository tunnels. Such an evaluation also should include an analysis of the long-term stability of the tunnels.

Response:

Before selecting a design for SR and LA, the Department will develop a sufficient technical basis to support this decision. A number of 2- and 3-dimensional models have been developed and used to depict temperature and humidity variations in the emplacement drifts with various waste package loadings. The Department believes that this work and existing analyses and evaluations will provide a sufficient basis for a selection between a high and low temperature repository.

Site Investigations

The Board is concerned about the deferral, at best, of critically important geologic, geochemical, and hydrologic studies in the east-west cross-drift that are aimed at understanding the magnitude and distribution of seepage into the repository under present ambient conditions, as well as under conditions existing in the past, when climates were very different. Technically defensible arguments about the repository's hydrologic environment, which is the single most important natural feature affecting repository performance, will be difficult to make without this information. These studies include:

- *Systematic analysis of the rock samples being collected, in particular with respect to chlorine-36 and other indicator isotopes.*
- *Flow and seepage tests at different locations along the drift, perhaps even closing off part of the drift for these studies.*
- *Tests in lithophysal zones, where the majority of waste packages may be emplaced.*
- *Studies of the Solitario Canyon fault.*

Response:

Although the scientific studies cited by the Board will not be completed in time for all the results to be incorporated in the initial versions of the License Application Design and Total System Performance Assessment-Site Recommendation (TSPA-SR), some results will be available for incorporation in later revisions of SR or as confirmatory data either before or during the licensing process. In particular, the iterative nature of the TSPA for SR and LA will allow test results to be used in support of suitability and licensing decisions. As was indicated in Volume 4 of the VA, a

substantive change in the design will necessitate a re-assessment of scientific and engineering work priorities. The Department is in the process of such a re-assessment based on proposed changes to both the design and the set of documents that will support the TSPA. Planned activities in the following discussion that will not produce results in a time frame that can support SR may be delayed or changed. The Department acknowledges that these activities are important to reducing uncertainties in the natural system.

Current plans include a systematic sampling program for hydrologic, hydrochemical, and mineralogic-petrologic-geochronologic studies. For the chlorine-36 analyses in the cross-drift, we have sampled every 50 meters from boreholes, collected feature-based samples, concentrating on faults and highly fractured zones, and collected systematic samples utilizing a modified sampling strategy based on comments of the Chlorine-36 Peer Review Panel. Some of these samples are being analyzed in Fiscal Year 1999, with more analyses planned in Fiscal Year 2000.

The Department is currently prioritizing the testing in the cross-drift and working to bring the most important testing forward in the schedule. The revised Fiscal Year 1999 plan includes: a) excavation and drilling at the Crossover Alcove, with testing to follow in Fiscal Year 2000 to address flow and transport processes in repository horizon rocks (Middle Nonlithophysal Subunit); b) excavation and start of drilling at Niche 5, with testing to follow in Fiscal Year 2000 to address flow and seepage processes in the repository horizon (Lower Lithophysal Subunit); and c) sealing the back half of the cross-drift with bulkheads for as long as a year to address flow and seepage processes under the relatively high infiltration areas and the Solitario Canyon Fault Zone (SCFZ).

Testing in the cross-drift in Fiscal Year 2000 will include the Cross-Drift Thermal Test in the repository horizon (Lower Lithophysal Subunit). Flow and seepage testing at Niche 6 (Lower Nonlithophysal Subunit); hydrologic testing underneath the high infiltration area (Crest Alcove); and borehole testing of the SCFZ may not provide data in time for the SR and, consequently, will probably be deferred to later years.

With respect to the SCFZ, the tunnel boring machine cut through the main splay of the fault, but stopped short of the west splay of the fault. We have completed detailed mapping of the main splay. We also plan to drill long boreholes to explore the undisturbed west splay and the main splay and conduct studies similar to those completed in Alcove 6 for the Ghost Dance fault.

The Board also is concerned about the apparent premature cessation of surfaced-based drilling at WT-24, the borehole that was meant to shed light on the origin of the large hydraulic gradient located just north of the proposed repository.

Response:

At its present depth, WT-24 is in a relatively tight section of the aquifer, and we are not able to conduct a pump test. The borehole would likely have to be deepened another 500 to 700 feet to get an acceptable aquifer pump test, and, even then, testing may not be feasible. Consequently,

we have demobilized the drilling rig. However, we have not precluded deepening the borehole at a later date based on needs generated from future results of the TSPA process or the LADS effort.

The Board will be very interested in the substantiation and interpretation of initial results from the EWDP indicating the existence of warm water at depth in some locations.

Response:

The Department is very pleased with the cooperation between Nye County and the Yucca Mountain Project on the first phase of the Early Warning Drilling Program (EWDP) and looks forward to similar successes in the planned follow-on EWDP efforts. We will continue to provide information to the Board on the interpretation of the results from the EWDP as they become available.

The Board is concerned that if cutbacks in science and engineering occur during the next two years, then the chances of accomplishing these needed activities also will decrease.

Response:

Our periodic re-evaluation of the priorities of ongoing and newly proposed Project activities in science, design and performance assessment has special significance because of the likely change in the reference repository and waste package design. We intend to emphasize in the current and near-term future work plans, which are likely to be revised as a result of the re-evaluation, the activities most important to site recommendation. We will issue only a site recommendation that has adequate scientific, engineering, performance assessment and environmental bases.

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

July 9, 1999

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

Dear Mr. Barrett:

During the last 10 months, the OCRWM's management and operating contractor (M&O) has been studying alternative repository designs for the proposed repository site at Yucca Mountain in Nevada. This study resulted in a recommendation by the M&O for a repository design. The Board understands that you will decide soon whether to accept, reject, or accept with modifications the M&O's recommended design.

High temperatures associated with the repository design used in the *Viability Assessment* issued in December 1998 create large and significant uncertainties about long-term repository performance. The Board believes that lower-temperature, below-boiling, designs have the potential to reduce the uncertainties as well as to simplify the analytical bases required for the Secretary's decision planned for July 2001 on whether to recommend the site for repository development.

The Board does not believe that its role is to endorse a particular repository design. However, because the design selected for the repository will affect confidence in decisions about the suitability of the Yucca Mountain site, the Board devoted considerable time to discussing repository design issues at its meeting last week in Beatty, Nevada. In this letter, the Board comments on the process for selecting the repository design and on the recommended design. Our comments are based on information from the Beatty meeting, from the Board's January 1999 meeting in Las Vegas, and from draft material furnished to the Board during the M&O's study of alternative repository designs.

Comments on the Process for Selecting the Repository Design

On April 14, 1999, the M&O recommended that the OCRWM select a design designated "Enhanced Design Alternative-II (EDA-II)." This design is characterized by (1) a repository "footprint" (area) of 1,050 acres for disposing of 70,000 metric tons of spent nuclear fuel and high-level radioactive waste and (2) peak tunnel-wall temperatures of approximately 160°C. EDA-II is one of six alternative designs studied by the M&O. The footprints of the designs

Dft 107

Telephone: 703-235-4473 Fax: 703-235-4495

range from 420 acres to 1,400 acres; the peak tunnel-wall temperatures range from below boiling (<96°C) to higher than 225°C.

The analytical process supporting the M&O's design recommendation was elaborate and resource-intensive. More than 25 reports analyzing individual design features or alternative repository designs were produced during this process. In the Board's opinion, this level of attention was appropriate because of the importance of repository design for the Secretary's site recommendation and for possible subsequent licensing. Because repository design has been considered a key issue by the Board for a long time, we are pleased that the study of alternative repository designs was undertaken. The presentations at the Board's meeting in Beatty indicate that this process has produced a much better understanding of the relative importance of the many factors involved in a repository design. The design recommended by the M&O shows much progress when compared with the design in the *Viability Assessment.*

The M&O's analysis of alternative designs was necessarily based on many assumptions. For example, the analysis assumed that the repository would be closed 50 years after the first emplacement of waste and that the ventilation system would be designed and operated so that only a portion (rather than nearly all) of the heat generated by the decay of radioactive material during the preclosure period would be removed in the ventilation exhaust. An important consequence of these assumptions was that many of the alternative designs had long periods with tunnel-wall temperatures above boiling after closure of the repository. Because of the potentially significant effects of these assumptions on repository behavior, their rationale and justification need to be carefully considered, well-grounded, and well-documented.

Selecting one design from several alternatives in the face of multiple and conflicting criteria necessarily requires value judgments. The M&O chose not to quantify or otherwise state explicitly the value judgments it used for recommending EDA-II. Because the values are not explicit, the Board — or anyone outside the process — cannot fully understand and evaluate the considerations applied in the selection. Therefore, the Board urges the DOE to be as explicit and quantitative as possible about its evaluation basis for deciding whether to accept the M&O's recommendation.

The Board realizes that issues such as operational flexibility, cost, and worker safety are important considerations in public policy: thus our emphasis on making explicit the values associated with the evaluation of these criteria. In addition, important policy choices — for example, how long the repository should remain open — currently are embedded in the evaluation process used by the M&O to reach its recommendation. These policy choices and their implications for predicted performance of alternative designs should be made explicit.

Comments on the Recommended Repository Design

In keeping with its statutory mission, the Board is most concerned about the technical defensibility of the repository system's design. The Board believes that understanding and quantifying uncertainty is central to the credibility of estimated repository performance, upon which many of the other criteria depend.

108

Repository design has a profound effect on the cumulative uncertainty about long-term repository performance. Thermal loading has a larger effect than any other single design attribute. In the recommended design, tunnel-wall temperatures would quickly increase to about 160°C shortly after repository closure and would remain above boiling for more than 300 years. According to present theory, during this high-temperature period, water in the rock near the tunnel walls would vaporize and migrate to cooler areas between the emplacement tunnels, where it would condense and drain. Early results from the drift-scale heater test tend to support this theory.

Unfortunately, the understanding of water mobilization and migration processes and effects during this initial high-temperature period is still far too limited to engender a reasonable degree of confidence. Some insight into thermohydrologic response has been gained from in situ thermal tests, including initial data from the ongoing drift-scale heater test. However, important results from the drift-scale heater test will not be available for several more years, precluding their use in the context of a site-recommendation decision. In addition, in the M&O's recommended design, more than 70 percent of the repository would be located in rock having properties that are potentially significantly different from the properties of the rock in which the drift-scale heater test is being conducted. A heater test may be conducted in a section of the cross drift containing the same rock in which the majority of the repository would be located, but at what time results from this test might be available for a site-recommendation decision is uncertain.

In general, the cooler the repository, the lower the uncertainty about heat-driven water migration and the better the performance of waste package materials. An important temperature for water migration is the boiling point of water. Above this temperature, technical uncertainties tend to be significantly higher than those associated with below-boiling conditions. For the most part, cooler repository conditions also tend to lead away from regimes where waste package materials are vulnerable to severe corrosion. Considering the current uncertainties created by high repository temperatures, the Board does not believe that a strong-enough technical basis exists at this time to support adequately any above-boiling repository design. To use an above-boiling design as the basis for a site recommendation would require a significant gain between now and the time of site recommendation in the understanding of thermohydrologic processes and their effects on materials behavior.

The Board believes that many of the above-boiling designs studied by the M&O, including the M&O's recommended design, could be modified to achieve a below-boiling design simply by increasing the rate or the duration, or both, of ventilation before repository closure. A design modified to achieve below-boiling temperatures would significantly reduce existing technical uncertainties about the long-term performance of the repository, while maintaining the flexibility to go to higher temperatures later if future data and analyses from the cross-drift heater test and the drift-scale heater test justify such action. Therefore, the Board urges the DOE to analyze carefully the implications of these and any other possible modifications that might be used to maintain below-boiling repository temperatures.

In comparison to the design in the *Viability Assessment*, additional features of the M&O's recommended repository design are titanium drip shields and backfill. The Board looks forward

108 109

to learning more about the technical bases for enhanced performance predicted because of the addition of these features.

The Board would like to thank you, your staff, and M&O personnel for participating in the Board's meeting in Beatty and for the material furnished to the Board during the M&O's study of alternative repository designs. We hope that you will find these comments on repository design timely and helpful.

Sincerely,

Jared L. Cohon

Jared L. Cohon
Chairman

DOE 110

Department of Energy
Washington, DC 20585

September 10, 1999

Dr. Jared L. Cohon
Chairman
U.S. Nuclear Waste Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

SEP 14 1999

Dear Dr. Cohon:

We appreciate the Nuclear Waste Technical Review Board's comments on our evaluation of alternative repository designs. We also appreciate your recognition that the comprehensive and resource intensive effort conducted by our Management and Operating (M&O) Contractor has resulted in a much better understanding of the relative importance of the many factors involved in a repository design. The evaluation performed by the M&O Contractor used the information gathered during site characterization and the understanding of repository system behavior gained from a series of performance assessments to guide the evolutionary process of design development. We have used the results from this evaluation, and the results from subsequent analyses performed by the M&O, to select the next generation design concept that will be developed for use in evaluating the site and preparing the license application if the site is suitable. A summary of our evaluation process, criteria, and results may be found in the enclosure.

We agree that the repository design concept and, in particular, the temperature regime associated with that concept may have a profound effect on the cumulative uncertainty in estimates of long-term repository performance. We also recognize that this uncertainty may affect confidence in decisions regarding the suitability of the Yucca Mountain site. We have sought to select a design and to specify conditions on its implementation that are responsive to the Board's concerns while balancing all significant factors, including long term public safety, inter- and intra-generational equity, worker safety, and cost. We have also emphasized the need for flexibility to ensure that scientific and engineering data gathered throughout site characterization, construction, operation and monitoring, and any evolution in national policy can be accommodated through reasonable changes in the repository design or operational concept.

After considering the technical information provided by our M&O Contractor, as well as the issues raised by external oversight groups, including the Board, we have selected a design concept to be used as the basis for the next phase of project activities. The selected design concept features much lower thermal impacts than the Viability Assessment design as well as significant enhancements in the engineered barrier system. We are in the process of incorporating this design basis in our programmatic and requirements documents. The concept we selected is based on the design alternative recommended by our M&O contractor, but includes the following, flexibility-enhancing conditions on its implementation:

111

1. The design will permit the repository to be kept open, with only routine maintenance, for approximately 125 years from initiation of waste emplacement, which is approximately the time necessary for the ventilation system to remove sufficient heat to keep the drift walls below boiling (96°C at the elevation of the potential repository) following closure.

2. The design will permit the repository to be closed during the period from 50 years to approximately 125 years from the start of waste emplacement. The design will not preclude keeping the repository open, with appropriate maintenance and monitoring, for 300 years after initiation of waste emplacement. A decision on when it is appropriate to close the repository will be made considering the results from performance confirmation testing and analyses, taking into account the need to dispose of the waste in a way that minimizes the transfer of the burden to future generations. This is consistent with current Program policy that future generations will make the ultimate decision on whether it is appropriate to continue to maintain the repository in an open monitored condition, or to close and seal it.

3. The sensitivity of the postclosure performance of the repository system to uncertainties associated with coupled, thermally driven processes will be examined for preclosure durations of 50 and 125 years.

4. The models that are the basis for the evaluation of thermal conditions will be refined to reduce conservatism. Design options that can increase the efficiency of heat removal will also be evaluated.

The selected design concept provides the flexibility to adjust emplacement conditions, and ventilation design and duration, to keep the rock temperatures below 96°C and as cool as is reasonably achievable given technical, institutional, and cost considerations. It also provides the flexibility to increase the rock temperatures, should new scientific and engineering data show that such an alternative is beneficial. The emphasis on flexibility in the evolutionary process of design development is consistent with the position taken by the Advisory Committee on Nuclear Waste (ACNW) in a recent letter to the Nuclear Regulatory Commission. The ACNW expressed the view that although a cooler repository design may simplify modeling of water redistribution, the potential for a higher temperature design to reduce the quantity of water reaching the emplacement drifts should not be abandoned without further assessment.

The design concept we selected also preserves the flexibility for future generations to determine whether to close the repository early or to keep it open for as long as 300 years with appropriate maintenance and monitoring, based on their own judgements regarding the significance of uncertainties. The early closure assumption of 50 years is consistent with the retrievability period required by the Nuclear Regulatory Commission and should provide adequate time to complete the performance confirmation program required before a Commission decision on closure can be sought.

We value the Board's feedback and recognize the contribution its has made to the quality of our products. We look forward to further input as we work toward completing the technical documentation necessary to provide a basis for a site recommendation decision. 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

ENCLOSURE

BASIS FOR DEPARTMENT OF ENERGY (DOE) DESIGN SELECTION

General Principles

DOE has selected the repository design to be used as the basis for development of the Site Recommendation (SR), as the next step in the evolutionary process of design development. The decision is based on general policy considerations of fairness and equity within and between generations, together with technical considerations involving five principal factors:

- *Public safety as measured by postclosure performance*
- *Demonstrability of postclosure performance in licensing*
- *Preclosure worker safety*
- *Flexibility to accommodate design changes and improvements in understanding*
- *Cost*

Policy Considerations of Fairness and Equity

The Nuclear Waste Policy Act includes among its findings that the national problem created by the accumulation of spent nuclear fuel and high-level waste requires that "*appropriate precautions must be taken to ensure that such waste and spent fuel do not adversely affect the public health and safety and the environment for this or future generations.*" A stated purpose of the Act is "*to establish the Federal responsibility...for the disposal of such waste and spent fuel.*"

In its 1990 report "*Rethinking High-Level Radioactive Waste Disposal,*" the National Research Council Board on Radioactive Waste Management considered what we owe to future generations and cited the Environmental Protection Agency (EPA) regulations requiring that radioactive releases be limited for 10,000 years as an illustration of concern for the distant future.

If a site for a repository is approved and the repository is licensed for emplacement of the Nation's high-level waste, any decision to close and seal the repository following an extended period of waste emplacement and monitoring will be made by some future generation. The design selected as the basis for site recommendation must provide the flexibility for future generations to make this decision based on their own criteria and to minimize the transfer of the burden from this generation to our descendents.

International organizations have developed position statements, representing the collective opinion of the parties involved, on the technical and ethical basis for geologic disposal. There is general agreement that the ethical basis for geologic disposal of long-lived radioactive waste involves considerations of fairness and equity within and between generations.

The International Atomic Energy Agency (IAEA), in its Report on Radioactive Waste Disposal (IAEA, 1993), states that a basic objective of safe waste disposal is "*to dispose of the waste in such a way that the transfer of responsibility to future generations is minimized.*" With regard to the responsibility of today's waste producers to future generations, the IAEA proposes as a safety principle that "*the burden to future generations shall be minimized by safely disposing of high level radioactive wastes at an appropriate time, technical, social and economic factors being taken into account.*"

The members of the Nuclear Energy Agency (NEA) Radioactive Waste Management Committee, in their report on The Environmental and Ethical Basis of Geological Disposal (NEA, 1995):

- *consider that from an ethical standpoint, including long-term safety considerations, our responsibilities to future generations are better discharged by a strategy of final disposal than by reliance on stores* [storage facilities] *which require surveillance, bequeath long-term responsibilities of care, and may in due course be neglected by future societies whose structural stability should not be presumed;*

- *believe that the strategy of geological disposal of long-lived radioactive wastes:*

  - *takes intergenerational equity issues into account, notably by applying the same standards of risk in the far future as it does to the present, and by limiting the liabilities bequeathed to future generations; and*

  - *takes intragenerational equity issues into account, notably by proposing implementation through an incremental process over several decades, considering the results of scientific progress;*

- *conclude that stepwise implementation of plans for geological disposal leaves open the possibility of adaptation, in the light of scientific progress and social acceptability, over several decades, and does not exclude the possibility that other options could be developed at a later stage.*

Consideration of these issues prompted DOE to adopt a policy that meets the obligation to provide for disposal of high-level waste at an appropriate time, while leaving flexibility to adapt and change in the future based on scientific progress or other considerations. Specifically, the repository design should permit future generations to close the repository as early as they might choose, allowing sufficient time to complete the performance confirmation program required for a Nuclear Regulatory Commission decision on an application for closure. The 50-year retrievability period from the initiation of waste emplacement, required by the Nuclear Regulatory Commission in both 10 CFR Part 60 and the proposed 10 CFR Part 63, was established as a reasonable estimate of the time that might be needed to complete the performance confirmation

115

program required to support a Commission decision on repository closure. At the same time, the design should permit future generations to keep the repository open for a longer period, with appropriate maintenance and monitoring, based on their own evaluation of the technical, social, and economic factors involved.

Technical Evaluation Factors and Basis of Evaluation

Five technical factors were identified and considered by DOE in its evaluation of design alternatives and selection of the design that will be developed to support site recommendation.

- *Public safety as measured by postclosure performance*
- *Demonstrability of postclosure performance in licensing*
- *Preclosure worker safety*
- *Flexibility to accommodate design changes and improvements in understanding*
- *Cost*

The order of discussion reflects DOE's view of the relative importance of each of these factors to the decision that is the outcome of the design selection process. The DOE's evaluation for each of the factors, based on the technical information and analyses presented in the License Application Design Selection (LADS) Report, is summarized below.

Public safety as measured by postclosure performance

All five enhanced design alternatives (EDAs) evaluated provide an adequate margin of safety as measured by a comparison of their calculated postclosure performance against the 25 millirem/year screening criterion imposed. All EDAs were estimated to provide at least a three-order-of-magnitude margin on the screening criterion at 10,000 years following closure. On this basis, safety, as measured by performance against the screening criterion, is not a discriminator. The same conclusion holds when the performance of the EDAs is compared to the individual protection standard of 15 millirem/year recently proposed by the EPA in 40 CFR Part 197.

The only potential basis for discrimination among the EDAs in terms of postclosure safety is found in the results of the long-term (>10,000 years) performance evaluation. All EDAs, other than EDA IV, have comparable performance in terms of the time required for the screening criterion to be exceeded (approximately 300,000 years) and the order of magnitude of the calculated peak dose rate (roughly 100 millirem/year). EDA IV, on the other hand, is estimated to exceed the screening criterion earlier (at about 100,000 years) and to have a peak dose rate that is an order of magnitude higher than the other EDAs. Although EDA IV appears to have better performance over the 10,000-year period, it was considered to be the least favorable design alternative on the basis of estimated long-term postclosure performance characteristics.

Demonstrability of postclosure performance in licensing

Although all EDAs provide an adequate margin of safety as measured by performance for the period following closure, there are uncertainties associated with understanding and modeling the processes that have the potential to significantly affect conclusions about performance. Such uncertainties may complicate the licensing process by making it more difficult to demonstrate with reasonable assurance that the postclosure performance objectives established by the NRC will be met. One means of dealing with these uncertainties is to enhance the defense-in-depth provided by the combination of barriers that comprise the repository system. The addition of a drip shield to the engineered barrier system for all EDAs and the use of highly corrosion-resistant alloy-22 as the outer barrier of the waste package in EDAs I, II, III, and V, are examples of this approach. Both of these enhancements are expected to compensate for uncertainties in modeling the processes that affect performance and to improve the calculated performance of the repository system over that for the VA design.

The complexity and uncertainty that may be associated with modeling of thermally-driven coupled processes may be reduced through a corresponding reduction in the magnitude of the driving force for these processes and, therefore, the spatial and temporal extent of their potential influence. This can be achieved by design choices, which include emplacing the waste so that the overall temperature in the repository is lowered, emplacing the waste so that the spatial and temporal characteristics of the thermal field are controlled, and using ventilation to remove waste-generated heat prior to repository closure to reduce the overall heat load and temperatures following closure. All five EDAs employ preclosure ventilation for 50 years following the start of emplacement to remove heat (and water vapor). Only two EDAs attempt to lower the intrinsic thermal driving force for coupled processes. EDA I employs smaller, more widely spaced waste packages with lower thermal outputs to reduce temperatures across the repository and keep the drift walls below 96°C. EDA II employs a line-loading concept with widely spaced emplacement drifts to tailor the thermal field such that the bulk of the rock between the emplacement drifts stays below 96°C, reducing the complexities associated with thermal coupling between drifts. Both of these alternatives are likely to significantly reduce the complexity and uncertainty associated with modeling of coupled processes, although in different ways.

None of the alternatives are intended to keep the waste package surface temperature below a specified value in an attempt to reduce the driving force for corrosion processes. Such a design would require a significant change from the alternatives considered in the LADS Report and would likely increase the risk to worker safety as well as increasing construction and operating costs for the same reason that EDA I affects these considerations. The incorporation of a drip shield in all five designs is intended to delay the onset of waste package corrosion and to greatly extend waste package lifetime, due to

117

the lower corrosion rates expected after temperatures return to near-ambient values. In addition, preliminary analyses indicate that the waste packages in EDA I and EDA II do not enter the temperature-humidity-water chemistry susceptibility window for crevice corrosion of alloy 22.

Preclosure worker safety

All of the EDAs, except EDA I, are comparable in terms of operational issues that may affect worker safety since they each require a similar number of waste packages and length of emplacement drift. EDA I, on the other hand, requires roughly fifty percent more waste packages and construction of more than double the total length of emplacement drift, because it relies on smaller, more widely spaced waste packages to achieve its thermal goals. As a result, the operational burden and the risk to worker safety are increased.

Flexibility to accommodate design changes and improvements in understanding

DOE must proceed with development of the technical basis for a decision on SR based on a defined design concept. DOE intends to proceed with development of a design concept that provides the flexibility to accommodate changes in national policy (increased repository capacity, for example); changes in technical understanding of the processes that affect repository performance; or changes in emplacement conditions, ventilation design, and duration of the period prior to closure.

EDAs III, IV, and V are predicated on emplacement at an areal heat loading that is equal to or higher than that for the VA design. All occupy an area comparable to or less than that for the VA design. All three result in temperatures that exceed 96°C across most or all of the repository and all produce a thermal field that will keep emplacement drifts dry for a prolonged period. Although the areal heat loading for these EDAs could be reduced, subject to construction of additional emplacement drifts, this can not be done without changing the essential basis for the designs.

EDAs I and II are based on areal heat loadings that are lower than for the VA design and consequently occupy larger areas. The heat loading can be increased or decreased for both alternatives, subject to certain constraints that are more restrictive for EDA I than EDA II. In both cases, decreasing the heat load would require expansion of the repository emplacement area and construction of additional emplacement drifts. The heat load for EDA I could be increased up to the point where the waste packages are emplaced in a line-load configuration in all of the drifts. This configuration results in temperatures in the rock between emplacement drifts that exceed 96°C. Modifying EDA I to approximate EDA II by emplacing waste packages as a line load in every other drift, while retaining the smaller waste package capacity of EDA I, would increase the repository area by about 20 percent and would raise only a small portion of the rock in the drift wall above 96°C. To increase the rock temperature further would require a change in the basic waste package design for EDA I.

EDA II employs a waste package comparable in capacity to EDAs III, IV, and V, but lower in thermal output than EDAs III and IV. EDA II offers significant flexibility to increase the heat loading, subject to construction of more closely spaced emplacement drifts. The heat loading for EDA II could be decreased by constructing additional emplacement drifts and spreading the waste packages over a larger area, but the ability to reduce local temperatures at the drift wall is limited by the capacity and thermal output of the individual packages, all other factors being held constant. Although the waste package capacity could be reduced, this is not necessary in order to achieve lower postclosure temperatures.

The design concept embodied in EDA I is determined by the thermal goal of keeping the drift wall temperature below 96°C following closure. EDA II, however, offers the flexibility to achieve a range of postclosure temperatures, including drift wall temperatures below 96°C, by adjusting the duration of the preclosure ventilation period, without changing the basic design concept. The ventilation rate might also be increased or other features included to improve the overall effectiveness of heat removal and possibly shorten the preclosure ventilation period. Current estimates are that a preclosure ventilation period of approximately 125 years at a ventilation rate of 10 cubic meters per second would be adequate to keep the drift wall temperature below 96°C. This estimate may be reduced as the models used in evaluating the thermal response to EDA II are refined.

In a August 9, 1999, letter to the Nuclear Regulatory Commission, the Advisory Committee on Nuclear Waste (ACNW) stated its view that further analyses must be done before a determination can be made on a choice between a repository where the postclosure temperature is kept below 96°C everywhere, and one in which the temperature is allowed to exceed 96°C over some portion of the repository volume. The ACNW expressed the view that although a cooler repository design may simplify modeling of water redistribution, the potential for a higher temperature repository design to reduce the quantity of water reaching the emplacement drifts should not be abandoned without further assessment.

Based on the considerations discussed above, DOE believes that EDA II offers the greatest range of flexibility, without the need for significant alteration of the basic design concept. EDA II, because it employs a line-loading concept with widely spaced emplacement drifts, provides the flexibility to raise the drift wall temperatures above 96°C after closure while the bulk of the rock between the emplacement drifts remains below 96°C, reducing the complexities associated with thermal coupling between drifts. EDA II also offers the flexibility to keep postclosure drift wall temperatures below 96°C, by adjusting the duration and rate of preclosure ventilation without changing the basic design concept.

Cost

All of the EDAs, except EDA I, are comparable in terms of construction and operating costs since they each require a similar number of waste packages and length of emplacement drift. EDA I, as noted above, requires roughly fifty percent more waste packages and more than twice the length of emplacement drift. As a result, the operational burden is increased and the cost is estimated to be 20-25 percent higher than the other four EDAs. The relative difference in cost between EDA I and the other four EDAs provides a basis for discrimination among the alternatives. This factor was considered but did not unduly constrain the DOE's design selection process.

Design Selection and Conditions

On the basis of the evaluations outlined above for each of the factors considered, DOE has approved a change to incorporate EDA II as the basis for project design activities for SR. The implementation of EDA II is subject to the following conditions:

1. The design will permit the repository to be kept open, with only routine maintenance, for approximately 125 years from initiation of waste emplacement, which is approximately the time necessary for the ventilation system envisioned as part of EDA II to remove sufficient heat to keep the drift walls below 96°C following closure.

2. The design will permit the repository to be closed during the period from 50 years to approximately 125 years from the start of waste emplacement. The design will not preclude keeping the repository open, with appropriate maintenance and monitoring, for 300 years after initiation of waste emplacement. A decision on when it is appropriate to close the repository will be made considering the results from performance confirmation testing and analyses, taking into account the need to dispose of the waste in a way that minimizes the transfer of the burden to future generations. This is consistent with current Program policy and requirements, which specify that future generations will make the ultimate decision on whether it is appropriate to continue to maintain the repository in an open condition, or to close it.

3. The postclosure performance of the repository system will be evaluated for potential preclosure periods of 50 years and approximately 125 years so that the sensitivity of system performance to uncertainties that may be associated with coupled, thermally driven processes may be examined as a function of preclosure duration.

4. The models that are the basis for the evaluation of thermal conditions will be refined to reduce conservatism that can increase the estimate of the preclosure period required to achieve a particular temperature at the drift wall. Design options that can increase the efficiency of heat removal will also be evaluated.

IRO

Conclusion

Selection of EDA II with the conditions specified provides DOE the flexibility to adjust emplacement conditions, and ventilation design and duration, to keep the rock temperatures below 96°C and as cool as is reasonably achievable given technical and cost considerations. It also preserves the flexibility for future generations to decide to close the repository as early as 50 years after the start of emplacement, thereby minimizing the transfer of responsibility to later generations, should that prove to be the appropriate option based on performance confirmation results and institutional considerations at the time. The 50-year period for early closure is consistent with the retrievability period required by the Nuclear Regulatory Commission in both 10 CFR Part 60 and the proposed 10 CFR Part 63. A preclosure period of 50 years should also provide sufficient time to complete the performance confirmation program required to support a Commission decision on repository closure, should such a decision be sought. The design selected would also permit future generations to keep the repository open for as long as 300 years with appropriate maintenance and monitoring, should they choose to do so.

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

August 3, 1999

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

Dear Mr. Barrett:

The June 1999 meeting of the Nuclear Waste Technical Review Board (Board) focused on two topics: repository design and the Yucca Mountain Project's scientific program. In my letter to you dated July 9, 1999, the Board commented on repository design. This letter provides the Board's comments on the scientific program.

Progress is being made in many of the ongoing scientific investigations. However, given the large amount of work that remains to be done as well as the OCRWM's tight schedule for decision making and the budget uncertainties, scientists, engineers, and analysts at Yucca Mountain face a serious challenge. This letter concentrates on several issues raised as a result of the June meeting that the Board believes merit your attention.

Regarding the natural system at Yucca Mountain, we would like to highlight three areas: the need for focused investigations into the rock strata that will actually host the repository; the applicability of studies at the Busted Butte facility to the repository; and the need for an integrated approach to saturated-zone investigations.

Regarding the engineered repository system, we would like to highlight four areas: the need to vigorously pursue ongoing studies of degradation associated with stress-corrosion cracking and phase instability of proposed waste package materials; the need to determine whether presently unrecognized corrosion mechanisms exist that would be important over the very long term; the need to complete experiments on the formation of radiolysis products in the near field and to model the effects of such radiolysis products on near-field component degradation; and the need to intensify investigations into the performance of a titanium drip shield and the effect this drip shield and associated backfill would have on other elements of the engineered system.

123

Telephone: 703-235-4473 Fax: 703-235-4495

The Natural System

Most of the detailed studies in the exploratory studies facility have, by necessity, been conducted in the middle nonlithophysal unit of the Topopah Springs formation. None has been carried out in the lower lithophysal unit, the primary host rock for the repository itself. This rock is exposed in the east-west cross drift, and initial studies show significant differences between nonlithophysal and lithophysal fracture density and the penetration depth of tunnel construction water. The thermal, hydrologic, mechanical, and geochemical properties of the lower lithophysal unit need to be investigated primarily because of their effects on the movement of water into, around, and out of the waste emplacement drifts. Closure of part of the cross drift to examine rewetting and possible seepage is very important, as are other cross-drift studies, including permeability measurements, geologic observations, and completion of analysis of chlorine-36 samples already collected. Some of these investigations are under way; others have been delayed. The Board believes that all are necessary.

Ongoing investigations at Busted Butte are beginning to show that the vitric unit of the Calico Hills formation (CHn) may significantly slow the transport of radionuclides from the repository to the water table. The CHn could emerge as an important natural barrier and play a key role in any defense-in-depth strategy. These studies need to be continued. One critical aspect of these studies not fully addressed at the meeting needs to be analyzed further: the applicability of the Busted Butte results to the rocks directly beneath the repository. At this time, the extent to which the Busted Butte results can be extrapolated to the repository and affect its predicted performance is unclear to the Board.

Before the meeting, the Board visited two sites of ongoing DOE-supported investigations conducted by Nye County scientists as part of the Nye County Early Warning Drilling Program (EWDP). We also heard a presentation on the EWDP at the meeting. The Board is impressed with the pace of these investigations and their potential for adding to the understanding of flow and transport in the saturated zone. U.S. Geological Survey and Los Alamos National Laboratory scientists also are participating in EWDP investigations. Information is being developed that challenges or adds more detail to previous conceptions of the saturated zone. The Board also noted, with interest, a conceptual model of north-south flow (presented by a State of Nevada-supported hydrologist) based on geologic structure, water temperature, and geochemistry. Clearly, much information is being gathered and needs to be incorporated in a coherent model of the saturated zone. We believe that the OCRWM should ensure the integration of these and other ongoing and proposed investigations of the saturated zone, such as the C-well type complex being considered for studies in the alluvium. Active scientific coordination and integration of saturated-zone studies would be beneficial to the program, ensuring that the maximum benefit is obtained from the data being collected and helping to prevent instances similar to the significant last-minute changes that occurred in modeling the saturated zone for the total system performance assessment in the viability assessment.

The Engineered System

The main component of the proposed waste package is made of Alloy 22. Current tests are aimed primarily at investigating this alloy's resistance to general and localized corrosion. Some studies are directed at assessing phase instability and the likelihood of stress-corrosion cracking in this material. The significance of these degradation modes at relevant repository temperatures and chemical conditions is not well known. The Board believes that these studies should be pursued vigorously, particularly those that relate to the welded and weld-affected zones of the waste package.

The primary mechanism for the corrosion resistance of both Alloy 22 and titanium is the formation of a very thin passive layer on their exposed surfaces. As long as this layer remains intact, it acts as a barrier between the metal and the oxidizing environment, greatly reducing the rate of further corrosion. Current estimates of long-term performance (i.e., performance over many thousands of years) are based on extrapolation from short-term experiments and the limited, recent history of similar metals. This extrapolation, several orders of magnitude beyond current experience, assumes that all the mechanisms for deterioration of the passive layer over thousands of years are known and can be quantified. The Board believes that there is considerable uncertainty associated with such an extrapolation. Additional research is needed to determine the likelihood of new mechanisms (beyond typical localized corrosion processes) of deterioration that could affect the very-long-term stability of the passive layer for critical waste package and other engineered barrier materials, such as Alloy 22 and titanium. This work could include, for example, examination of fundamental models of passive-regime stability and the factors that may cause deviation from passive-layer dissolution behavior assumed from short-term experiments, prediction of the behavior of the alloy surface under a thick layer of previous passive dissolution products, and a search for relevant natural and archeological analogs.

The effects of radiolysis on the degradation of waste package materials and near-field structural components in the tunnels (steel sets, rock bolts, etc.) may be much more significant using the thinner-walled containers presently being considered than the waste package assumed in the viability assessment. Research addressing the effect of radiolysis product formation on the corrosion potential of the Alloy 22 barrier was described in recent presentations to the Board. These experiments are fundamental to the development of an understanding of waste package performance. A more critical issue may be the effects of radiolysis products (nitric acid, hydrogen peroxide, etc.) on the degradation of near-field structural components. The Board supports the completion of experiments to quantify the formation of radiolysis products in the near-field environment surrounding the proposed waste package and modeling efforts for predicting the effects of such radiolysis product formation on near-field component degradation.

All five repository design alternatives presented to the Board at the June 1999 meeting rely on a titanium drip shield to protect the waste packages. Two of the designs also rely on backfill to protect the drip shield from rockfall. Although some investigations are planned or are under way for investigating the resistance of titanium to corrosion and the behavior of a scale-model stainless-steel drip shield, the Board believes that a more comprehensive program is necessary if the drip shield or backfill is to be relied on. This program should include evaluating the effects of the drip shield and backfill on the thermal and moisture regime between the drip

shield and the waste package and evaluating the corrosion behavior of titanium when it is in contact with backfill or rockfall. The vulnerability of the drip-shield connections to vibratory earthquake motion also needs to be addressed.

Finally, we note that the OCRWM is in the midst of making a decision on repository design. This choice of design could affect the importance of some scientific studies of both the natural and the engineered system. Determining the relationship among different design alternatives, the need for flexibility (e.g., going from a hot repository to a cold repository or vice versa), and the need for building long-term confidence is important. Once a design decision is made, we recommend that the scientific program be reexamined, taking these issues into account. We understand that such a process is already under way.

In conclusion, we would like to thank you, your staff, and the management and operating contractor staff for participating in the meeting. We hope that you will find these comments on the scientific program both helpful and timely.

Sincerely,

Jared L. Cohon
Chairman

126

Department of Energy
Washington, DC 20585
November 23, 1999

NOV 29 1999

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

Dear Dr. Cohon:

We appreciate the Nuclear Waste Technical Review Board's letter of August 3, 1999, providing comments on the information we presented on the Yucca Mountain Project's scientific program at the full Board meeting on June 29-30, 1999. Our responses to the specific issues raised in your letter may be found in the enclosure.

We agree with the Board that we face a significant challenge in completing the work planned to support future programmatic decisions on the current schedule, given the uncertainties in our budget. We also agree that our September 1999 decision in selecting the next phase in design evolution could affect the importance of some scientific studies for both the natural system and the engineered system. In our ongoing efforts to revise the repository safety strategy, we have been examining our scientific testing program in light of this design selection. We expect that some work planned in the viability assessment can logically be eliminated or deferred into the performance confirmation program as a result of our design enhancements. Our plans for Fiscal Year 2000 work reflect the preliminary results of this examination.

As discussed at the Board's June and September meetings, we are prioritizing the activities to identify those most important for developing the information needed to support a Secretarial decision on whether to recommend the site to the President in 2001. We will emphasize those science and engineering activities that most effectively reduce the level of uncertainty in the performance of the repository and which are needed to improve our confidence in decisions regarding the suitability of the Yucca Mountain site.

We continue to value the Board's feedback on our program as we complete work toward a decision on site recommendation. If you have any questions, please contact me at (202) 586-6842.

Sincerely,

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

Enclosure

127

Department of Energy Responses to the August 3, 1999, Letter of the Nuclear Waste Technical Review Board

cc:
L. Barrett, RW-1
R. Milner, RW-2
R. Clark, RW-3
D. Shelor, RW-40/50
A. Brownstein, RW-52
N. Slater, RW-52
R. Dyer, YMSCO
D. Horton, YMSCO
S. Brocoum, YMSCO
C. Newbury, YMSCO
A. Benson, YMSCO
R. Goffi, Booz-Allen
J. York, Booz-Allen
T. Bruno, M&O
M. Pendleton, M&O
T. Rodgers, M&O

Department of Energy Responses to the August 3, 1999, Letter of the Nuclear Waste Technical Review Board

Natural System Issues

- *The need for focused investigations into the rock strata that will actually host the repository*

The DOE agrees with the need for focused investigations in the lower lithophysal and lower nonlithophysal units that may host the potential repository and expects that the results from ongoing and planned investigations will be adequate to support site recommendation. Ongoing work in the Cross Drift in these units includes: a) systematic sampling; b) geologic mapping and small-scale fracture mapping; c) fracture mineral geochemistry and geochronology; d) ^{36}Cl-Chloride analyses of systematic and feature-based samples; e) moisture monitoring; and f) seepage studies. This work was initiated in late Fiscal Year 1998 and will be completed in Fiscal Year 2000, with the exception of moisture monitoring and the seepage studies. The seepage studies involve isolating a section of the Cross Drift from ventilation for purposes of long-term hydrologic monitoring. This work will provide data on flow and seepage properties of the lower lithophysal and lower nonlithophysal units under the relatively high infiltration areas and within the Solitario Canyon Fault Zone.

The DOE has reprioritized the near-term alcove/niche testing in the Cross Drift to initiate construction in Fiscal Year 1999 and testing in Fiscal Year 2000. Excavation and drilling at the Crossover Alcove started in September 1999. Testing will follow in Fiscal Year 2000 to address flow, matrix diffusion, and seepage processes, at the scale of tens of meters, in the repository horizon (middle nonlithophysal subunit). Excavation and drilling at Niche 5 will begin in Fiscal Year 2000, with testing in Fiscal Year 2000 to address flow and seepage processes in the repository horizon (lower lithophysal subunit). Additionally, we will continue the seepage studies in the non-ventilated drift section and the systematic borehole characterization of fracture properties and seepage characteristics in the lower lithophysal unit in FY 2000.

Cross Drift testing planned in Fiscal Year 2001 and beyond also includes:

a) the Cross Drift Thermal Test in the lower lithophysal subunit;
b) flow and seepage testing at Niche 6 (lower nonlithophysal subunit);
c) hydrologic testing beneath the high infiltration area (Crest Alcove); and
d) borehole testing of the Solitario Canyon Fault Zone.

- *The applicability of studies at the Busted Butte facility to the repository*

The DOE agrees with the Board's view that the applicability of the Busted Butte results to strata beneath the potential repository block needs to be carefully evaluated.

129

The main objective of the unsaturated zone flow and transport field test at Busted Butte is to validate key assumptions and inputs to the large-scale, unsaturated zone flow and transport model and to probabilistic, unsaturated zone transport calculations. This test was designed specifically to investigate the applicability of laboratory-scale flow and transport data to field-scale flow and transport processes.

The data available for determining the characteristics of the Calico Hills Formation beneath the potential repository footprint come from a variety of laboratory measurements on drill core and cuttings from surface-based boreholes. These data include quantitative mineralogic-petrologic data on core and cuttings and hydrologic property data on core samples. The Calico Hills unit underneath the potential repository horizon is quite variable, ranging from vitric, non-zeolitic to completely zeolitized tuff. In a broad sense, the northern half of the block is dominated by zeolitic rocks and the southern half is dominated by vitric rocks. There is a more pressing need for understanding flow and transport in unsaturated vitric Calico Hills rocks through field testing because the vitric units are difficult to study from a flow and transport perspective using core samples (unlike zeolitized tuffs, the vitric nonwelded materials are seldom preserved as cores). Zeolitized units have been extensively studied from core samples, and their performance in flow and transport is much better known.

The test section at Busted Butte is not an analog for the Calico Hills unit beneath the potential repository; it is the southern extension of that same formation. The test is located primarily in a vitric unit of the Calico Hills Formation, located to the southeast of the potential repository location. The vitric nature of the Busted Butte section and the relatively low abundance of clay and/or zeolite alteration resemble the lower Topopah Spring/upper Calico Hills section observed in several boreholes surrounding the potential repository block (H-3, H-5, SD-6, SD-7, and SD-12). The Busted Butte section is most similar to the sections in boreholes H-5 and SD-6. A comparison of mineralogical analyses of core samples from borehole USW H-5 (located in the NNW part of the potential repository block) and the Busted Butte site indicates that the relative proportions of glass and zeolites are also similar.

Retardation in the Calico Hills unit below the repository horizon can occur due to sorption and to fracture-matrix interaction and matrix diffusion processes. The Busted Butte results are allowing quantification of these retardation mechanisms in a vitric unit of the Calico Hills Formation. The flow and transport conceptual models for the vitric part of the Calico Hills presented in the viability assessment and planned for the site recommendation are consistent with the Busted Butte data collected to date.

The data from boreholes surrounding the block and the results to date of the Busted Butte test lend credibility to and build confidence in the application of the conceptual models for flow and transport in unsaturated Calico Hills rocks beneath the potential repository.

- *The need for an integrated approach to saturated-zone investigations*

130

The DOE agrees that coordination and integration of saturated zone studies are beneficial to the program, ensuring that the maximum benefit is obtained from the data being collected. The following describes the steps that DOE has taken in integration of the Nye County Early Warning Drilling Program (EWDP) investigations into DOE investigations of the saturated zone (SZ).

The DOE is incorporating information and data from the EWDP (including lithology, water level data, hydraulic test results, alluvium sorption measurements, hydrochemistry data, and Eh/pH data) into the DOE models of the SZ (the hydrogeologic framework model, the SZ site-scale flow and transport model, and the regional model).

The DOE is planning an Alluvial Testing Complex (ATC) similar to the C-well complex. This facility will help to characterize the alluvium, test and confirm conceptual models of flow and transport of radionuclides in the alluvium, and derive hydraulic and transport properties to be used in the SZ site-scale flow and transport model. The derived properties will be used in conducting total system performance assessment. The complex will be drilled as part of the EWDP. Plans for testing include:

1. Hydraulic Testing at the complex to derive hydraulic properties of the alluvium
2. Conservative tracer testing
3. Reactive tracer testing
4. Natural gradient testing.

The planning for testing is ongoing, and testing will start in Fiscal Year 2000 after the complex is drilled and the required permitting is in place. The DOE is also working with Nye County to establish processes and appropriate interfaces for data access and control to speed up the integration of Nye County EWDP investigation results into the DOE SZ program.

In Fiscal Year 1999, the DOE also initiated an effort to integrate regional geologic and hydrologic interpretations into a three-dimensional ground-water flow model utilizing data from other Nevada Test Site programs and other government agencies, including the National Park Service and the U.S. Geological Survey. This effort utilizes very recent data and interpretations from these programs. The intent is to develop an integrated three-dimensional SZ hydrologic framework and numerical ground-water model at the regional and site scales that would be available for the potential license application. Though the model will not be available in time for the site recommendation, information from this effort will be reviewed as the site recommendation is prepared and appropriate information will be incorporated or referenced in site recommendation discussions.

Engineered Repository System Issues

- *The need to vigorously pursue ongoing studies of degradation associated with stress-corrosion cracking and phase instability of proposed waste package materials*

131

Stress-corrosion cracking (SCC)

The DOE agrees with the Board's view that the Project should vigorously pursue ongoing studies associated with SCC. Efforts in this area have recently been augmented by supplementing the Lawrence Livermore National Laboratory SCC program with experimental and modeling support from the General Electric Corporate Research and Development Laboratory and the Babcock and Wilcox McDermott Corporate Research and Development Laboratory. In addition, experimental and modeling efforts to more fully define the aqueous environments contacting the waste package and drip shield surfaces over time have been accelerated.

The initial SCC crack growth/K_{ISCC} results on Alloy 22 and Ti Gr-12 were obtained in 90°C deaerated and acidified 5% sodium chloride solutions. Tests are ongoing on Alloy 22 and Ti Gr-7 (the Ti alloy selected for the drip shield) in environments and temperatures that are more directly relevant to the waste package and drip shield surfaces. In addition to crack growth measurements, testing will include measuring SCC initiation stress thresholds with and without crevices present. Also, SCC modeling efforts have been expanded to include both the initial threshold stress intensity (K_{ISCC}) approach and a more comprehensive and fundamental oxide film rupture/repassivation model.

In addition to the experimental testing and modeling efforts, a parallel effort is underway to remove the stress driving force for SCC by developing processes such as laser peening and post-weld heat treatment to reduce residual stresses in the closure welds.

Phase stability studies on Alloy 22

The DOE agrees with the Board's view with respect to aggressively pursuing phase stability studies on Alloy 22. The current studies include samples of Alloy 22 aged at Haynes International to various times ranging up to 16,000 hours and at temperatures in the range of 427 – 760°C. The DOE is actively conducting aging studies on additional samples and plans to expand these studies to include welded and weld affected samples. These samples will provide information on the formation of grain boundary carbides and intermetallic precipitation as a function of material conditions and aging times at various temperatures.

Short-term aging studies are underway to determine the corrosion behavior of specimens with various degrees of grain boundary precipitation. The specimens will be aged at 700°C for 10 to 100 hours and evaluated using cyclic polarization tests. These tests will provide information on the effects of the amount of grain boundary coverage on corrosion behavior.

Long-term aging studies at repository relevant temperatures are planned as part of the Performance Confirmation program.

- *The need to determine whether presently unrecognized corrosion mechanisms exist that would be important over the very long term*

132

The DOE agrees with the Board's view that the extremely long performance lifetimes expected from the drip shield and waste package are based on data from relatively short periods. To enhance confidence in extrapolations over such long time periods, it is essential to examine fundamental corrosion mechanisms in an effort to determine whether currently unrecognized mechanisms are likely to occur. Short and long-term testing, and consideration of longer term engineering and natural analogs are used to validate the models. Multiple barriers, using different high performance materials, provide a measure of defense-in-depth to compensate for unknown mechanisms that may affect one of the diverse components.

Based on the fundamental corrosion mechanisms, both Alloy 22 and titanium are expected to be highly corrosion resistant; that is, they have extremely low general corrosion rates due to the passive thin oxide films that quickly form on their exposed surfaces. Corrosion of these materials is based on slow dissolution of the outer monolayer of the oxide film into the aqueous solution. One mechanism for explaining the low corrosion rates of corrosion resistant metals is that the oxygen ions released by the dissolution of the oxide diffuse through the thin oxide film and oxidize base metal at the interface with the oxide. The rate-limiting step for this three-stage process is the initial dissolution (leading to constant corrosion rates after the extremely fast formation of the oxide layer, a constant thickness oxide layer, and the ability to repassivate quickly after any mechanical disruption of the oxide layer). These metals have stable passive layers because of the low solubility of their oxide films.

For Alloy 22 and titanium, the low solubility of the oxide film minimizes scenarios in which the oxide film can be removed by chemical means. For example, if the aqueous solution is static and becomes saturated in metal cations, the corrosion rate decreases. Similarly, the constant (small) thickness of the oxide layer, and its ability to quickly heal, minimizes the scenarios in which the material deteriorates due to mechanical damage to the passive oxide film.

DOE is conducting a broad-based, comprehensive corrosion testing program that considers the known corrosion mechanisms expected for the candidate alloy systems, as well as examining engineered and natural analogs. The ongoing tests focus on the corrosion mechanisms considered to be relevant to the expected repository conditions. Accordingly, the program includes testing under both service conditions and aggressive conditions in order to develop models for prediction of the long-term performance of candidate materials. Samples have been placed in the Drift Scale Heater Test. Samples will also be exposed in the repository as part of the Performance Confirmation effort. Samples will be withdrawn periodically for characterization. While this testing program will not guarantee that unrecognized corrosion mechanisms are detected, the process should greatly enhance confidence in the ability to extrapolate material behavior for the evaluation of repository performance. This approach will also be applied to examining the stability of passive films.

133

Based on corrosion studies conducted in the Long-Term Corrosion Test Facility at Lawrence Livermore National Laboratory in both acidic (pH 2.7) and basic (pH 10.5) environments in 1000X J-13 water chemistry, the passive oxide film on Alloy 22 is very stable. Extremely low rates of corrosion have been measured both by conventional weight loss and more sensitively by standard optical microscopy and by Atomic Force Microscopy (AFM). Additional work is planned to study the initiation, growth, and dissolution of passive films on Alloy 22 on a more fundamental basis with a combination of AFM and other surface measurement techniques.

The DOE has also conducted short-term aggressive tests under potentiodynamic control. The exposed samples are being examined by AFM. Longer-term controlled-potential tests are planned for quantitative measurement of ultra-low passive surface corrosion rates in the long-term test solutions. Also planned are cyclic polarization corrosion tests in concentrated J-13 solutions containing dissolved Alloy 22 cation species (e.g., Cr, Ni, and Mo). The samples removed from the Drift Scale Heater Test and from the *in situ* Performance Confirmation tests, the latter up to the time of repository closure, will provide data that should enhance confidence in long-term model predictions. The combination of the long-term and short-term data should provide a solid basis for predicting passive film behavior.

Some analog data may be useful in supporting the argument for long-term passive film stability and the absence of unrecognized corrosion mechanisms. For example, a sample of Alloy C plate has been exposed to aggressive marine environments at Kure Beach for almost 60 years without noticeable corrosion. The initially polished plate still reflects an image. Also, the nickel-iron mineral Josephinite has withstood dissolution in streambeds over long periods of time.

- *The need to complete experiments on the formation of radiolysis products in the near field and to model the effects of such radiolysis products on near-field component degradation*

With adoption of the new waste package design consisting of thinner container materials, the radiation levels at the surface of the waste packages are expected to be higher than the thicker-walled viability assessment design. With these elevated radiation levels, the Board is concerned about the potential for the formation of aggressive radiolysis products and associated change in corrosion potential of the waste package and near-field structural components.

To assess potential radiolysis effects, the project has conducted calculations of radiation levels at various locations within the drift for the new design. These calculations show that the waste package surface radiation dose levels for the bounding case (21-PWR, 75,000 MWD/MTU, 5-year cooled fuel) are less than 3000 rad/hr at emplacement and decrease to about 260 rad/hr after 50 years. Since the radiation levels required to cause significant enhancement of corrosion ranges from 10,000 to 100,000 rad/hr, for the nickel and titanium alloys, potential impact on the new design is expected to be insignificant.

134

For the near-field structural components, the current plans call for forced ventilation for at least 50 years after emplacement. During this time, there is little likelihood of forming a water film on the near-field components within the emplacement drifts. In addition, the calculated radiation levels on the near-field components are expected to be about 2000 rad/hr or less at emplacement and decrease to less than 200 rad/hr after 50 years. Doses at the rock bolts would be substantially lower. This suggests that the potential for the radiolysis enhanced corrosion of near-field structural components or rock bolts is negligible.

- *The need to intensify investigations into the performance of a titanium drip shield and the effect this drip shield and associated backfill would have on other elements of the engineered system*

The DOE agrees with the Board's view, and has initiated investigations of titanium drip shield performance and the effects of the drip shield and backfill on other elements of the engineered system.

The drip shield and backfill components have been added to the engineered barrier system because of their potential to beneficially affect the performance of the other components, such as the waste package. The function of the drip shield is to serve as a barrier between the waste package and seepage, either ambient or mobilized by the thermal pulse, during the time that waste package temperatures are high. The drip shield is intended to reduce the uncertainty in performance of the waste package at elevated temperatures, by limiting water contact. It also reduces the sensitivity of performance to geochemical changes during the thermal period, since the drip shield limits the water that contacts the waste package to condensate that has much less opportunity to become concentrated by contact with minerals in the natural system and by evaporation.

One function of the backfill is to mitigate the dynamic structural loads that rockfall could impose on the drip shield and waste package. Another function of the backfill is to provide a more predictable hydrologic environment for the drip shield and waste package. The drip shield and backfill have other effects on engineered components, primarily by increasing temperatures and affecting relative humidity. Modeling, laboratory scale testing, and ¼ (pilot) scale testing have been initiated to develop our understanding of the interrelationships among the components. These interrelationships and activities are briefly discussed below.

Drip Shield

The drip shield divides the emplacement drift into inner and outer sections, and inhibits vapor-phase communication between the sections. Calculations show that this behavior is controlled to a large extent by the thermal-hydrologic properties of the invert ballast material, and the flux of heat to the invert relative to the drip shield surface. Invert materials will be selected to optimize environmental conditions under the drip shield, based on results from pilot-scale testing.

The thermal influence of the drip shield on the waste package has been calculated, and confirmed by pilot-scale tests. The drip shield acts as a thermal radiation shield; however, by itself, it raises waste package temperatures by only a few degrees.

135

The temperature difference between the drip shield and waste package could, under certain conditions, cause water vapor to condense on the underside of the drip shield and then drip onto the waste package. This condensate would be relatively pure, but because dust will be present, there may be some dissolved species present in any liquid that contacts the waste package. These effects will be taken into account in the engineered barrier system models describing thermal, hydrologic, and chemical conditions and are being investigated in the pilot-scale testing.

Other sections of this letter address the current and planned work for titanium stress corrosion cracking, radiolysis, and unrecognized corrosion mechanisms. Another potential corrosion mechanism of the titanium drip shield is hydrogen embrittlement. This mechanism has been observed in some titanium alloys, and the alloy being considered for the drip shield is currently being tested. A necessary condition for hydrogen embrittlement of titanium is a source of hydrogen that can diffuse into the titanium alloy. Corrosion of carbon steel components in contact with the titanium drip shield could produce such hydrogen, in the aqueous film. In addition to direct testing of the titanium alloy (grade 7), DOE is evaluating the potential of using design features, such as Alloy 22 base plates, that could separate the carbon steel hydrogen source from the titanium drip shield. We will also evaluate whether radiolysis of water inside or outside the drip shield could be a source of hydrogen in quantities significant for embrittlement.

The potential vulnerability of the drip-shield connections to vibratory earthquake motion is being addressed through the assessment of the effects of ground motion on the drifts and the evaluation of design features that, if needed, would preclude significant drip-shield movement. A review of the anticipated emplacement drift ground motion is underway. Ground motion due to earthquakes is significantly lower for subsurface facilities than for surface, thereby reducing the loads on the underground system and the potential for movement of underground components such as the drip shield. To accommodate differential motion caused by seismic events, the drip-shield design will include a "coupler" section that spans adjacent drip shield segments to prevent any separation that could allow backfill or water contact with the waste package. Based on current knowledge of ground motion characteristics and the flexibility in drip-shield design, it is not anticipated that ground motion would affect long-term performance.

Backfill

In addition to reducing dynamic structural loads on the drip shield and waste package from rockfalls, the backfill will also stabilize the drip shield and reduce the potential for movement in response to seismic shaking. The presence of backfill also decreases the volume of the drift opening at closure, which will contribute to the predictability of drift seepage by limiting changes in the opening profile. For expected values of the seepage flux, the backfill can also divert water from cracks or gaps that may form in the drip shield. These effects are being quantified through modeling.

136

The use of backfill may substantially improve the predictability of in-drift thermal, hydrologic, and chemical processes, by interposing a porous medium with known properties and composition around the drip shield and waste package. Without backfill, the uncertainty in timing and morphology of rockfall may also increase uncertainty in performance estimates.

Backfill will increase the peak temperature of the waste package, compared with an idealized open drift, within a few tens of years after closure. The magnitude of the relative temperature increase will depend on the backfill thermal conductivity, which is being measured and compared with assumptions on the thermal properties of debris that could accumulate without backfill. Corrosion testing considers the temperatures of the waste package material, and performance assessment modeling considers waste package and cladding temperatures. The known properties and timing of backfill decrease the uncertainty in these temperatures, compared to drifts that are not backfilled at closure and experience varying degrees of rockfall at varying times.

137

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

November 10, 1999

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

Dear Mr. Barrett:

As has become customary, I am writing to give you the Board's reactions to information presented by the DOE at the Board's latest meeting, which was held in Alexandria, Virginia, on September 14-15, 1999.

Board members uniformly feel that the meeting was very productive. This outcome was due, in large part, to the participation by the DOE and its contractors. The Board was pleased with the efforts of your team to develop presentations that addressed specific Board issues and concerns. The presentations were of high quality, well-integrated, and tightly focused. DOE and contractor staff responded to the Board's questions in an open and informative fashion.

The Board encourages the DOE to continue important work in three areas. First, the DOE should complete its latest revision of the repository safety strategy. This document can establish a critical foundation for explaining to both policy-makers and members of the general public how a repository at Yucca Mountain might function, for prioritizing investigations, and for developing a licensing safety case. Second, the DOE should continue pursuing experiments in the east-west cross drift aggressively. These studies can produce important data about seepage into the drifts and flow in the unsaturated zone, variables that strongly influence repository performance. Finally, the Board realizes that the DOE is making progress in evaluating new designs for the waste package and the engineered barrier system. For example, corrosion testing has produced important information about the degradation rates of Alloy 22. This work needs to be sustained into the future because it supports a central premise of the repository safety case.

The Board would like to communicate to the DOE the following specific thoughts about some of the topics that were addressed at the meeting.

139

Telephone: 703-235-4473 Fax: 703-235-4495

Repository Safety Strategy

Previously the Board stated that an appropriate repository safety strategy consists of an assessment of projected repository performance, design margin and defense-in-depth, consideration of disruptive processes and events, insights from natural or man-made analogs, and a performance confirmation plan. The Board is pleased, therefore, that the DOE is revising its repository safety strategy along these lines in light of new information collected and changes in repository design adopted since the viability assessment was completed. In particular, the Board is encouraged by the importance attached to demonstrating defense-in-depth. Barrier importance analysis seems to be a promising vehicle for describing how much defense-in-depth is available within a repository system. The Board, however, believes that this methodology needs to be refined further before valid conclusions can be drawn about defense-in-depth.

According to the presentations at the meeting, the DOE plans to focus on seven "principal factors." These factors apparently will strongly influence what investigations will be conducted during the next two years. Moreover, these factors apparently will be the key variables for upcoming performance assessments; other, less important, influences on repository performance may be only bounded. Given the importance assigned by the DOE to these factors, it is essential that their selection be based on rigorous technical analyses that are clearly presented and supported with as much empirical data as possible. The DOE also will need to consider carefully whether bounding other, less important, variables is appropriate. Unless the DOE can support its choice of principal factors and its use of bounding analysis, making the repository safety strategy technically persuasive will be difficult.

Model Validation

As DOE's presentations and our subsequent roundtable discussion revealed, the technical defensibility of a mathematical model of complex and only partially observed physical processes can sometimes be a matter of degree. In some situations, however, particularly under conditions beyond those for which calibration data are available, the model's inadequacies may clearly and unequivocally render it invalid. The use to which the model will be put may affect the standard by which technical defensibility is judged. For example, a model like TSPA that is used to guide decision-makers carries a higher burden of defensibility than a model that is used by field investigators to gain detailed process-level understanding and to guide a discrete and limited field sampling program.

On the basis of the DOE presentations, the Board is concerned that significant issues associated with model validation may not be examined adequately by the time the final site recommendation report is currently scheduled to be sent to the President. Among the questions the Board believes that the DOE needs to address in a technically defensible way are the following.

- Have sufficient data been collected to test and to evaluate adequately alternative process-level models?

- To what extent will multiple and independent lines of evidence, including natural analogs, be marshaled to test a model's validity?
- What will be the basis for judging a model's validity over long periods of time when the model was calibrated using short-term data?
- How will external peer review be used in the validation process?
- How will the validity of the overall performance assessment be judged in relation to the validity of the individual process models?

Answering these questions is admittedly challenging. Nonetheless, the Board feels that providing policy-makers, the technical community, and the general public with well-developed responses to the questions is essential for developing a credible site recommendation report.

Treatment of Uncertainty

As you know, the Board has a long-standing interest in how the DOE analyzes and presents the inherent uncertainty that will surround its performance assessments. The Board realizes that the DOE will have to follow applicable regulations and regulatory guidance when it presents its performance assessment findings in the context of a license application. The DOE has significantly more discretion, however, in how it treats uncertainty in the site recommendation report. In particular, the Board believes that the DOE has an important obligation to present its technical analyses in a way that gives policy-makers in the executive and legislative branches as well as interested members of the general public a clear understanding of the uncertainties involved in projecting the performance of a repository at Yucca Mountain.

The Board will be devoting a significant part of its upcoming meeting in January to how uncertainty can be analyzed and presented. Among the topics that will be considered are the following.

- The different kinds of uncertainty and how they can be treated
- Displaying uncertainty in a manner that best communicates its nature and extent
- Alternative ways of incorporating and considering uncertainty in decision-making.

After the January meeting, the Board will provide you with additional views on the evaluation and description of uncertainty.

Modeling Results and Technical Investigations

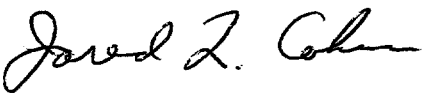
The Board wants to comment on two presentations. The presentation dealing with the model of seepage flux into a repository drift concluded tentatively that seepage in drifts constructed in the middle nonlithophysal zone would not occur unless the percolation flux exceeds 1000 mm/year. This conclusion is an extremely important one, but as acknowledged in the technical analysis, it is highly dependent on assumptions about the shape of the drift and

about its long-term structural integrity. The Board will be looking closely at this model and will comment in greater detail about its appropriateness for inclusion in forthcoming performance assessments.

The presentation on waste package degradation indicated that valuable information is being collected on Alloy 22 at a rapid pace. However, concern still exists about the effects on corrosion of radiolytic species, including species formed in the vapor phase. Resolving that concern may necessitate additional experimental and theoretical work. In addition, in the last year or two, the project has done a significant amount of work to determine, or at least to bracket, the entire range of chemical compositions and temperatures that could exist in water films on waste package surfaces. It is important that the DOE's suite of corrosion tests continues to be performed in environments that approximate that range. Finally, the information needed to evaluate the adequacy of the new drip shield design is still fragmentary. The DOE has not established the technical foundation for the performance claims it is making for this element of the engineered subsystem.

In closing, I would like to repeat the Board's view that the DOE team's efforts made the Board's September meeting highly productive.

Sincerely,



Jared L. Cohon
Chairman

142