Department of Energy
Washington, DC 20585

QA: N/A

September 10, 2004

Richard R. Parizek, Ph.D.
Chair, Panel on the Natural System
U.S. Nuclear Waste Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

Dear Dr. Parizek:

Thank you for your letter of May 3, 2004, providing the Nuclear Waste Technical Review Board's (Board) response to the information presented by the U.S. Department of Energy (Department) at the March 9-10, 2004, meeting of the Board's Panel on the Natural System (Panel). The Department appreciates the Board's continuing review of our activities as we work to develop and document the technical basis for the license application for a repository at Yucca Mountain. Our responses to the Panel's views and recommendations are summarized in the enclosure to this letter.

The Department looks forward to further dialog on the Natural System and related issues.

Sincerely,

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

Enclosure

ENCLOSURE

U.S. DEPARTMENT OF ENERGY (DOE) RESPONSES TO THE MAY 3, 2004, LETTER FROM THE NUCLEAR WASTE TECHNICAL REVIEW BOARD (BOARD) PANEL ON THE NATURAL SYSTEM

1.0 INCREASING FUNDAMENTAL UNDERSTANDING

1.1 RECOMMENDATION

Field and laboratory observations and analyses presented by the Department of Energy (DOE) and others suggest that the natural system provides an effective barrier to migration of some radionuclides over time periods that may be comparable to the regulatory period. However, several key hydrogeologic features or processes that may significantly affect fluid flow and radionuclide transport are presently not well understood, are constrained by limited or poor data, or both.

The DOE often deals with uncertain features and processes by making conservative estimates of their effects on radionuclide transport. Such conservativisms regarding the performance of the natural system tend to emphasize more-rapid advective transport processes. More realistic estimates that might arise from further evaluation of some features and processes could lead to slower transport predictions for some radionuclides. However, there is a possibility that some other poorly understood features or processes may lead to faster radionuclide transport. Therefore, it is important that the DOE develop a better fundamental understanding of the overall behavior of the natural system.

1.1.1 RESPONSE

We concur that some aspects of fluid flow and radionuclide transport are uncertain. The most significant uncertainties that affect performance of these natural barriers in affecting radionuclide transport have been included in the performance assessment. Although in some cases, conservative approximations have been utilized, this can be acceptable in a licensing analysis.

In Fiscal Year (FY) 2002, the DOE defined a technical work plan that focused on improving confidence in the models for the repository system, including specific testing and analyses aimed at increasing the fundamental understanding of the natural system. This plan was presented to the Board in May 2002[1]. We are in the process of documenting the results of these activities as part of the comprehensive technical basis in a license application that will be submitted to the

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[1] Swift, P. 2002. Project Plans for Fiscal Year 2002-2003: Performance Assessment. Presentation to the Nuclear Waste Technical Review Board, May 8, 2002.

Nuclear Regulatory Commission later this year. The DOE believes that the fundamental understanding of key hydrogeologic processes that may significantly affect fluid flow and radionuclide transport is adequate to support the licensing basis for the Yucca Mountain site.

The DOE will continue to evaluate fluid flow and radionuclide transport to the extent that these processes are important to overall system performance through our Performance Confirmation Program. Activities in the Performance Confirmation Program will evaluate the adequacy of assumptions, data, and analyses that may lead to the findings that permit construction of the repository and subsequent emplacement of wastes. Key parameters that evaluate barrier capability will be monitored and/or tested to evaluate conditions assumed in the license application that may affect compliance with the performance objectives of 10 CFR Part 63[2], as discussed in the following responses to comments on specific testing needs.

The DOE is also initiating work to further investigate some of the key conservatisms in the natural system models and to enhance our understanding of repository performance[3]. This work includes efforts to more completely understand processes involving fracture-matrix interaction, drift shadow, saturated zone groundwater movement, retardation, site-scale hydrologic parameters, and scaling effects in hydrologic parameter estimation. Results could lead to potential modifications of the technical basis at future stages of the licensing process.

2.0 TECHNICAL AND SCIENTIFIC RECOMMENDATIONS

2.1 RECOMMENDATION: HYDRAULIC PROPERTIES OF MAJOR BLOCK-BOUNDING FAULTS

First, although the hydraulic properties of major block-bounding faults, such as the Solitario Canyon fault, never have been field-tested, it seems clear that these faults can influence fluid flow and radionuclide transport substantially. Large-scale hydraulic tests of those major faults are therefore needed.

2.1.1 RESPONSE

In the past two decades, significant amounts of data (geologic, hydrologic, and geochemical) have been collected from the Yucca Mountain site. In the unsaturated zone, the DOE has completed air injection testing in the Bow Ridge fault and the southern Ghost Dance fault and hydrologic testing to determine air permeability, porosity, and gaseous tracer transport characteristics (transport porosity and longitudinal dispersivity) in the northern Ghost Dance fault. Although data on water flow in faults are relatively limited in the unsaturated zone, faults are explicitly incorporated in models using the dual-permeability conceptual model. Hydraulic properties for the fractures in fault zones were separately calibrated to account for differences in

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[2] 10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available.

[3] Budnitz, R. 2004. Update on OCRWM's Science and Technology Program. Presentation to the Nuclear Waste Technical Review Board, January 20, 2004.

fracture properties as compared to fractures outside of fault zones. Flow and transport parameters for the matrix of fault zones were assumed to be identical to the matrix outside of fault zones. Various model simulations have been completed to capture the uncertainties that result from data limitations and the complexity of unsaturated zone flow. Additional testing of faults in the unsaturated zone is not planned at this time.

Although faults were not directly tested in the saturated zone, the results of testing at the C-wells complex provided insight into the role of faults in the saturated zone. Numerous fault traces (e.g., Midway Valley Fault, Paintbrush Canyon Fault, Bow Ridge Fault, and Fran Ridge Fault) traverse between the pumping well and the distant monitoring wells. The measured drawdown during testing at the C-wells complex indicated the existence of connected fault anisotropy. Test results also indicate that the flow system behaved like an equivalent continuum or as a dual porosity system over large scales.

Major faults in the saturated zone are conceptualized as zones of enhanced permeability that simulate preferential flow in faults with gridblocks that are nominally 500-by-500 m in a horizontal direction. Representing faults by 500-by-500 m gridblocks accounts for uncertainties in their geographic location. While the precise flow regime within a fault may not be representative when using volume-averaged representations of faults, the overall flow through the system, particularly at the model boundaries, is not significantly affected by the volume averaging approach. The impact of grid cell averaging is expected to be minimal at the scale of the site-scale flow model and is implicitly included in the specific discharge uncertainty, as applied to the saturated zone transport abstraction model. Hydraulic and tracer testing of fault zone hydrologic characteristics, including anisotropy, is planned to evaluate and test these modeling results in the Performance Confirmation Program. This testing will evaluate fault zone hydraulic conductivity (permeability), porosity, dispersivity, and anisotropy in fractured rock along the flow path from the repository. Quantified results from these tests will be compared to values used in the saturated zone flow and transport models.

Therefore, the relevant effects of faults on groundwater flow paths and rates of radionuclide transport have been included in the performance assessment, as has the uncertainty associated with these faults.

2.2 RECOMMENDATION: SPATIAL DISTRIBUTION AND SEDIMENTARY ARCHITECTURE OF ALLUVIUM

Second, improvements in the characterization of the spatial distribution and sedimentary architecture of the saturated alluvium could substantially enhance fundamental understanding of groundwater flow and radionuclide transport along Fortymile Wash south of Yucca Mountain. For example, the recent sonic log drilled by Nye County is an excellent source of data for supporting studies of sorption of radionuclides in alluvial sediment; additional logs from locations where uncertainties are high have the potential to yield similar benefits. Deeply weathered cobbles from that geologic log suggest the potential for delays in radionuclide transport due to diffusion that could be demonstrated if the DOE conducts field-scale long-term tracer studies (for example, at the Alluvial Testing Complex). These studies should be done.

2.2.1 RESPONSE

As you know, the testing at the Alluvial Testing Complex (ATC) was suspended during site characterization when a permit to withdraw and inject water was denied by the State of Nevada. Before the testing was terminated, single-hole hydraulic and tracer testing and multiple well hydraulic tests were conducted at the ATC. The results of these tests were used to develop estimates of groundwater specific discharge in the alluvium. The DOE plans to restart testing at the ATC, pending resolution of permitting issues with the State of Nevada, using multiple borehole tracer testing as part of the Performance Confirmation Program. Cross-hole pump and tracer transport tests are planned to evaluate conceptual and numerical models for flow and transport in the alluvium south of Yucca Mountain. In addition, Nye County is planning a multi-well test in the alluvium as part of the Early Warning Drilling Program and has plans to investigate the geometry of the alluvium-tuff interface geophysically.

2.3 RECOMMENDATION: MATRIX DIFFUSION

Third, depending on rock properties such as fracture frequency and thin coatings on the fracture faces, matrix diffusion could either increase or decrease current estimates of radionuclide transport time by thousands of years. For this reason, a better empirical basis for predicting matrix diffusion is needed.

2.3.1 RESPONSE

The drift-to drift liquid release and tracer tests (Alcove 8-Niche 3) provide information on seepage, matrix diffusion, and transport over spatial scales in the range of 20 meters in the vicinity of a near-vertical fault[4]. Alcove 8 is located in the upper lithophysal tuff of the Topopah Spring directly above Niche 3, located in the middle nonlithophysal tuff of the Topopah Spring. The role of matrix diffusion is examined by comparing the experimental observations collected from Alcove 8-Niche 3 and results of tracer tests in Alcove 1 with model predictions. The results support conceptual models of unsaturated zone flow and transport and confirm that numerical approaches used in the models adequately represent physical processes controlling unsaturated zone flow[5].

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[4] BSC (Bechtel SAIC Company) 2003. In Situ Field Testing of Processes. ANL-NBS-HS-000005 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031208.00001.

[5] BSC (Bechtel SAIC Company) 2004. UZ Flow Models and Submodels. MDL-NBS-HS-000006 REV 02. Las Vegas, Nevada: Bechtel SAIC Company.

Similar tracer behavior with different diffusion coefficients was observed by Reimus et al. in tracer experiments in fractured volcanic tuff at the C-wells site[6]. This consistency suggests that similar transport processes (advection and matrix diffusion) are at work in the unsaturated and saturated zone barriers in the fractured tuffs of low matrix permeability.

Laboratory and field tests have demonstrated that matrix diffusion occurs in fractured volcanic tuffs near Yucca Mountain and provide a basis for quantifying the effect of matrix diffusion on radionuclide migration through the fractured tuff of the saturated zone. An empirical relationship relating matrix diffusion coefficients to matrix porosity and permeability has been developed from laboratory experiments of diffusion coefficients in intact volcanic tuff matrices and from corresponding matrix porosity and permeability measurements. In the field, the observed tracer breakthrough curves in multiple tracer tests at the C-wells can be explained and interpreted only using transport models incorporating matrix diffusion.

Three additional projects are underway on the subject of matrix diffusion, including a laboratory study to determine the effect of pore connectivity and episodic flow on matrix diffusion, a field study of isotopic disequilibrium as an indicator of in-situ matrix diffusion, and a study to verify the scale-dependence of matrix diffusion parameters. Further, the 2-km natural gradient tracer test, in the saturated zone, will provide a better empirical basis for predicting matrix diffusion.

2.4 RECOMMENDATION: COLLOID-FACILITATED TRANSPORT

. . . evidence from a nuclear weapons test site suggests that some water-borne colloids can lead to rapid radionuclide transport in the saturated zone. Laboratory and computer studies conducted by the DOE show that other colloids might substantially slow radionuclide migration. Consequently, understanding of this phenomenon should be improved by field, laboratory, and modeling studies.

2.4.1 RESPONSE

Colloid filtration rate constants and retardation factors for colloidal transport in fractured volcanic rocks and alluvium have been estimated from a number of laboratory and field experiments. These experiments suggest that the longer the colloids have to travel through saturated medium, the higher the probability that they will be reversibly or irreversibly filtered by the rock phase.

Field and laboratory experiments using both natural and surrogate colloids indicate that most colloids will be filtered by the volcanic rock and the alluvium, and that only a small percentage will remain unretarded (mobile) during migration in the saturated zone. Attachment rate constants and detachment rate constants of colloids to the rock matrix have been measured, and

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[6] Reimus, P.W.; Haga, M.J.; Adams, A.I.; Callahan, T.J.; Turin, H.J.; and Counce, D.A. 2003. "Testing and Parameterizing a Conceptual Solute Transport Model in Saturated Fractured Tuff Using Sorbing and Nonsorbing Tracers in Cross-Hole Tracer Tests." Journal of Contaminant Hydrology, 62-63, 613-636. New York, New York: Elsevier. TIC: 254205.

separate uncertainty distributions of colloid retardation factors have been developed for the fractured volcanic rocks and alluvium.

There are uncertainties associated with the colloid retardation factors obtained for the volcanic rocks and alluvium. These uncertainties are accounted for in the DOE's technical basis for the license application.

The DOE requested that the University of Nevada, Las Vegas, propose an integrated, multi-disciplinary, multi-organizational effort to provide more understanding of the role of colloids in radionuclide movement. Initiative of that work is on hold pending resolution of budget issues.

2.5 RECOMMENDATION: ACTIVE FRACTURE MODEL

. . . for unsaturated zone fluid flow and radionuclide transport, predictions are influenced significantly by assumptions inherent in the formulation of the active fracture model (AFM). The AFM needs to be tested and evaluated to establish a technical basis for using this approach.

2.5.1 RESPONSE

The active fracture model is important for unsaturated zone flow and transport calculations. This model is supported by comparisons of transport simulations with field data, such as carbon-14 measurements and mineral fracture coating data. Because field data are relatively sparse and only indirectly support the active fracture model, total system performance assessment (TSPA) analyses use a range of active fracture model parameters from three infiltration scenarios. The implementation of the active fracture model in the abstraction model (finite element heat and mass particle tracker) was shown to reproduce the qualitative features of the breakthrough curves documented in the unsaturated zone transport process model reports on which the abstraction was based[7]. Thus, the abstraction has been compared with the full complexity of the unsaturated zone model and was found to represent the system robustly for the entire range of parameters and conceptual models required.

Further, testing in a cubic meter block from the lower lithophysal unit, planned for FY 2005, is specifically designed to verify the van-Genuchten parameters of the characteristic curves for the fractured tuff, and to validate the active fracture model.

2.6 RECOMMENDATION: SITE-SCALE MODEL BOUNDARIES

Third, in the saturated zone, the technical basis for the DOE's site-scale flow model would be stronger if the model were more consistent with the most recent regional model calculations of flow across the site-scale model boundaries. Updating the DOE's model on the basis of these calculations could affect predictions of radionuclide transport times.

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[7] BSC. 2004. Particle Tracking Model and Abstraction of Transport Processes. MDL-NBS-HS-000020 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040120.0001.

2.6.1 RESPONSE

The DOE is in the process of revising the *Site-Scale Saturated Zone Flow Model [Analysis Model Report] AMR* to document an alternative conceptual model, using the updated hydrologic framework model and boundary fluxes derived from the 2002 regional flow model. This analysis will consider:

1) Additional water-level data from Phase 2 of the Nye County Drilling Program,
2) A reinterpreted Hydrologic Framework Model,
3) Revised recharge distribution from the 2002 Regional Model and the 2003 Unsaturated Zone Model,
4) Updated boundary fluxes from the 2002 Regional Model,
5) Additional permeability data, and
6) Fifteen new Nye County head targets for calibrations.

The analysis will evaluate the potential impacts of the resulting flow fields (flow paths and specific discharge) on transport calculations and breakthrough curves. The analysis will also include additional evaluation of alternative conceptual models, such as an alternative representation of the Solitario Canyon fault and the large hydraulic gradient. Work initiated recently seeks to optimize the interface between site and regional groundwater models and will incorporate up-to-date versions of each.

3.0 MULTIPLE LINES OF EVIDENCE

3.1 RECOMMENDATION

Multiple lines of evidence and argument can be used to supplement and evaluate the conceptual understanding of the natural systems at the site, the models used to represent those concepts, and the scenarios predicted by those models. The Peña Blanca analogue site in Chihuahua, Mexico, having many similarities to Yucca Mountain, provides a good opportunity to evaluate, for example, whether consideration of secondary mineralization processes may reduce overall system dose estimates substantially and what effect alpha decay of radionuclides in minerals may have on mobility. The Board commends the Science and Technology program for its plans to test Yucca Mountain modeling approaches at the Peña Blanca analogue site. Naturally occurring radioisotopes at Yucca Mountain provide another valuable line of evidence for flow and transport. Additional isotopic data, such as carbon-14 measurements, collected from discrete zones in the flow path from Yucca Mountain, could be used to test and evaluate DOE models and predictions and to constrain recharge rates in the model domain. In summary, the validity of model forecasts can be evaluated better in the presence of a list of independent physical and chemical lines of evidence that support or challenge the forecasts.

3.1.1 RESPONSE

The DOE agrees with the Board that multiple lines of evidence can be used to supplement and evaluate the conceptual understanding of the natural system at Yucca Mountain. The

Peña Blanca analogue site provides an opportunity to evaluate models of the Yucca Mountain site by testing against field observations and process modeling of these observations at the Peña Blanca site. The ongoing work at Peña Blanca is evaluating fracture-matrix interactions, transport behavior, and colloidal transport.

One of the few methods to investigate transport processes over the spatial and temporal scale of interest to repository performance is the use of naturally occurring radioisotopes, such as carbon-14. The DOE has used observations of carbon and other isotopes to test and evaluate transport properties developed at smaller scales in the saturated zone. Although uncertainty and variability exists in these observations, they generally indicate advective transport times of unretarded species that range from a few hundred to a few thousand years along likely flow paths in the tuff and alluvial aquifers. These advective travel times are similar to those that result from the saturated zone flow and transport model. The DOE has also used isotopic data, along with hydrochemical data, to provide bounds on the magnitude and timing of recharge in the saturated zone at the regional scale. New methods of interpreting carbon-14 and carbon-13 analyses together provide an independent line of evidence related to saturated zone processes, for example, advective transport of natural tracers.

4.0 CONCLUDING COMMENTS

4.1 RECOMMENDATION

At a May 2002 meeting of the Board, you stated your intention to devote attention to aspects of the natural system, and we are encouraged by your interest in this important work. Observations during our field trip to Yucca Mountain demonstrated two things in particular: (1) better understanding the behavior of the natural barriers at Yucca Mountain is challenging because of the complexity of the geologic system, and (2) based on recent progress in characterizing the natural system, enhanced understanding of the natural system is attainable. The Board believes strongly the important work you have done in this area should be continued.

4.1.1 RESPONSE

At the May 2002 Board meeting, I introduced my vision of the Science and Technology Program, noting that one focus of this program would be activities that enhance understanding through continuous improvement in scientific understanding of the Yucca Mountain repository system. This program is managed as a separate activity from the license application. Science and technology projects are not needed to support the license application, but may provide useful information after the initial license application. One of the key focus areas of the Science and Technology Program is the natural system. Results of testing and analyses completed in the Science and Technology Program will be available after license application and can be incorporated at a later stage in the program, as appropriate.

At this same meeting in May 2002, the DOE summarized its plans for additional technical work to support the license application based on a risk-informed prioritization and emphasizing a defensible and sound technical basis for the license application, as noted above. The extensive

testing and modeling program undertaken to understand and characterize flow and transport in the unsaturated and the saturated zones at Yucca Mountain provides a sufficient basis for predicting radionuclide releases at the compliance boundary. While it is clear that enhanced understanding of the natural system is attainable, the DOE believes that the technical basis for a license application is adequate. As noted previously[1], scientific studies of the natural system will be completed in the Performance Confirmation Program to evaluate the adequacy of the technical basis that led to findings that may permit construction of a repository at Yucca Mountain.