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RESPONSE TO THE ADDITIONAL INFORMATION NEED (AIN) ASSOCIATED WITH KEY TECHNICAL ISSUE (KTI) AGREEMENTS RADIONUCLIDE TRANSPORT (RT) 3.05 AIN-1, COMMENT 8 AIN-1, AND STRUCTURAL DEFORMATION AND SEISMICITY (SDS) 3.01 AIN-2

References: (1) Ltr, Kokajko to Ziegler, dtd 4/8/05 (Pre-Licensing Evaluation of KTI Agreements: SDS 3.01 AIN; RT 3.05; and USFIC 6.03)
(2) Ltr, Schlueter to Ziegler, dtd 2/14/03 (Staff Review of Information Addressing RT 3.06 and SDS Agreement 3.02, Status Partly Received)

On April 8, 2005, the U.S. Nuclear Regulatory Commission (NRC) provided a prelicensing evaluation of responses from the U.S. Department of Energy (DOE) to KTI agreements RT 3.05 and SDS 3.01 AIN-1 (Reference 1). This evaluation resulted in requests for additional information for both KTIs regarding the Alcove 8/Niche 3 tests. These tests investigated flow and transport between the floor of Alcove 8, located in the Enhanced Characterization of Repository Block Cross Drift, and the ceiling of Niche 3, located about 20 m below in the Main Drift of the Exploratory Studies Facility. Between March 2001 and October 2004, two types of tests were conducted at this site: fault tests and the large-infiltration-plot tests.

The letter of April 8, 2005 (Reference 1) also contained an evaluation of DOE responses to eight specific comments that arose from the NRC's review (Reference 2) of two other KTIs that dealt with Alcove 8/ Niche 3 tests: RT 3.06 and SDS 3.02. In the evaluation, the NRC indicated that only Comment 8 required additional information, and that the information needed to address RT 3.05 would also address Comment 8.

This letter provides summary responses to RT 3.05 AIN-1, Comment 8 AIN-1, and SDS 3.01 AIN-2. Additional information regarding the large-infiltration-plot testing in Alcove 8/Niche 3 is presented in the enclosed report, *Analysis of Alcove 8/Niche 3 Flow and Transport Tests*, ANL-NBS-HS-000056, Revision 01 (Enclosure 1). Additional information regarding the fault testing is provided in the following enclosed reports: *In Situ Field Testing of Processes*, ANL-NBS-HS-000005, Revision 03, ACN 02 (Enclosure 2) and *UZ Flow Models and Submodels*, MDL-NBS-HS-000006, Revision 02, ACN 01 (Enclosure 3). The portions of these contractor reports cited in this letter were reviewed by DOE, and are acceptable for addressing the AINs, although the reports in their entirety were not formally reviewed and accepted by DOE. The documents are subject to revision, and if revised, the revisions would be available when issued. Enclosure 4 is a compact disk (CD) containing the electronic files of Enclosures 1, 2 and 3. The electronic file of Enclosure 1 is in a .pdf format containing 13,182,886 bytes; the electronic file of

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Enclosure 2 is in a .pdf format containing 48,428,511 bytes, and the electronic file of Enclosure 3 is in a .pdf format containing 18,709,730 bytes. All of these reports can be made publicly available.

RT 3.05 AIN-1 and Comment 8 AIN-1

The text of RT 3.05 AIN-1 is as follows:

> *Appendix H of Bechtel SAIC Company, LLC (2003a) does not provide a discussion of results for the tracer testing conducted at Alcove 8-Niche 3, nor does it provide information or interpretation of results compared to pretest predictive modeling. Some results of tracer tests of the fault and small block are presented in Bechtel SAIC Company, LLC (2003b) and Liu, et al. (2004). As noted in the evaluation of USFIC.6.03, the limited test results available indicate matrix diffusion is an important process affecting transport of the tracers used in the Alcove 8-Niche 3 tests. Results appear consistent with the expected behavior of the tracers used in the tests. The DOE indicated the Alcove 8-Niche 3 tests do not directly support the development or abstraction of unsaturated zone process models for performance assessment (Bechtel SAIC Company, LLC, 2003a, Appendix E). Results of tracer testing for the large-plot test can provide important insight into: (i) the processes affecting radionuclide transport in the unsaturated zone; and (ii) the capabilities of current transport models to adequately capture these processes. Until DOE publishes the results of the remaining tracer tests and comparison of results to the pretest predictions, the staff considers Agreement RT 3.05 as incomplete.*

The text of Comment 8 AIN-1 is as follows:

> *<u>Comment 8</u> requests descriptions of all features, events, and processes observed in the Alcove 8-Niche 3 tests. The DOE response and the Analysis Model Report for in-situ testing (Bechtel SAIC Company, LLC, 2003b) provide detailed descriptions of experimental initial and boundary conditions, observed fracture patterns, and the results and interpretations of tracer transport tests. As discussed in the staff evaluation of Agreement RT 3.05 herein, DOE's response does not provide a discussion of results for the tracer testing conducted at Alcove 8-Niche 3, nor does it provide information or interpretation of results compared to pretest predictive modeling. The additional descriptions of test results needed to address Agreement RT.3.05 would serve to address this comment.*

The enclosed report, *Analysis of Alcove 8/Niche 3 Flow and Transport Tests*, ANL-NBS-HS-000056, Revision 01 (Enclosure 1), documents the two types of information requested in RT 3.05 AIN-1 and Comment 8 AIN-1: (1) results of the tracer portion of the large-infiltration-plot tests, and (2) the interpretation of test results including comparisons to pretest predictions.

Section 6.1.1 of Enclosure 1 describes the testing methods used in the large-infiltration-plot tests. The main objective was to evaluate the modeling approaches used and the importance of the matrix diffusion process by comparing simulation and actual test observations. During the tests, infiltration water and tracers were applied at the floor of Alcove 8 through an infiltration plot, which was divided into 12 square subplots (about 1 m^2 each) using steel boundaries. Seepage and tracer recovery were monitored at the ceiling of Niche 3. In addition, the advancing saturation front was monitored at several boreholes drilled in the test interval between Alcove 8 and Niche 3.

Section 6.1.2 of Enclosure 1 provides the results of the seepage and tracer tests, including measured concentrations of seepage water samples. The test results show variability in seepage rate even during periods when infiltration was substantially constant. One possible explanation is that movement of in-fill materials (i.e., rock particles) in fractures affected flow rates. This explanation is consistent with a recent laboratory and field study of particle transport in unsaturated fractured rock by Weisbrod et al. (2002).[1] No tracer breakthrough was observed from the start of the test to about 740 days, at which time the infiltration plots were scrubbed to remove biofilms. After the scrubbing, there was an infiltration pulse followed by breakthroughs of two of the six injected tracers. One possible mechanism to explain the observed breakthrough behavior is that the infiltration pulse caused particle movement, which resulted in the opening of previously blocked flow paths.

Section 6.2 of Enclosure 1 contains information regarding pretest predictions of the large-infiltration-plot tests including details of model development, calibration, and predictions. As requested in RT 3.05 AIN-1 and Comment 8 AIN-1, the comparisons between pretest predictions and observed test results are presented in Section 6.2.3 and discussed further in Section 6.2.4 of Enclosure 1.

While the predicted seepage rates are comparable on average with the observed values, tracer concentrations are overestimated for the time period before scrubbing. No comparison of tracer results was done for the time period after scrubbing because of the modeling uncertainties involved. The test results before scrubbing show essentially no observations of the applied tracers (excluding the background concentrations), while pretest predictions indicated considerable concentrations for different tracers. The results of tracer testing provide insight into processes affecting radionuclide transport in the unsaturated zone. Modeling analyses of the tracer results and associated uncertainties (Sections 6.3 and 6.4 of Enclosure 1) suggest that the use of a small-scale matrix diffusion coefficient in modeling underestimates the tracer retardation at the field scale of the test site. This result is consistent with findings from a number of studies published in the literature (Shapiro 2001; Liu et al. 2003; *UZ Flow Models and Submodels*, MDL-NBS-HS-000005, Revision 02, ACN 02, Section 7.6 [Enclosure 3]), including multiple studies of tracer test data collected from the Äspö site (Neretnieks 2002).[2, 3, 4]

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[1] Weisbrod, N.; Dahan, O.; and Adar, E.M. 2002. "Particle Transport in Unsaturated Fractured Chalk under Arid Conditions." *Journal of Contaminant Hydrology, 56,* 117-136. New York, New York: Elsevier.
[2] Shapiro, A.M. 2001. "Effective Matrix Diffusion in Kilometer-Scale Transport in Fractured Crystalline Rock." *Water Resources Research, 37,* (3), 507-522. Washington, D.C.: American Geophysical Union.
[3] Liu, H-H.; Haukwa, C.B.; Ahlers, C.F.; Bodvarsson, G.S.; Flint, A.L.; and Guertal, W.B. 2003. "Modeling Flow and Transport in Unsaturated Fractured Rock: An Evaluation of the Continuum Approach." *Journal of Contaminant Hydrology, 62-63,* 173-188. New York, New York: Elsevier.
[4] Neretnieks, I. 2002. "A Stochastic Multi-Channel Model for Solute Transport – Analysis of Tracer Tests in Fractured Rock." *Journal of Contaminant Hydrology, 55,* (3-4), 175-211. New York, New York: Elsevier.

SDS 3.01 AIN-2

The text for SDS 3.01 AIN-2 is as follows:

The DOE characterization of fractures in the Alcove 8-Niche 3 tests was limited to mapping fractures with trace lengths greater than 1 m [3.28 ft]. During unsaturated conditions, however, it is often the smallest interconnected fractures with the narrowest apertures that control flow patterns, capillary diversion, and seepage because these are the fractures with the highest capillary strength. Under fully saturated conditions, the more readily observable fractures are more likely to play a role in conducting flow. The differences in hydrologic properties between the larger, more observable fractures and the smallest, difficult-to-observe fractures are a possible explanation for the observations in Alcove 8/Niche 3 tests. Infiltration under ponded conditions showed a moderate to weak positive correlation to observable fracture density, while seepage rates under unsaturated conditions showed no clear correlation to fracture density. Although detailed studies of microfractures (i.e., fractures visible with the aid of a microscope) at scales relevant to making inferences about drift seepage throughout the potential repository would be time consuming, such studies are standard methodology in structural geology (e.g., Dezayes, et al., 2000; Ortega and Marrett, 2000; Laubach, et al., 2002; Wilson, et al., 2003). Further, DOE staff collected data about small-scale fractures (i.e., trace lengths less than 1 m [3.28 ft]) in the Enhanced Characterization of the Repository Block (DTN: GS990908314224.009), and these data could have been used to better fracture-inform the infiltration and seepage results for the Alcove 8-Niche 3 tests.

Although DOE staff made some efforts toward fracture-informing the infiltration and seepage results of the Alcove 8/Niche 3 large-plot test, they did not conduct these analyses for the fault test. DOE should explain what was learned about the hydrologic characteristics of the fault under the conditions of the fault test, or the effects of the fault on the infiltration and seepage results, or demonstrate that the fault had little or no impact on the test results. As such, NRC considers DOE'S response to SDS.3.01 AIN-2 to be insufficient for completion of the agreement at this time.

In accordance with SDS 3.01 AIN-2, an explanation of what was learned about the hydrologic characteristics of the fault under the conditions of the fault test as well as the effects of the fault on the infiltration and seepage results is documented in two enclosed reports: *In Situ Field Testing of Processes*, ANL-NBS-HS-000005, Revision 03, ACN 02 (Enclosure 2) and *UZ Flow Models and Submodels*, MDL-NBS-HS-000006, Revision 02, ACN 01 (Enclosure 3).

Section 6.12 of *In Situ Field Testing of Processes* (Enclosure 2) discusses various aspects of Alcove 8/Niche 3 testing, including the test setup (Section 6.12.1) and the results of the fault tests (Section 6.12.2). The fault tests used water and two liquid tracers. Water, first without and then with tracers, was released into an infiltration plot consisting of four trenches excavated along a fault-trace on the floor of Alcove 8. The fault-trace is located near the area used for the large-infiltration-plot tests. The advancing moisture front in the rock within the test interval was monitored using boreholes drilled into the rock between the floor of Alcove 8 and the ceiling of Niche 3. Water seeping from the ceiling of Niche 3 was quantified and analyzed for tracer returns.

Model analysis of measured seepage and tracer recovery from the fault tests is presented in Section 7.6 of *UZ Flow Models and Submodels* (Enclosure 3). The model was first calibrated against only the seepage and water-travel-velocity data to obtain the calibrated rock properties and the corresponding water flow field. The calibration process provides a measure of the effective properties governing flow and transport in the vicinity of the fault. Then, forward tracer transport simulations that varied chemical transport parameters were carried out to evaluate the effects of matrix diffusion and other related processes on solute transport in the fault.

Analysis results show that the fault had a significant impact on infiltration and seepage. The fault permeability, an important hydrologic characteristic, was found to be two to three orders of magnitude greater than that of the adjacent fractured rocks. Based on both experimental observations and model analysis results, the macrodispersion process was not found to be significant within the fault. However, the effective fracture-matrix interface area within the fault is much higher than geometric surface area.

As presented in Section 6.4.1 of Enclosure 1, the tracer test results from the large-infiltration-plot test and studies such as Wu et al. 2001 and Liu et al. 2003 indicate that the existence of many small-scale fractures may be the main reason for the need to enhance the effective matrix diffusion coefficient for the Alcove 8/Niche 3 test bed model, which does not explicitly consider small-scale fractures, to match the large-infiltration-plot data.[5, 6] This result is consistent with the analyses of the tracer concentrations from the fault test. The need to increase the fracture-matrix interface area for interpreting results from the fault tests is comparable to the need to increase the effective matrix diffusion coefficient discussed previously with respect to the large-plot infiltration tests. Increasing either parameter leads to greater diffusion of tracer into the matrix and longer transport breakthrough times. Thus, the results of both the large-plot-infiltration tests and the fault tests support the conclusion that matrix diffusion is a key mechanism for retarding radionuclide transport in the unsaturated zone at Yucca Mountain, Nevada.

Based on the information presented in this letter and in the enclosed documents, pending NRC review and approval, DOE recommends that SDS 3.01 and RT 3.05 (as well as the associated Comment 8) be closed.

There are no new regulatory commitments in this letter or its enclosures. Please direct any questions concerning this letter to J. Russell Dyer at (702) 794-1301 or e-mail russ_dyer@ymp.gov, or Eric T. Smistad at (702) 794-5073 or e-mail eric_smistad@ymp.gov.

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[5] Wu, Y.S.; Liu, H.H.; Bodvarsson, G.S.; and Zellmer, K.E. 2001. *A Triple-Continuum Approach for Modeling Flow and Transport Processes in Fractured Rock.* LBNL-48875. Berkeley, California: Lawrence Berkeley National Laboratory.

[6] Liu, H-H.; Haukwa, C.B.; Ahlers, C.F.; Bodvarsson, G.S.; Flint, A.L.; and Guertal, W.B. 2003. "Modeling Flow and Transport in Unsaturated Fractured Rock: An Evaluation of the Continuum Approach." *Journal of Contaminant Hydrology, 62-63,* 173-188. New York, New York: Elsevier.

Enclosures:
1. *Analysis of Alcove 8/Niche 3 Flow and Transport Tests*, ANL-NBS-HS-000056, Revision 01
2. *In Situ Field Testing of Processes*, ANL-NBS-HS-000005, Revision 03, ACN 02
3. *UZ Flow Models and Submodels*, MDL-NBS-HS-000006, Revision 02, ACN 01
4. CD containing Enclosures 1, 2, and 3

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