REQUEST FOR ADDITIONAL INFORMATION (RAI)
Volume 3—Postclosure Chapter 2.2.1.3.6 (Flow Paths in the Unsaturated Zone)
1st Set (RAIs 1 through 9)
(DEPARTMENT OF ENERGY'S SAFETY ANALYSIS REPORT SECTIONS 2.3.2 and 2.3.3)

RAI #1 Traceability of Data Used for Calibration of Site-Scale Flow Model

Explain how the calibrated and uncalibrated properties used in unsaturated flow models are adequately supported by observations.

To support the explanation, provide a summary table describing the hydrologic and pneumatic observations used to calibrate the three-dimensional unsaturated zone site-scale flow model. The description should include information for each borehole, including as appropriate: (i) the name of the borehole; (ii) parameter name; (iii) observation or sensor depth; (iv) unsaturated zone model layer; (v) number of observations, minimum, maximum, average, and standard deviation of the parameter, (vi) aggregation process, and (vii) Data Tracking Numbers (DTNs) where the data are identified. The summary table should include saturation, water potential, and pneumatic pressure data. If a data value is aggregated from a set of observations or measurements, describe and justify the data selection and aggregation process. This information is needed to evaluate compliance with 10 CFR 63.114(a) and (b).

Basis: Neither the SAR nor supporting AMR (SNL, 2007, *Calibrated Unsaturated Zone Properties*) provides information sufficient to evaluate the adequacy of data for calibrating the site-scale model. SNL (2007, Table 6-4) describes the observations by listing the boreholes with observations and pointing to the DTNs supplying the data. SNL (2007, Figures 6-1 through 6-8) also plots observations from 5 of the 19 boreholes having saturation or water potential observations used in the calibrations. However, these figures do not indicate the individual model layers. Also SNL (2007) does not provide the observations or model estimates for the remaining boreholes. Therefore, the extent to which parameters in individual model layers are based on observations is not clear, nor is it clear how consistently the observations support model predictions among boreholes.

Further, SAR Section 2.3.2.4.1 and the supporting AMR (SNL, 2007) do not consistently represent the source of the input data. For example, SAR Section 2.3.2.4.1 states that 16 boreholes are used for one-dimensional calibration of drift-scale matrix properties but SNL (2007) identifies 16 (SNL, 2007, Section 6.3.2), 19 (SNL, 2007, Table 6-4), and 23 (SNL, 2007, Appendix D) boreholes as being used to estimate drift-scale properties, and SAR Section 2.3.2.4.1 identifies 2 boreholes used for one-dimensional calibration of mountain-scale fracture permeability but SNL (2007, Section 6.3.3) identifies 5 boreholes. Also, SNL (2007, Table 6-4) does not indicate a source for matrix saturations in SD-12 but SNL (2007, Figures 6-1, 6-3, 6-5, and 6-7) plots a set of measured matrix saturations in SD-12.

Reference:

SNL. 2007. Calibrated Unsaturated Zone Properties. ANL-NBS-HS-000058 Rev00. Las Vegas, Nevada: Sandia National Laboratories.

RAI #2 Consistency of Seepage Conceptualization with Observations

Explain how the TSPA seepage conceptualization and abstraction are consistent with observations and interpretations of the presence of liquid water in the Passive Test in the Enhanced Characterization of the Repository Block (ECRB) drift. Explain how the volume of water entering a drift is not underestimated by the TSPA seepage abstraction, which neglects vapor migration into the drifts through fractures or other air pathways, redistribution within the drift, and subsequent condensation. See related RAI from Scenario Chapter, Set 5, RAI #3. This information is needed to verify compliance with 10 CFR 63.114(a), (c), (e), and (g).

Basis: DOE concluded (SAR Section 2.3.3.2.2.2) that observations related to the presence of liquid water in the Passive Test were consistent with condensation, and not consistent with water dripping into the drift. The distribution of water in the drift of the Passive Test is qualitatively explained by condensation after gas-phase redistribution driven by small temperature and relative humidity variations (SAR Section 2.3.3.2.2.2.5). Similar variations of temperature and relative humidity would be expected to occur after the thermal perturbation period in emplacement drifts, in both the 10,000-yr and post-10,000-yr periods. Open vapor air pathways may include interconnected fractures and other pathways, such as open boreholes.

Salve and Kneafsey (2005) describe how observations of liquid water in the Passive Test (BSC, 2004, Section 6.10.2.2) of the ECRB drift can be explained using a conceptual model of vapor migration through the fracture network and into the drift. They describe three models for vapor flux into the drift, and the degree to which each model appears to best fit the observations of hydrologic conditions and liquid water in the drift. In their models that best fit the observations, vapor migration through the fracture network acts as the supply of water to the in-drift environment. Salve and Kneafsey (2005) suggest that evaporation directly from the drift wall surface did not appear adequate as a supply of water to support observations.

The origin of liquid water in drifts during the later stages of the thermal period and continuing through the ambient period may be a combination of condensation and seepage. The in-drift condensation submodel (SAR Section 2.3.5.4.2.4) does not account for the processes nor the period of concern mentioned in this RAI.

References:

BSC. 2004. In-Situ Testing of Field Processes. ANL-NBS-HS-000005 Rev03. Bechtel-SAIC Company, LLC., Las Vegas, Nevada. LSN# DN2001977697.

Salve, R. and T.J. Kneafsey. 2005. Vapor-phase transport in the near-drift environment at Yucca Mountain. Water Resources Research, Volume 41, W01012, doi:10.1029/2004WR003373.

RAI #3 Consistency of Thermal Seepage Abstraction with Observations

Explain how the DOE abstraction estimate for thermal seepage temperature threshold (SAR Sections 2.3.3.3 and 2.3.3.4) is consistent with observations from heater tests. Explain why the DOE thermal seepage abstraction would not underestimate water seeping into the drift when considering: (i) observations in heater tests related to temperature fluctuations recorded by sensors in both grouted and open boreholes, and (ii) the uncertainty of boiling temperature of water inferred from the possibly high total dissolved solids associated with water that corroded test apparatus. Aspects of this request related to open boreholes should reflect the DOE response to Scenario Chapter Set 5, RAI #4 concerning FEPs 1.1.01.01.0B and 2.1.06.04.0A. This information is needed to verify compliance with 10 CFR 63.114(a), (c), (e), and (g).

Basis: The DOE abstraction for thermal seepage is that seepage into the drift is set to zero if the drift wall temperature is calculated to be above 100°C (SAR Section 2.3.3.4). This temperature, being several degrees above boiling, reportedly accounts for modeling uncertainties and the possibility of a heat pipe occurring near the drift wall (SAR Section 2.3.3.3.4).

Analysis of several heater tests suggests that observations of temperature fluctuations could be explained by liquid water preferentially breaching the dryout zone (Green, et al., 2008) at temperatures above 100°C. Large temperature fluctuations at temperatures above boiling could be indicative of pulses of water preferentially flowing in the dryout zone. These observations occurred in both grouted and ungrouted boreholes. Observations in grouted boreholes would appear to reflect pulses of water flowing in fractures. Observations in ungrounted boreholes (e.g., MPBX boreholes in the Drift Scale Heater Test) would appear to reflect heat pipes inside an open borehole.

In addition, there are post-test observations consistent with water having entered the heated opening and corroding test components; however, the temperature at which this occurred has not been determined (Green, et al., 2008). Because the chemistry of the liquid entering the drift is unknown, though apparently corrosive, the boiling temperature of the liquid would be uncertain. The 100°C thermal seepage threshold does not account for the uncertainty related to refluxing water redissolving evaporites (SAR Section 2.3.3.3.4).

References:

Green, R., C. Manepally, R.W. Fedors, and M.M. Roberts. 2008. Examination of Thermal Refluxing in In-Situ Heater Tests. Center for Nuclear Waste Regulatory Analyses, San Antonio, Texas. LSN No. NRC000029847, or ADAMS No. ML083030097.

SNL. 2008. Total System Performance Assessment Model/Analysis for the License Application. MDL-WIS-PA-000005 REV00. Las Vegas, Nevada: Sandia National Laboratories.

RAI #4 Representative Seepage for Each Percolation Subregion

Explain how averaging seepage rates from individual waste package locations to create representative seepage rates for each percolation subregion impacts EBS radionuclide releases and doses. In addition, provide the technical basis for the assumption that five percolation subregions are sufficient to represent seepage and EBS release variability over the repository footprint. Consideration should be given to both the nominal and seismic ground motion scenarios. This information is needed to verify compliance with 10 CFR 63.114(b).

Basis: One representative waste package with one representative seepage rate is used to calculate EBS release from individual percolation subregions (SNL, 2008a, p. 6.3.7-2). Given the nonlinearity in estimating seepage, it is not clear how averaging to obtain representative values for each percolation subregion may affect EBS release. In addition, justification is not apparent in SAR Section 2.3.5.4.1.4.1 or SNL (2008b, Section 8.3) for why five percolation subregions is sufficiently representative of seepage and EBS radionuclide release variability.

Reference:

SNL. 2008a. Total System Performance Assessment Model/Analysis for the License Application. MDL-WIS-PA-000005 REV00. Las Vegas, Nevada: Sandia National Laboratories.

SNL 2008b. Multiscale Thermohydrologic Model. ANL-EBS-MD-000049 REV03 ADD 02. Las Vegas, Nevada: Sandia National Laboratories.

RAI #5 TSPA Results, Precipitation to Seepage

Explain how the magnitude and timing of seepage is related to percolation, net infiltration, and precipitation over the repository footprint.

To support this explanation, provide a summary table consistent with TSPA-LA results that contains (i) precipitation, (i) net infiltration (using weights from SNL, 2008), (ii) net infiltration (using GLUE-derived weights), (iii) percolation at repository horizon, and (iv) seepage all averaged over the same domain (i.e., repository). The summary values for seepage also should include flux values for percolation subregion and seeping environment in the percolation subregion, and seepage fraction. Consider the nominal and seismic ground motion cases, and the glacial transition and post-10,000-yr climates (percolation and seepage only). This information is needed to verify compliance with 10 CFR 63.114(b).

Basis: It is difficult to extract from the SAR a consistent set of values to use in a comparison of flux values on and through the mountain because of the different procedures used to develop summary values in SAR Sections 2.1, 2.3.1, 2.3.2, 2.3.3, and 2.4. The summary values are derived from (i) different modeling domains, (ii) infiltration uncertainty scenarios, (iii) unadjusted and adjusted net infiltration weights (for the latter, GLUE-derived weights), (iv) areas based on the entire repository or percolation region and seeping environment, (v) different rock types, and (vi) calculations from an example exercise.

Reference:

SNL. 2008. Simulation of Net Infiltration for Present-Day and Potential Future Climates. MDL-NBS-HS-000023, REV 00 AD01. Las Vegas, Nevada: Sandia National Laboratories.

RAI #6 Effect of Spatial Variability on Seepage

Demonstrate that seepage and radionuclide releases are not underestimated by the performance assessment representation of spatial variability in percolation flux. This information is needed to evaluate compliance with 10 CFR 63.114(a), (b), (c), and (e).

Basis: SAR Section 2.3.3.2 describes the ambient seepage model as parameterized by local percolation flux and two hydraulic properties. The local percolation flux used in the seepage model is the product of a percolation flux at the base of the PTn (derived from the site scale flow model) and a sampled flow focusing factor. Site scale flow fields describe percolation fluxes uniformly distributed within a 100 m [330 ft] grid cell at the temporal scale of a climate state, and the seepage model considers steady fluxes at the scale of a few drift diameters (SNL, 2007, Abstraction of Drift Seepage, Section 6.6.2.5.1). Based on this description, the flow focusing factor logically can be considered to represent all seepage-affecting variability at spatial scales intermediate between the site-scale model grid cell and the drift scale. As described in SAR Section 2.3.3.2 and by SNL (2007), the flow focusing factors are derived from a two-dimensional steady state model that considers the region between the base of the PTn and the repository horizon.

Given that the flow focusing factor distribution is based on a model analysis without field observations of flow, the representation of flow focusing factors might not account for all aspects of spatial variability. For example, in some areas, variability could be even smaller than represented in the model, or could be much larger. It is not clear from the SAR and supporting documentation what effect spatial variability at the drift scale has on performance, or if conditions may exist where spatial variability does not affect performance.

Spatial variability may be under represented, when it is not clear that a two-dimensional model, which represents flow features as infinite sheets in the third dimension, is representative of a three-dimensional model that has flows with a finite extent. Accordingly, high fluxes may be concentrated in a smaller area when a third dimension is considered, implying a larger variability than considered in the flow focusing factor.

Also, spatial variability may be under represented, even if the two-dimensional model appropriately characterizes flow in the TSw, when variability in flow at the base of the PTn is not fully considered. The model uses top boundary conditions that are either uniform or have regularly spaced sources. SNL (2007, Figure 6.6-13) suggests that fluxes calculated by the two-dimensional model remain coherent at scales on the order of 10 to 20 m [33 to 66 ft], which can be interpreted as implying that flow variability at the base of the PTn at spatial scales as small as 10 m [33 ft] may increase flow variability at the drift scale. Several mechanisms may result in flow variability at this scale, such as (i) localized infiltration, (ii) local heterogeneity in the PTn, and (iii) episodic flow focusing into widely scattered discrete fast pathways due to temporary perching above the heavily altered low-permeability zone at the TCw/PTn transition.

Reference:

SNL. 2007. Abstraction of Drift Seepage. MDL-NBS-HS-000019, REV 01. Las Vegas, Nevada: Sandia National Laboratories.

RAI #7 Performance Sensitivity to GLUE Weights

Describe the seepage, release, and transport sensitivity arising from the use of the GLUE procedure in performance assessment, including changes in estimated uncertainty. This information is needed to evaluate compliance with 10 CFR 63.114(a), (b), and (c).

Basis: The GLUE procedure results in a set of weights applied to the infiltration scenarios (SAR Section 2.3.2.4.1.2.4.5.5). These weights yield lower expected mean annual infiltration than the original weights provided in SNL (2008).

The SAR and supporting documents do not clearly describe how performance changes when the infiltration scenario weights are modified using the GLUE procedure. Therefore, it is not possible to evaluate the effects of the GLUE-derived weights on seepage, release, and transport.

Reference:

SNL. 2008. Simulation of Net Infiltration for Present-Day and Potential Future Climates. MDL-NBS-HS-000023, REV 00 AD01. Las Vegas, Nevada: Sandia National Laboratories.

RAI #8 Thermal Data Used in GLUE Method

Explain (i) the procedure for selecting thermal observations used in the GLUE procedure and (ii) the procedure for verifying temperature boundary conditions. Explain why the Sass et al. (1988) borehole temperature profiles and thermal conductivity measurements are not used in the GLUE procedure. This information is needed to evaluate compliance with 10 CFR 63.114(a), (b), and (c).

Basis: The temperature observations used for the thermal model in the GLUE analysis (SAR Section 2.3.2.4.1.2.4.5.3) were drawn from long-term monitoring at six boreholes and from observations by Sass, et al. (1988). NRC staff analysis suggests three factors in the DOE modeling of temperature data may lead to underestimates of percolation: (i) the water table temperature appears to be incorrectly interpolated, (ii) the top temperature boundary condition may be cooler than is consistent with borehole observations in some boreholes, and (iii) the thermal conductivity values below the TSw appear to be underestimated in several layers based on numerous observations by Sass et al. (1988). For example, temperature profiles in borehole SD-12 may be affected by underestimated thermal conductivity values in the Tptpv3, Tptpv1, Tpbt1, Tcpuv, Tcpuc, Tcplc, and Tcplv GFM2000 layers; these GFM2000 layers are included in the tsw38, ch1, and pp1 through pp4 unsaturated zone model layers. Further, the temperature boreholes used in the analysis are located in areas expected to have low infiltration, and the Sass et al. (1988) temperature profiles (which includes locations where infiltration is expected to be relatively large) were not considered in the GLUE procedure although apparently qualified by SNL (2007, Appendix I). Specific issues include:

- Water table temperatures shown in SAR figures 2.3.2-13 through 2.3.2-16 differ by between 1 and 2°C from the temperatures that would be obtained by linear interpolation between the nearest boreholes with water table temperatures reported by Sass et al. (1988);
- Modeled temperatures are systematically cooler than the topmost observed temperature by approximately 0.5°C in NRG-7 and UZ #5, approximately the difference between the modeled 10th and 50th percentile temperature profiles at the elevation of the lowest observed temperature; and
- Thermal conductivity parameter values used for model layers below the TSw are assigned estimates based on samples from other horizons. Thermal conductivity measurements by Sass et al. (1988) have larger values than those assigned in the model for layers below the TSw. Using smaller thermal conductivities low in a profile results in lower estimates of percolation.

Reference

Sass, J.H., A.H. Lachenbruch, W.W. Dudley Jr., S.S. Priest, and R.J. Monroe. 1988. Temperature, Thermal Conductivity, and Heat Flow near Yucca Mountain, Nevada: Some Tectonic and Hydrologic Implications. Open-File Report 87-649. Denver, Colorado: U.S. Geological Survey. LSN No. DN2000415402.

SNL. 2007. UZ Flow Models and Submodels. MDL-NBS-HS-000006. Rev. 03. AD 01. Las Vegas, Nevada: Sandia National Laboratories.

RAI #9 Geochemical Data Used in GLUE Method

Explain the procedure for selecting geochemical observations for the GLUE procedure.

Support the explanation by providing a table (e.g., ASCII file or spreadsheet) describing each geochemical sample for which chloride concentrations were measured and which was obtained during site characterization from those boreholes and drifts that are used in the GLUE procedure, including (as relevant): (i) sample identifier; (ii) borehole or drift identifier; (iii) DTN, (iv) sample type (porewater, perched water, aquifer); (v) date obtained; (vi) depth; (vii) station; (viii) lithographic and hydrology units; (ix) chemical and isotopic composition; (x) Q status; and (xi) a note indicating whether the data is included in GLUE procedure or providing the reason for excluding from the analysis (where applicable). This information is needed to evaluate compliance with 10 CFR 63.114(a), (b), and (c).

Basis: The chloride data used in the GLUE procedure is not clearly traced in the SAR and supporting AMR. Chloride observations displayed in SAR figures 2.3.2-18 through 2.3.2-25, 2.3.2-27, and 2.3.2-28 appear to be inconsistent with the corresponding number of observations identified by SNL (2007, Table 6.5-3) or the set of DTNs within the LSN (including those identified by SNL (2007, Table 6.5-1). Specific examples of chloride discrepancies include:

- There are 60 ECRB and 49 ESF chloride concentrations reported in DTNs identified by DN2002418952 and LA0002JF12213U.002, but the SNL (2007) Table 6.5-3 reports 26 and 31 values and Figures 6.5-4 and 6.5-5 report 23 and more than 70 values, respectively;
- SNL (2007) Table 6.5-3 ascribes 6 chloride concentration values to borehole UZ-N55 but there are only 3 unique values in the DTNs reported in Table 6.5-1;
- Table 6.5-3 reports 10 chloride concentration values for borehole SD-7 but there are 37 values identified by DN2002418952 and LAJF831222AQ98.011; and
- Table 6.5-3 reports 3 chloride concentration values for borehole SD-7 but there are 38 values identified by DN2002418952.

The number of samples identified from the LSN matched for boreholes G-2 and UZ-7a, Table 6.5-3 identified more samples than were found in the LSN for NRG-6, SD-12, UZ-14, and UZ-N55, and more samples were identified in the LSN than cited in Table 6.5-3 for the remaining 6 boreholes, the ESF, and the ECRB.

Reference:

SNL. 2007. UZ Flow Models and Submodels. MDL-NBS-HS-000006. Rev. 03. AD 01. Las Vegas, Nevada: Sandia National Laboratories.