Department of Energy
Washington, DC 20585
October 8, 2003

Dr. Michael L. Corradini, Ph.D.
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Arlington, VA 22201-3367

Dear Dr. Corradini:

Thank you for your letter of June 27, 2003, providing the Nuclear Waste Technical Review Board's (Board) perspective on information presented by the U.S. Department of Energy (Department) on seismic issues at the joint meeting of the Board's Natural System and Engineered System Panels in February 2003.

The Department appreciates the Board's continuing review of our activities as we develop the license application for a repository at Yucca Mountain. Our responses to the views expressed by the Board are summarized in the enclosure to this letter.

The Department continues to benefit from the constructive views of the Board and we look forward to further dialogue on seismic issues.

Sincerely,

Dr. Margaret S.Y. Chu, Director
Office of Civilian Radioactive
Waste Management

Enclosure:
Responses to the Nuclear Waste Technical Review Board Comments on U.S. Department of Energy Presentations Given at the February 2003 Joint Natural System and Engineered System Panel Meeting on Seismic Issues

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Responses to the Nuclear Waste Technical Review Board Comments on U.S. Department of Energy (DOE) Presentations given at the February 2003 Joint Natural System and Engineered System Panel Meeting on Seismic Issues

Preclosure Ground Motions

With respect to preclosure, the ground motions proposed for design at annual probabilities of exceedance (APE) of 10^{-3} to 10^{-4} appear reasonable. However, as Bechtel SAIC (BSC) consultant Robert Kennedy stated, an evaluation to see if the surface facilities meet performance goals for critical systems, structures, and components could require using ground motions whose APE is as low as 10^{-6}. If physically unrealistic, as may be the case (as discussed below), such motions could pose an undue burden on the design and operation of these facilities.

Response:

10 CFR Part 63.102[1] only requires consideration of initiating events that are reasonable, i.e., based on the characteristics of the geologic setting and the human environment and consistent with precedents adopted for nuclear facilities with comparable or higher risks to workers and the public. Given this requirement, the DOE plans to evaluate seismically initiated event sequences for preclosure safety analyses for earthquake ground motions with APEs of 10^{-4} and greater.

Postclosure Ground Motions

In the Board's view, the very-low-probability (APEs of 10^{-6} to 10^{-8}) ground motions proposed for the use in postclosure performance assessment are generally unrealistic, physically unrealizable, or outside the limits of existing worldwide seismic records or experience. . . . Many DOE and BSC presenters at the meeting shared many of these views. However, as discussed later in this letter, differences of opinion may exist between the Board and DOE on how to proceed, given this lack of physical realism.

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[1] 66 FR 55732. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, NV. Final Rule 10 CFR Part 63.

The very-low-probability ground motions need to be bounded on the basis of sound physical principles. The DOE indicated that it is carrying out such studies (e.g., limitations posed by source conditions and local site conditions). The studies will be challenging. Aside from an ongoing study in Switzerland, we are not aware of other recent systematic attempts to place physical bounds on earthquake ground motions.

Despite these difficulties, the Board strongly recommends that the DOE complete these studies, subject them to external peer review, and implement them accordingly to limit the proposed very-low-probability ground motions.

Response:

As the Board notes, the DOE is conducting studies to bound the very-low probability ground motions. While the results may not be available in time to provide direct input to Total System Performance Assessment for the License Application (TSPA-LA), they will be available after independent technical review to support the U.S. Nuclear Regulatory Commission staff's review of the LA and provide clarification regarding the level of conservatism in the LA.

The DOE also should evaluate and consider the work being carried out by Dr. James Brune and his colleagues at University of Nevada at Reno (UNR) as an alternative line of evidence for limiting ground motions. The evaluation of precarious rocks and other formations at Yucca Mountain suggests that during the last 10,000,000 years, ground motions that have occurred at Yucca Mountain may have been substantially less than those estimated by the Probabilistic Seismic Hazard Analysis (PSHA). Dr. Brune attributes this to the incorrect handling of uncertainty in the PSHA and other seismic hazard analyses.

Response:

The DOE agrees and is considering Dr. Brune's observations as an alternative line of evidence for limiting ground motions. His observation that there is no shattered rock at Yucca Mountain as would be expected if there had been extreme ground motion during the last 13 million years is the basis for one of the ongoing studies to bound the very-low probability ground motions. Specifically, a strain threshold at which rock failure would be expected is being identified from consideration of measured rock properties. The strain threshold is then being used to establish an upper limit on ground motions that have occurred in the last 13 million years (the approximate age of the tuff units). The results of these studies may be included as *a priori* information in the development of updated ground motion distributions.

The DOE is currently negotiating with Dr. Brune and his associates at UNR to continue their studies of near-surface attenuation (kappa) and possibly conduct finite-source ground motion calculations to investigate possible limiting effects on the very low-probability (10^{-6} and less) ground motions of physically bounded source parameters.

The Board notes two additional areas where lack of data may affect the magnitude of the estimated ground motions: insufficient geotechnical data on the Topopah Spring Lower Lithophysal unit (Tptpll), which constitutes some 80 per cent of the emplacement rock in the proposed repository and shear modulus data at strains larger than 0.1 per cent, the range of strains induced by the proposed very-low probability ground motions.

Response:

The ongoing studies to bound the very-low probability ground motions are also addressing high-strain shear-modulus reduction and damping. Specifically, high-strain properties for the volcanic tuff below the repository horizon are being developed by nonlinear numerical modeling. These properties will then be input to the site response model to generate "saturated" ground motions at the repository waste-emplacement level. While the results may not be available in time to provide direct input to Total System Performance Assessment for the License Application (TSPA-LA), they will be available after independent technical review to support the U.S. Nuclear Regulatory Commission staff's review of the LA and provide clarification regarding the level of conservatism in the LA.

Drift Degradation and other topics

Models used to predict tunnel behavior need to be calibrated against the conditions expected in the repository (e.g., information obtained from the Exploratory Studies Facility and, in particular, the cross drift). Models used to predict tunnel performance under extreme dynamic loading should be compared to nuclear test damage data and rock burst damage observed in mines with comparable rock-mass conditions. Analyses also need to account for long-term behavior (e.g., static fatigue) using representative rock-mass properties to simulate raveling and spalling processes expected during preclosure and postclosure periods. Particular attention should be focused on rock properties and analytical models to understand brittle failure and to predict the outcome of the failure process for this heterogeneous rock mass with its spatial and temporal variability in properties.

Response:

The short time available for presentation at the Seismic Panel Meeting unfortunately did not allow for a detailed review of all the geomechanical studies that have been performed and are now underway that address some of the issues brought out in this comment. During the process of validation of the numerical modeling techniques used for the drift degradation models, comparison was made to the observed sidewall fracturing in the Enhanced Characterization of the Repository Block lithophysal units. Comparison was also made between the small number of observed wedge-type failures in non-lithophysal units to the model predictions. Details of the validation can be found in BSC (2003)[2].

The 3-Dimensional Distinct Element Code (3DEC) and Universal Distinct Element Code (UDEC) models used for the dynamic stability analyses have been extensively validated in other projects. The validation was against field data from high explosive testing (for the Defense Nuclear Agency) and against damage from rockbursts in deep mines (by numerous authors in the United States, Canada, and South Africa). An example of a validation exercise involving detailed comparison of the ability of a number of continuum and discontinuum numerical models (including UDEC) to simulate supported tunnels in fractured rocks can be found in Senseny (1993)[3]. We have not explicitly compared the models here to nuclear tests at the Nevada Test Site, but this would be a good confidence-building exercise, with the caveat that the characteristics of the incoming waveforms are significantly different between explosions and earthquakes, with resulting potential difference in damage mechanisms.

The project is currently addressing the issue of time-dependent rock mass degradation via a combined laboratory testing and numerical modeling program. We are conducting static fatigue measurements on tuff core samples to better understand the relationship of "time to failure" as a function of stress level. To understand the impact of lithophysal porosity, the DOE is:

1) calibrating the Particle Flow Code (PFC) model against the laboratory data to establish its ability to reproduce the basic static fatigue response of non-lithophysal tuff;

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[2] BSC (2003). *Drift Degradation Analysis*, ANL-EBS-MD-000027, Rev. 02. Las Vegas, Nevada: Bechtel SAIC Company.

[3] Senseny, P.E. 1993. "Stress Wave Loading of a Tunnel: A Benchmark Study." *Proceedings of the Symposium – Dynamic Analysis and Design Considerations for High-Level Nuclear Waste Repositories, San Francisco, California, August, 19-20, 1992*. Hossain, Q.A., ed. Pages 311-338. New York, New York: American Society of Civil Engineers.

2) investigating the impact of lithophysal voids numerically by adding porosity to the calibrated numerical rock samples, and conducting simulated static fatigue experiments to derive lithophysal time to failure plots; and

3) incorporating this logic into previously validated tunnel scale models for investigation of time-related degradation under in situ and thermal loading. The PFC model is used here to predict brittle fracturing modes of the solid matrix between lithophysae. The primary heterogeneities examined here are the lithophysae and their variability in size, shape and porosity. This work will be completed in Fiscal Year 2004.

Recent studies of brittle failure in heterogeneous rocks near excavations have shown that conventional linear or curved failure criteria may not be appropriate for the Tptpll unit. The Board recommends that models be adopted and developed that can properly simulate the strain-dependent tensile spalling mechanism clearly observed in the cross drift and that drift design be based on such failure criteria. If tunnel openings have the potential to collapse, raveling and failure processes will continue until rock mass bulking substantially fills the drift. During this process, dynamic forces and nonsymmetrical rock pressures will develop on the drip shield. The potential for drip shield deformation and corrosion under these conditions needs to be analyzed.

Response:

This comment goes to the heart of modeling of brittle rock behavior. The project is currently using the PFC program (using parallel bonds for particles) to model and understand the brittle fracturing response of lithophysal rock. The DOE has performed extensive calibration of the model against laboratory testing of large lithophysal samples and their failure mechanisms. The PFC model provides a reasonable prediction and representation of tensile fracturing during axial splitting failure of the laboratory samples. The basic failure mechanism in compression for lithophysal rock, shown by the PFC model, is tensile fracturing between lithophysae, which subsequently coalesce as the sample macroscopically yields. This process is porosity dependent, leading to reduction of strength and modulus as the lithophysal porosity increases.

The PFC model has been shown to successfully reproduce the relationship of uniaxial compressive strength to lithophysal porosity as shown in the laboratory. It appears that the model adequately represents the small-scale mechanism of tensile failure between lithophysae, leading to the larger sample-scale failure mechanisms at the laboratory and field scale. Because it is computationally difficult to examine tunnel-scale problems with PFC, the basic failure response

defined by the laboratory and field testing and supplemented by PFC has been encapsulated into the UDEC program that is used to represent tunnel-scale degradation processes. The UDEC program has been calibrated to produce an equivalent mechanical constitutive model to the PFC model and is verified by comparison to laboratory data and observations of damage in the Enhanced Characterization of the Repository Block. UDEC, which is a discontinuum model, is used to predict the tunnel degradation process, including the raveling and bulking process. The model has been used to examine drip shield static and dynamic loadings that are generally non-symmetric in nature. The load distributions on the drip shield have been supplied to the drip shield structural designers who are using them to estimate stresses and deformations.

If, after considering the consequences and the risks to the public, the DOE decides to modify the repository design to mitigate the effects of seismic activity, such modifications need to be evaluated in terms of their overall impact upon repository operations and performance.

Response:

The DOE does not expect modifications to the repository design will be required to mitigate the consequences of high-amplitude, low-probability ground motions. Even using the present, probably unrealizable ground motion estimates, it appears that the calculated consequences will be acceptable. Any proposed changes to repository design to mitigate the potential effects of seismic activity will be processed through our design control procedures to evaluate the overall impact on repository operations and performance.

Implications of highly conservative assumptions

A number of highly conservative assumptions have been used in addressing seismic issues. It appears that the DOE intends to use the ground-motion bounding studies as evidence of conservatism rather than a means of modifying the ground motion estimates themselves. Not all the assumptions in the Project's analysis of this complex, highly coupled system have been fully assessed, e.g., the effects of seismically and thermally induced drift degradation on seepage and local flow and transport, and consideration of seismically induced waste package failure modes not related to stress-corrosion. These assumptions need to be evaluated. If they are important, the assumed level of conservatism could be affected.

The Board recommends that the DOE not take a physically unrealistic or highly conservative approach for several reasons: (a) High levels of conservatism can

lead to a skewed understanding of repository behavior and the significance of different events; (b) High levels of conservatism can introduce consideration of events for which there is little or no understanding or engineering experience; (c) Compounding conservative assumptions does not always produce conservative results, e.g., the worst case for drift stability is not when the horizontal and vertical stresses are both very high; (d) High levels of conservatism may lead to unreasonably high costs and may have a serious effect on the eventual development of both surface and subsurface designs; (e) If conservatism stems from a lack of understanding, it tends to undermine confidence in the scientific basis of the process under consideration. Physically unrealistic results, inappropriately extrapolated from physically realistic databases and analyses, could cast unwarranted doubt on much of the truly excellent work carried out in this area; (f) Finally, if "unacceptable" consequences are discovered later, it may be more difficult to justify subsequent reductions of elevated ground-motion estimates previously assumed to be acceptable.

Response:

The DOE agrees with the Board that the seismic ground motions that we will be using in the LA corresponding to the very lowest annual probabilities of exceedence (APEs of 10^{-6} and below) are highly conservative and may indeed be "physically unrealizable". However, despite the various issues with using these probably conservative values, the DOE considers that using them is acceptable in the TSPA that will support the LA. To address the problems associated with using such ground motions, we are now carrying out several different studies to bound the very low-probability ground motions; whose ultimate objective is to provide a technical basis for a more realistic set of ground motions in the very-low-APE range.

The DOE agrees with all of the reasons cited by the Board as to why taking a physically unrealistic or highly conservative approach is not desirable. We are working to assure ourselves that none of the potential problems cited by the Board will actually occur for the case of the highly conservative extreme seismic ground motions that we will be using in the LA. Most importantly, we are taking care to assure that using these conservative values will actually produce conservative results throughout.

Also, we agree with the Board's concern that using these values can produce a skewed understanding of actual behavior. We have performed various analyses of the system response at what we believe are more realistic ground-motion levels, and we will be performing more such analyses in the future. Furthermore, we are very sensitive to the possibility that using the unrealistically high ground-motions

may "cast unwarranted doubt on much of the truly excellent work carried out in this [seismic] area" (quoting from the Board's letter). We will therefore take care, as we develop the text supporting this aspect of our LA, to explain how to interpret the analysis results appropriately, and why possible misinterpretations are not correct.

The implications of unrealistically high seismic ground motions as inputs to the design of both the surface facilities and the underground facilities are important to DOE. This includes not only the implications for the physical designs themselves but also the cost implications. This is one reason why we are pursuing the work to bound the very-low probability ground motions. Another reason is the important implications of these extreme ground motions on drift degradation, on seepage and in-drift transport, and on possible seismic-induced failures of the waste-packages. While the results may not be available in time to provide direct input to Total System Performance Assessment for the License Application (TSPA-LA), they will be available after independent technical review to support the U.S. Nuclear Regulatory Commission staff's review of the LA and provide clarification regarding the level of conservatism in the LA.