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

cc:
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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.

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*

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*

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*

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.

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.

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.

<u>Drip Shield</u>

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.

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.

<u>Backfill</u>

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.

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.