**RAI Volume 3, Chapter 2.2.1.1, First Set, Number 1, Supplemental Question:**

> In the response, Attachment A, p. 2, "Percolation Flux," clarify how "qualitative description of barrier function" and "quantitative evaluation of barrier capability" entries account for the re-weighting of infiltration model results using the GLUE methodology.

## 1. SUPPLEMENTAL RESPONSE

The NRC question summarized above relates to Table 2.1-1 of the SAR, which was supplemented in response to RAI 3.2.2.1.1-001, thereby producing Table 2.1-1 Expanded. The portion of Table 2.1-1 Expanded that is relevant to the question is provided as an attachment to this supplemental response.

The observations in the "Percolation Flux" entry of Table 2.1-1 Expanded, such as pore-water chloride concentrations and damping of episodic flow, are based on field data and unsaturated zone flow model results, as described in the SAR sections referenced in the table, and Sections 6.8.5.1, 6.8.5.2, and 6.9 of *UZ Flow Models and Submodels* (SNL 2007). In particular, pore-water chloride concentration observations support the basis and justification for using the generalized likelihood uncertainty estimation (GLUE) methodology to re-weight the infiltration model results so the unsaturated zone flow model is calibrated to match field observations. Thus, qualitative and quantitative entries in the table are inherently consistent with the GLUE-derived weighting factors.

## 2. COMMITMENTS TO NRC

None.

## 3. DESCRIPTION OF PROPOSED LA CHANGE

None.

## 4. REFERENCES

SNL (Sandia National Laboratories) 2007. *UZ Flow Models and Submodels.* MDL-NBS-HS-000006 REV 03 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080108.0003; DOC.20080114.0001; LLR.20080414.0007; LLR.20080414.0033; LLR.20080522.0086; DOC.20090330.0026[a].

NOTE: [a]Provided as an enclosure to letter from Williams to Sulima, dtd 06/01/09, "Yucca Mountain – Request for Additional Information – Safety Evaluation Report, Volume 3 – Postclosure Chapter 2.2.1.3.6 – Flow Paths in the Unsaturated Zone, Set 1 – (Department of Energy's Safety Analysis Report Sections 2.3.2 and 2.3.3)."

## 5. LIST OF ATTACHMENTS

Attachment 1: Relevant Portion of Table 2.1-1 Expanded.

# ATTACHMENT 1 – RELEVANT PORTION OF TABLE 2.1-1 EXPANDED

Relevant Portion of Table 2.1-1 Expanded. Summary of the Capability of the ITWI Features/Components Supporting Each of the Three Barriers

| Barrier, Feature, and Relevant ITBC FEPs | Barrier Function and Qualitative Description of Barrier Functions<br>[*] = *potential for decreased capability* | Safety Classification and Quantitative Evaluation of Barrier Capability |
|---|---|---|
| **UNB**<br>**Unsaturated Zone above the Repository** | **Prevents or substantially reduces the rate of movement of water** | **ITWI** |
| **Percolation Flux**<br>*(included FEPs are described in SAR Table 2.3.2-1)*<br>2.2.07.02.0A – Unsaturated groundwater flow in the geosphere<br>2.2.07.08.0A – Fracture flow in the UZ<br>2.2.03.01.0A – Stratigraphy<br>1.3.01.00.0A – Climate change<br>1.4.01.01.0A – Climate modification increases recharge<br>1.2.02.01.0A – Fractures<br>2.2.03.02.0A – Rock properties of host rock and other units | **Attenuated percolation prevents or substantially reduces the rate of movement of water**<br>(SAR Sections 2.1.2.1.2, pp. 2.1-19 to -20; and 2.1.2.1.6.2, p. 2.1-28) (SAR Section 2.3.2.2, pp. 2.3.2-6 to -16)<br>1. Low percolation rates (arid climate with low infiltration) (SAR Sections 2.1.2.1.1, p. 2.1-17; and 2.1.2.1.6.2, p. 2.1-28)<br>2. Large depth to repository (greater than 200 m everywhere) (SAR Section 2.1.1.1 p. 2.1-5)<br>3. Damping of episodic pulses of precipitation and infiltration (SAR Sections 2.1.1.1, p. 2.1-6; and 2.1.2.1.2, p. 2.1-19 to -20) | **Attenuated Percolation** (SAR Sections 2.1.1.1, p. 2.1-6; and 2.1.2.1.6.2, p. 2.1-28)<br>The average percolation flux flowing to the repository is within a few percent of the net infiltration rate (SAR Section 2.1.2.1.6.2, p. 2.1-28).<br>The stratigraphic sequence of both welded and nonwelded tuffs affects the transient propagation of infiltration pulses and tends to spatially redistribute the percolation rates (SAR Section 2.1.2.1, p. 2.1-15). The dominance of matrix flow in the PTn, and the relatively large storage capacity of the matrix within the PTn, resulting from its high porosity and typically low saturation, give the PTn significant capacity to attenuate infiltration pulses (SAR Section 2.1.2.1.2, p. 2.1-19).<br>Damping of episodic flow is shown to have the potential to reduce seepage rates by anywhere from 5 to ~2,200 kg/yr/WP depending on the episodic period, for percolation fluxes ranging from 5 to 100 mm/yr (see response to RAI 3.2.2.1.1-002, Section 1.4 and Table 1-2).<br>The chemical compositions of pore water in different lithologic units provide an understanding regarding the hydrologic relations among the major hydrogeologic units. Chloride concentrations in pore water within the TCw unit support percolation estimates on the order of 7 mm/yr. Dating of fracture coatings in the TSw unit indicate a seepage flux of 2 to 20 mm/yr. $^{14}C$ data indicate average transport times through the TSw on the order of 5,000 to 10,000 years. Analysis of perched water below the repository horizon yields $^{14}C$ dates ranging from 3,300 to 11,000 years. The fact that bomb-pulse $^{36}Cl$ signals were not detected in perched water and modern $^{14}C$ is absent in perched water suggests that only a small component of younger water results from fast flow paths. (SAR Section 2.3.2.3.4, p. 2.3.2-30) |

NOTE: FEPs = features, events, or processes; ITBC = important to barrier capability; ITWI = important to waste isolation; UNB = Upper Natural Barrier; UZ = Unsaturated Zone; PTn = Upper Paintbrush non-welded vitric; TCw = Tiva Canyon welded hydrogeological unit; TSw = Topopah Spring welded hydrogeologic (unit).

**RAI Volume 3, Chapter 2.2.1.1, First Set, Number 5, Supplemental Question:**

> In the response, Section 1.5, pp. 24-25, and Section 1.6, p. 26, clarify how the statement on p. 26 "colloidal processes are not significant relative to dissolved radionuclide transport" addresses the request to describe "why colloidal processes do not affect engineered system barrier capability in nominal and igneous intrusive scenarios." Clarify how the description of colloidal processes in Section 1.5 (of the response) is consistent with DOE's treatment of barrier capability of engineered barrier components in the SAR (e.g., p. 2.1-32, wherein "absence or slow rate of potentially deleterious processes generally results in preventing or substantially reducing the release of radionuclides from the waste" is used to describe barrier capability). Specifically, clarify why the large reduction in transport of colloids out of the EBS (i.e., reduction in release of radionuclides) is not considered a barrier capability.

## 1. SUPPLEMENTAL RESPONSE

RAI 3.2.2.1.1-005 requested additional information regarding the barrier capability of waste form and waste package internal components, i.e., how waste form degradation rates, waste package breach area, solubility limits, sorption to stationary corrosion products, and colloidal processes affect the barrier capability of the waste form and waste package internals feature of the Engineered Barrier System (EBS). Section 1.5 of the response to RAI 3.2.2.1.1-005 describes why colloidal processes, including uncertainties, are classified as not important to barrier capability (ITBC), and Section 1.6 summarizes the response.

The statement "colloidal processes are not significant relative to dissolved radionuclide transport" is clarified by defining the six "colloidal processes" that are meant in this context. Section 1.5 of the original response lists six "colloidal process" features, events, or processes (FEPs) specifically related to colloid *transport* that are included in the total system performance assessment but that are not considered to be ITBC:

- 2.1.09.16.0A (Formation of Pseudocolloids (natural) in EBS)
- 2.1.09.17.0A (Formation of Pseudocolloids (corrosion product) in EBS)
- 2.1.09.19.0B (Advection of Colloids in EBS)
- 2.1.09.23.0A (Stability of Colloids in EBS)
- 2.1.09.24.0A (Diffusion of Colloids in EBS)
- 2.1.09.25.0A (Formation of Colloids (waste-form) by Co-Precipitation in EBS).

The basis for this classification is the colloidal processes' relatively low significance compared to dissolved radionuclide transport processes. As stated in Table A-2 of *Postclosure Nuclear Safety Design Bases* (SNL 2008a), "Although considered and accounted for in the postclosure analyzed basis, the contribution of colloid transport processes is less significant than that associated with the transport of dissolved radionuclides and parameter characteristics associated with the transport of colloids are not considered ITBC." The technical basis for this statement is provided in Section 1.5 of the response to RAI 3.2.2.1.1-005, which references SAR Figures 2.1-20 and 2.1-23. These figures demonstrate that releases of plutonium irreversibly

sorbed to colloids are relatively low and do not exceed 30% of the total plutonium activity released from the EBS in the combined nominal/early failure modeling case and the seismic ground motion modeling case. The figures also demonstrate that releases of all radionuclides irreversibly sorbed to colloids are always much less than 1% of the total activity released from the EBS in these two modeling cases. In the igneous intrusion modeling case, the release of plutonium irreversibly sorbed to colloids is relatively low with only about 1% of the release of dissolved plutonium from the EBS (compare Figures K6.3.2-1(b) and K6.3.2-4(b) of SNL 2008b). Thus, transport of dissolved radionuclides is more important to EBS performance than is transport of colloid-associated radionuclides.

**Colloid Instability Limits Colloid-Facilitated Radionuclide Transport.** There are several reasons why colloidal transport processes are not as significant as dissolved radionuclide transport processes in the nominal and igneous intrusion modeling cases. One is that colloid-facilitated transport in the EBS is limited by the lack of colloid stability, as discussed in the response to RAI 3.2.2.1.3.4-2-003.[1] Colloids with irreversibly attached radionuclides that become unstable settle out and become immobile, contributing to the large reduction in colloid-facilitated transport of radionuclides out of the EBS. Colloid stability is controlled by pH and ionic strength in both the waste form domain and in the corrosion products domain. These effects on colloid stability are incorporated into the analysis through inclusion of ITBC FEPs 2.1.09.01.0B (Chemical Characteristics of Water in Waste Package) and 2.1.09.02.0A (Chemical Interaction with Corrosion Products). These ITBC FEPs account for the barrier capability of the EBS with respect to colloidal transport processes, as described in *Postclosure Nuclear Safety Design Bases* (SNL 2008a, p. 6-77).

**Mobile Dissolved Radionuclide Mass Greater than Mobile Colloid-Associated Radionuclide Mass.** Another reason that colloid transport processes are not as significant as dissolved radionuclide transport processes is the slow diffusion rate of colloids compared to dissolved species, as discussed in the response to RAI 3.2.2.1.3.4-2-003. The slow rate of diffusion of colloids could be considered an example of a slow rate of a deleterious process that substantially reduces the release of radionuclides from the waste. However, as demonstrated in the response to RAI 3.2.2.1.3.4-2-007, it is frequently the case that almost all mobile radionuclide mass (i.e., either dissolved or associated with mobile colloids) is dissolved, rather than associated with mobile colloids (e.g., see Figures 1.1-13 through 1.1-15; Figures 1.1-17 through 1.1-20; Figures 1.1-26 and 1.1-27; Figures 1.1-33 through 1.1-35; Figures 1.2-13 through 1.2-15; Figures 1.2-17 through 1.2-19; Figures 1.2-21 through 1.2-24; Figures 1.2-26 through 1.2-29; Figures 1.2-34 through 1.2-36; and Figures 1.2-41 through 1.2-43), so the slow rate of colloid diffusion affects only a very small mass of mobile radionuclides. This is true of the other

[1] The response to RAI 3.2.2.1.3.4-2-003 addresses colloid-facilitated transport for the seismic ground motion and igneous intrusion modeling cases; however, the conclusions drawn in that response are also applicable to the nominal modeling case because the nominal modeling case is embedded in the seismic modeling case (SNL 2008b, Section 8.2). Some of the processes that are important to modeling colloid-facilitated transport and to the conclusion of the response to RAI 3.2.2.1.3.4-2-003 (e.g., waste package failure primarily by stress corrosion cracking resulting in high ionic strengths in the waste package and diffusion-dominated radionuclide transport for long periods of time (SNL 2008b, Sections 8.2.1 and 8.2.4.1)) are part of both the nominal and the seismic ground motion modeling cases.

non-ITBC colloid transport FEPs in the bulleted list provided earlier: these colloid transport processes affect a very small mass of mobile radionuclides, compared to the transport processes for dissolved radionuclides. In addition, the colloid transport FEPs do not involve radionuclides such as $^{99}$Tc, $^{129}$I, $^{36}$Cl, and $^{14}$C, which are significant contributors to mean annual dose, because these radionuclides do not attach to colloids.

Therefore, FEPs related to colloid transport in the EBS (2.1.09.16.0A, 2.1.09.17.0A, 2.1.09.19.0B, 2.1.09.23.0A, 2.1.09.24.0A, and 2.1.09.25.0A) are not considered to be ITBC because they are not a significant contributor to the barrier capability relative to dissolved radionuclide transport processes. However, FEPs 2.1.09.01.0B and 2.1.09.02.0A related to chemical interactions in the waste package affect colloid stability, thereby contributing to the large reduction in colloid-facilitated transport of radionuclides out of the EBS, and are ITBC.

## 2. COMMITMENTS TO NRC

None.

## 3. DESCRIPTION OF PROPOSED LA CHANGE

None.

## 4. REFERENCES

SNL (Sandia National Laboratories) 2008a. *Postclosure Nuclear Safety Design Bases.* ANL-WIS-MD-000024 REV 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080226.0002; DOC.20080314.0004; LLR.20080507.0018; DOC.20080610.0007.

SNL 2008b. *Total System Performance Assessment Model/Analysis for the License Application.* MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001; LLR.20080414.0037; LLR.20080507.0002; LLR.20080522.0113; DOC.20080724.0005; DOC.20090106.0001[a].

NOTE: [a]Provided as an enclosure to letter from Williams to Sulima dtd 02/17/2009. "Yucca Mountain – Request for Additional Information Re: License Application (Safety Analysis Report Section 2.1), Safety Evaluation Report Volume 3 – Postclosure Chapters 2.2.1.1 and 2.2.1.3.7 – Submittal of Department of Energy Reference Citations."