

**2.2.1.2.1 Scenario Analysis – Set 2  
RAIs**

**REQUEST FOR ADDITIONAL INFORMATION (RAI)  
Volume 3—Postclosure Chapter 2.2.1.2.1 (Scenario Analysis)  
2<sup>nd</sup> Set (RAIs 1 through 19)**

**(DEPARTMENT OF ENERGY’S SAFETY ANALYSIS REPORT SECTION 2.2, TABLE 2.2-5)**

**Exclusion of FEP 1.2.04.07.0B Ash Redistribution in Groundwater**

The FEP 1.2.04.07.0B Ash Redistribution in Groundwater is excluded from the performance assessment model based on low consequence (Safety Analysis Report Section 2.2, Table 2.2-5; Sandia National Laboratories, 2008a). The staff considers that the technical bases of the screening argument are not sufficient to support exclusion of the FEP from the performance assessment model.

**RAI #1:** For the fraction of contaminated tephra that is deposited or redistributed fluvially in Fortymile Wash in the volcanic eruption modeling case, evaluate the potential transport of radionuclides that could be leached into groundwater and transported to the compliance location from Fortymile Wash. Compare the potential contributions to dose from this short groundwater transport pathway with the reported contributions to dose for the volcanic eruption modeling case (e.g., SAR Figure 2.4-32). This information is needed to verify compliance with 10 CFR 63.114 (e).

**Basis:** Depending on timing of the eruptive event in the volcanic eruption modeling case, the released inventory leads to dose exposures from short-lived radionuclides (e.g., Cs-137, Sr-90, Am-241, Pu-240, and Pu-239) that are not transported to the accessible environment in significant quantities in any of the other modeling cases in the performance assessment model. The volcanic eruption modeling case calculated the dose consequences of an eruptive event by using a model for the airborne transport of tephra and subsequent redistribution of the particles in the accessible environment, leading to exposure of the Reasonably Maximally Exposed Individual by inhalation, external radiation, and ingestion of radionuclides from contaminated particles (Sandia National Laboratories, 2008). DOE has not assessed the relative importance of a dose contribution from radionuclides leached into near-surface groundwater from the contaminated tephra in the vicinity of Fortymile Wash, where the transport pathways to the accessible environment may be short compared to transport from the repository.

**References**

Sandia National Laboratories. “Features, Events, and Processes for the Total System Performance Assessment: Analyses.” ANL–WIS–MD–000027. Rev. 00. Las Vegas, Nevada: Sandia National Laboratories. 2008.

**Exclusion of FEPs 2.1.03.02.0B Stress Corrosion Cracking (SCC) of Drip Shields, and 2.1.03.10.0B Advection of Liquids and Solids through Cracks in the Drip Shield**

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

The FEPs 2.1.03.02.0B Stress Corrosion Cracking (SCC) of Drip Shields and 2.1.03.10.0B Advection of Liquids and Solids through Cracks in the Drip Shield are excluded from the performance assessment model based on low consequence (Safety Analysis Report Section 2.2, Table 2.2-5; Sandia National Laboratories, 2008). The technical basis for exclusion of FEP 2.1.03.02.0B depends on the exclusion of FEP 2.1.03.10.0B Advection of Liquids and Solids through Cracks in the Drip Shield. The staff considers that the technical bases of the screening arguments are not sufficient to support exclusion of these two FEPs from the performance assessment model.

**RAI #2:** Analyze water flow rates through open cracks (i.e., initially open cracks, cracks that open at a later time, or cracks that are not effectively plugged), or alternatively provide the technical bases for disregarding non-plugged cracks on the drip shield. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: Water flow rates of the order of 4 mL/yr through cracks were estimated in the screening argument for FEP 2.1.03.10.0B Advection of Liquids and Solids through Cracks in the Drip Shield (Sandia National Laboratories, 2008). These flow rates were estimated using the hydraulic conductivity of plugged cracks with mineral precipitates or corrosion products. Based on these low flow rates, DOE concluded that the consequences of advective flow through cracks would be negligible. However, there was no consideration in the screening argument of initially open cracks, cracks that open at a later time, or cracks that are not effectively plugged. Information is needed to assess the extent of flow rates through a broader range of crack conditions.

#### References

Sandia National Laboratories. "Features, Events, and Processes for the Total System Performance Assessment: Analyses." ANL–WIS–MD–000027. Rev. 00. Las Vegas, Nevada: Sandia National Laboratories. 2008.

#### Exclusion of FEP 2.1.03.04.0B Hydride Cracking of Drip Shields

FEP 2.1.03.04.0B, Hydride Cracking of Drip Shields, is excluded from the performance assessment model based on low probability (Safety Analysis Report Section 2.2, Table 2.2-5; Sandia National Laboratories, 2008). The staff considers that the technical bases of the screening argument are not sufficient to support exclusion of the FEP from the performance assessment model.

**RAI # 3:** Provide technical basis for constraining the range of the critical hydrogen concentration for fast fracture of Ti Grade 29 between 400 and 600 ppm given that empirical data suggest different values. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: The FEP screening analysis estimated that the critical hydrogen concentration leading to fast fracture of Titanium Grade 29 is between 400 and 600 ppm based in part on the results of Hardie and Ouyang (1999) for Titanium Grade 5. Figure 10 of the paper (Hardie and Ouyang,

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

1999) showed that fast fracture occurred when the hydrogen concentration in Titanium Grade 5 was greater than 200 ppm (Hardie and Ouyang, 1999). Hardie and Ouyang (1999), however, did not unequivocally establish 200 ppm as the critical hydrogen concentration of Titanium Grade 5. For example, Figure 12 of the paper (Hardie and Ouyang, 1999) showed crack growth in Titanium Grade 5 at hydrogen levels as low as 30 ppm, but at a high threshold stress intensity factor value of about  $36 \text{ MPa(m)}^{1/2}$ . It is unclear whether the FEP screening analysis considered a full range of values of the critical hydrogen concentration that could cause cracks on the drip shield. While lower values are associated with a higher probability for delayed hydride cracking, higher values may be associated with more extensive brittle rupture on a drip shield, potentially allowing for advective water flow through cracks.

**RAI #4:** Provide technical basis to justify the assumed beneficial role of Pd and Ru in increasing the critical hydrogen concentration values. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: The FEP screening analysis indicated that Pd and Ru have a beneficial role by increasing the critical hydrogen concentration value. For Ru the analysis indicated that it can increase the critical hydrogen concentration value by a factor of two to three. However, according to Schutz (2003), the effect of Pd or Ru alloying to Ti on titanium alloy hydrogen absorption resistance is not definitive in all cases. Depending on the environmental conditions, titanium resistance to hydrogen absorption can either be unaffected or enhanced by Pd or Ru alloying, potentially negating the beneficial effect of the increase in the critical hydrogen concentration value.

**RAI #5:** Provide technical basis for not considering potential enhancement of hydrogen absorption in Ti Grade 7 and Grade 29 at cracks from stress corrosion cracking and delayed-hydride cracking. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: In the FEP screening analysis the hydrogen absorption efficiency value was estimated assuming that hydrogen generated from aqueous corrosion process on the metal surface is absorbed into the metal by passing through the passive oxide film. On the basis of that efficiency, it was concluded that only a small fraction of hydrogen generated would be absorbed by the metal because the passive film works as a hydrogen diffusion barrier. However, the analysis did not consider the potentially enhanced hydrogen absorption efficiency at stress corrosion cracks and delayed-hydride cracks where the metal loses its passivity.

**RAI #6:** Provide rationale of assuming hydrogen absorption efficiency of Ti Grade 29 based on  $\alpha$ -phase titanium alloys given that Ti Grade 29 is  $(\alpha+\beta)$ -phase titanium alloy. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: In the hydrogen-induced cracking model used to evaluate the quantity of hydrogen absorbed in the titanium base alloys, Ti Grades 7 and 29, a fractional efficiency for hydrogen absorption of 0.015 for Ti Grade 29 was assumed, based on the referenced literature data on  $\alpha$ -phase titanium alloys. However, microstructure is known to affect the hydrogen absorption

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

efficiency. Titanium Grade 29 is ( $\alpha+\beta$ )-phase material containing Al, V, and Ru alloying constituents, which is different from the  $\alpha$ -phase titanium alloys relied on to estimate the hydrogen absorption efficiency. The information is needed to understand the applicability of hydrogen absorption efficiency of Ti Grade 29 assumed based on  $\alpha$ -phase titanium alloys.

**RAI #7:** Provide technical basis for not considering potential hydrogen redistribution in drip shield induced by stress due to seismic events or rockfall and the hydrogen redistribution consequences on delayed-hydride cracking or fast fracture. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: Waisman et al. (1977) investigated hydrogen distribution in titanium alloys in the presence of a stress gradient. They found that hydrogen moves up the stress gradient toward the region under tension. Moody and Gerberich (1981) showed that applied stress could contribute to hydride formation as a delayed-hydride cracking mechanism. Hydrogen will diffuse to, and accumulate in, regions of tensile stress due to possible seismic events and rockfall. The solubility limit of hydrogen in titanium can be exceeded in these stressed regions and hydrides could precipitate.

**RAI #8:** Provide technical basis that Ti Grade 28 as weld filler metal will avoid the abrupt aluminum gradient that can lead to hydrogen redistribution and an enhanced hydride formation. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: Ti Grade 28 weld filler would be used for Ti Grade 7 to Ti Grade 29 welds. Industry experience in titanium application shows that hydrides formed at Ti Grade 5/Grade 2 welds commonly result in failure at the welded region due to hydrogen activity difference in Ti Grades 5 and 2 (Waisman et al., 1977; Kennedy et al., 1993). Similarly the hydrogen activity difference in Ti Grade 29/Grade 28/Grade 7 welds may induce hydrogen uphill diffusion from Ti Grade 29 to Grade 28, and to Grade 7, which may result in hydrogen accumulation at the welds between Grade 29 to Grade 28 or Grade 28 to Grade 7. The document Sandia National Laboratories (2008) states that this potential issue is not relevant in the case of the drip shield for the following reason: Ti Grade 28 will remove the abrupt aluminum gradient that can lead to hydride redistribution and enhanced hydride formation. However, no calculation or laboratory results were provided showing that by adding the Titanium Grade 28, the sharp aluminum concentration gradient is removed.

#### References

Hardie, D. and S. Ouyang. "Effect of Hydrogen and Strain Rate Upon the Ductility of Mill-Annealed Ti6Al4V." *Corrosion Science*. Vol. 41. pp. 155-177. 1999.

Kennedy, J.R., P.N. Adler, and H. Margolin. "Effect of Activity Differences on Hydrogen Migration in Dissimilar Titanium Alloy Welds." *Metallurgical Transactions A*. Vol. 24A. pp. 2763–2670. 1993.

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

Moody, N.R. and W.W. Gerberich. "Solubility Considerations for Threshold Stress Intensities Controlled by Hydride Fracture." *Scripta Metallurgica*. Vol. 15. pp. 709–11. 1981.

Schutz, R.W. "Platinum Group Metal Additions to Titanium: A Highly Effective Strategy for Enhancing Corrosion Resistance." *Corrosion*. Vol. 59. pp. 1043–1057. 2003.

Sandia National Laboratories. 2008. "Features, Events, and Processes for the Total System Performance Assessment: Analyses." ANL–WIS–MD–000027 Rev. 00. Las Vegas, Nevada: Sandia National Laboratories.

Waisman, J.L., R. Toosky, and G. Sines. "Uphill Diffusion and Progressive Embrittlement: Hydrogen in Titanium." *Metallurgical Transactions A*. Vol. 8A. pp. 1249–56. 1977.

#### **Exclusion of FEP 2.1.06.06.0B Oxygen Embrittlement of Drip Shields**

The FEP 2.1.06.06.0B Oxygen Embrittlement of Drip Shield is excluded from the performance assessment model based on low probability (Safety Analysis Report Section 2.2, Table 2.2-5; Sandia National Laboratories, 2008a). The staff considers that the technical bases of the screening argument are not sufficient to support exclusion of the FEP from the performance assessment model.

**RAI #9:** Provide technical bases for exclusion of Oxygen Embrittlement of Drip Shields accounting for (i) the different alloys to construct the drip shields, titanium grades 7 and 29, and (ii) diffusion of oxygen through grain and phase boundaries. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

**Basis:** DOE concluded the Oxygen Embrittlement of Drip Shields is unlikely based on the low values of lattice diffusion coefficients of oxygen in titanium (Sandia National Laboratories, 2008a). The screening argument relied on oxygen diffusion data at 300 °C by Rogers et al. (1988). These authors used single crystal pure titanium to estimate the oxygen lattice diffusion coefficient in alpha phase titanium. The DOE then used oxygen lattice diffusion data to calculate oxygen penetration depth for titanium grade 7 and concluded that any penetration depth would be minimal in 10,000 years. The screening argument did not contain an analysis of titanium grade 29 as structural component of the drip shield. Also, the DOE did not consider that oxygen diffusion in any real crystalline metal or alloys are dominated by grain boundary diffusion and not by lattice diffusion (Shewmon, 1963). Titanium grade 29 is a two phase alloy consisting of alpha and beta phases, as well as alpha and beta phase boundaries (Schutz, 2003). The oxygen diffusion rates in the two-phase titanium alloy and phase boundaries are potentially higher than lattice diffusion rate of single phase alpha titanium.

#### **References**

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

Sandia National Laboratories. "Features, Events, and Processes for the Total System Performance Assessment: Analyses." ANL–WIS–MD–000027. Rev. 00. Las Vegas, Nevada: Sandia National Laboratories. 2008a.

Rogers, Jr. J.W., K.L. Erickson, D.N. Belton, R.W. Springer, T.N. Taylor and J.G. Beery. "Low Temperature Diffusion of Oxygen in Titanium and Titanium Oxide Films." *Applied Surface Science*, Vol.35, pp. 137-152. 1988.

Shewmon, P.G. in Diffusion in Solid. "High Diffusivity Path." McGraw-Hill Book Company. New York. pp. 164-187. 1963.

Schutz, R.W. "Platinum Group Metal Additions to Titanium: A Highly Effective Strategy for Enhancing Corrosion Resistance." *Corrosion*. Vol. 59. pp. 1043–1057. 2003.

#### **Exclusion of FEP 2.1.09.03.0B Volume Increase of Corrosion Products Impacts Waste Package**

The FEP 2.1.09.03.0B Volume Increase of Corrosion Products Impacts Waste Package is excluded from the performance assessment model based on low consequence (Safety Analysis Report Section 2.2, Table 2.2-5; Sandia National Laboratories, 2008). The staff considers that the technical bases of the screening argument are not sufficient to support exclusion of the FEP from the performance assessment model.

**RAI #10:** Evaluate the effect of volume expansion of the corrosion products of Type 316 Stainless Steel and Alloy 22 and potential sources of stress on Alloy 22 outer barrier under scenarios where the Type 316 Stainless Steel is not fully corroded or cracked. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: In the screening argument for FEP 2.1.09.03.0B Volume Increase of Corrosion Products Impacts Waste Package, DOE concluded the effect of volume increase by general corrosion of Type 316 Stainless Steel and Alloy 22 on Alloy 22 would be negligible because stainless steel is prone to stress corrosion cracking. Cracking of the stainless steel would thus relieve any stress buildup on Alloy 22. The screening argument did not evaluate the feasibility for the formation of solution compositions (groundwater chemistry/in-package chemistry and temperature) that could support stress corrosion cracking. In general, the screening argument did not evaluate processes where the stainless steel may be partially corroded or cracked. Complete corrosion or cracking of stainless steel may relieve stresses on Alloy 22. However, if corrosion of stainless steel is partial and corrosion products are supported by a non-corroded substrate of stainless steel, stresses could develop due to the volume expansion of the corrosion products that could affect Alloy 22. These stresses could cause stress corrosion cracks on Alloy 22 or open existing cracks. A more complete technical basis is needed addressing a range of corrosion mechanisms that could affect Type 316 Stainless Steel.

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

Potential galvanic corrosion between dissimilar metals of stainless steel and Alloy 22 may accelerate the accumulation of corrosion products from fast galvanic corrosion of stainless steel. The corrosion of stainless steel could be partial if the corrosion products prevent further electric contact between the two metals during the corrosion. If the corrosion products are supported by a non-corroded substrate of stainless, stresses could develop due to the volume expansion of the corrosion products that could affect Alloy 22.

**RAI #11:** Evaluate the possibility of Alloy 22 crevice corrosion from the inside of the waste package due to the formation of tight crevices between Alloy 22 and corrosion products of the inner container. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: The screening argument did not evaluate the possibility of inside-out crevice corrosion of Alloy 22. This may increase the size of the compromised waste package area or additional susceptibility to mechanical damage.

#### **References:**

Sandia National Laboratories. "Features, Events, and Processes for the Total System Performance Assessment: Analyses." ANL-WIS-MD-000027. Rev. 00. Las Vegas, Nevada: Sandia National Laboratories. 2008.

#### **Exclusion of FEP 2.1.09.28.0A Localized Corrosion on Waste Package Outer Surface Due to Deliquescence**

The FEP 2.1.09.28.0A Localized Corrosion on Waste Package Outer Surface Due to Deliquescence is excluded from the performance assessment model based on low consequence (Safety Analysis Report Section 2.2, Table 2.2-5; Sandia National Laboratories, 2008). The staff considers that the technical bases of the screening argument are not sufficient to support exclusion of the FEP from the performance assessment model.

#### Summary of Screening Argument

Salts in the dust may accumulate on the waste package surface, which may sorb moisture from the drift atmosphere and undergo a deliquescence process to become brine. This brine may result in localized corrosion and cause penetration of the waste package outer barrier.

The analysis of the possibility of the penetration of the Alloy 22 waste package outer barrier by localized corrosion induced by dust deliquescence brines was based on the following five questions (Sandia National Laboratories, 2008, pages 6-705 to 6-710):

1. Can multiple-salt deliquescent brines form at elevated temperature?
2. If deliquescent brines form at elevated temperature, will they persist?
3. If deliquescent brines persist, will they be corrosive?
4. If deliquescent brines are potentially corrosive, will they initiate localized corrosion?
5. Once initiated, will localized corrosion penetrate the waste package?

The answers to the above five questions (Sandia National Laboratories, 2008) are (1) yes, (2) sometimes, (3) not expected, (4) no, and (5) no, respectively. Because all 5 steps must happen

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

to cause the penetration of the outer container, localized corrosion of the Alloy 22 waste package outer barrier was excluded.

**RAI #12:** Provide justification to resolve the apparent discrepancy between the localized corrosion model and the FEP analysis for temperatures between 100 and 120 °C. The nitrate-to-chloride ratio in this temperature range may be as low as 0.125 (Sandia National Laboratories, 2007a, Fig 6-7[a]) and localized corrosion may initiate according to the localized corrosion model if the nitrate-to-chloride ratio is less than 0.5 (Sandia National Laboratories, 2007b, Section 6.4.4.6). This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

**Basis:** In the analysis for Questions 3 and 4, the brine was considered to be not corrosive to initiate localized corrosion of Alloy 22. One of the DOE arguments was that the ratio of nitrate-to-chloride is expected to be high (Sandia National Laboratories, 2008, pages 6-707 to 6-708; Sandia National Laboratories, 2007a, Sections 7-1.3 and 6.4[a]) in the potential dust deliquescence brine and localized corrosion would not be possible in those brines.

For temperatures from 100 to 120 °C, deliquescent brines with nitrate-to-chloride ratio as low as 0.125 were predicted to be stable under the potential Yucca Mount drift condition (Sandia National Laboratories, 2007a, Fig 6-7[a]). According to the localized corrosion model, localized corrosion may be initiated at the nitrate-to-chloride ratio less than 0.5 (Sandia National Laboratories, 2007b, Section 6.4.4.6) in this temperature range. The “No” answer to Questions 3 and 4 appears inconsistent with the localized corrosion model for temperatures between 100 and 120 °C.

**RAI #13:** Resolve the apparent discrepancy between the repassivation potential and corrosion potential measurements (Felker et al., 2006) and the localized corrosion observed in the drip test conducted by Lee and Solomon (2006, page 117). Available data show that the repassivation potential is higher than the corrosion potential for brines with nitrate-to-chloride ratio greater than 10, and thus, localized corrosion would be impossible according to the repassivation potential model. However, in drip tests simulating the potential drift condition and a nitrate-to-chloride ratio higher than 10, localized corrosion was observed, calling into question the validity of the repassivation potential model and the assumption that localized corrosion is unlikely in solutions with high nitrate concentrations with respect to chloride. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

**Basis:** At 140 °C, the experiment in a drip test at ambient pressure using concentrated solutions containing nitrate indicated that localized corrosion of Alloy 22 initiated (Lee and Solomon, 2006, page 117). The drip test simulated a potential Yucca Mountain drift condition under a high nitrate-to-chloride ratio (>10). This observation appears to contradict the repassivation potential concept for high nitrate-to-chloride brines as threshold criterion for the initiation of localized corrosion. The measurements indicated establishment of a repassivation potential above  $0.5 V_{Ag/AgCl}$  (Felker, et al., 2006, Figure 9), while the corrosion potential was less than  $0.1 V_{Ag/AgCl}$  (Felker, et al., 2006, Figure 7) for brines with nitrate-to-chloride ratio greater than 10 and pH values down to 3. The Lee and Solomon (2006) and the Felker, et al. (2006) tests were aimed

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

at simulating conditions under dripping, instead of deliquescent solutions. However, the repassivation potential model used by the DOE to identify conditions where localized corrosion is not feasible does not differentiate dripping from non-dripping conditions. Therefore, it is also necessary to address the question of whether the repassivation potential or the nitrate-to-chloride ratio is reliable criteria to address the likelihood of localized corrosion in elevated temperature deliquescent solutions.

Localized crevice corrosion was also observed for specimens exposed to liquid and vapor phases in closed autoclaves at 160 °C and 220 °C at nitrate-to-chloride ratios up to 7.4 and nitrate concentration of 15.1 m (Dixit, et al., 2006). Although the closed autoclave test may not simulate the potential drift condition and the nitrate-to-chloride ratio would be higher than 7.4 in an open system at 160 °C (Sandia National Laboratories, 2007a, Section 6.4.2.1.3[a]), a nitrate-to-chloride ratio of 7.4 is within the range predicted for the nitrate and chloride bins at temperatures between 115 and 125 °C at ambient pressure (Sandia National Laboratories, 2007a, Section 6.4.2.1.3[a]). The observation by Dixit et al. could suggest the possibility of localized corrosion at temperatures between 115 and 125 °C under the potential open repository conditions

Preliminary experimental results for the corrosion of brine-coated Alloy 22 specimens exposed to an open system at 180 °C have been reported (Sandia National Laboratories, 2007a, Section 6.4.2.2[a]). No localized corrosion was observed in these open-system exposure tests. However, these tests were short-term (50 days) and conducted only at a single temperature (180 °C). Potential dependencies of localized corrosion on salt-loading, orientation of the specimens, time effects, have not been addressed.

**RAI #14:** Justify the assumptions that localized corrosion is always prone to stifle, and that stifling will prevail over long periods. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: In the analysis for Question 5, stifling of localized corrosion was modeled in the form of a Power Law to compute the corrosion rate as a function of time, derived from short-term and limited data that showed stifling (Sandia National Laboratories, 2008, page 6-708 to 6-709; Sandia National Laboratories, 2007a, Sections 7.1.5 and 6.5[a]). The Power Law thus derived was extrapolated to long terms to estimate the time it would take for the corrosion front to penetrate the waste package thickness and it was concluded that full penetration was impossible. Implicit in these computations are the assumptions that (i) localized corrosion always stifles, and (ii) the mechanism for stifling prevails over long-terms. The limited crevice corrosion data presented by DOE (Sandia National Laboratories, 2007a, Figure 6.5-2) did show a decreasing trend in the first 160 hours. But the corrosion currents at the end of the 160 hour tests were still high (about  $10^{-4}$  A, surface area is not known). It is not clear if the crevice corrosion current will continue to decrease in a long-term experiment. Also, it is not clear if stifling of localized corrosion will always occur or if some solutions exist for which stifling does not happen.

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

**RAI #15:** The FEP screening argument needs to include a technical basis of the effect of temperatures above 140 °C on the likelihood of localized corrosion. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: The maximum temperature considered in the reports supporting the screening rationale for the FEP is 160 °C (Sandia National Laboratories 2007a, 2007b). Only limited experimental data for the repassivation and corrosion potentials are available at temperatures between 140 and 150 °C (Felker, et al., 2006, Table 6) and no experimental data for the repassivation potential are available above 150 °C. The limited number of repassivation data between 140 and 150 °C does not allow for direct extrapolation to higher temperatures. In principle, it may be possible for nitrate to be a less effective inhibitor as the temperature increases. The FEP screening rationale needs to be complemented with an analysis for temperatures beyond 140 °C that could be experienced by the waste package.

#### References

Dixit, S., S. Roberts, K. Evans, T. Wolery, and S. Carroll. 2006. "General Corrosion and Passive Film Stability." UCRL-TR-217393. Livermore, California: Lawrence Livermore National Laboratory.

Felker, S., P.D. Hailey, T. Lian, K.J. Staggs, and G. Gdowski. 2006. "Alloy 22 Localized Corrosion Susceptibility in Aqueous Solutions of Chloride and Nitrate Salts of Sodium and Potassium at 110-150°C." UCRL-TR-218195. Livermore, California: Lawrence Livermore National Laboratory.

Lee, S.G. and A.A. Solomon. 2006. "Localized Corrosion of Alloy C22 Nuclear Waste Canister Material Under Limiting Conditions." Materials Science and Engineering. Vol. A 434. pp.114-123.

Sandia National Laboratories. 2007a. "Analysis of Dust Deliquescence for FEP Screening," ANL-EBS-MD-000074 REV 01 AD 01. Las Vegas, Nevada: Sandia National Laboratories.

Sandia National Laboratories. 2007b. "General Corrosion and Localized Corrosion of Waste Package Outer Barrier," ANL-EBS-MD-000003. Rev 03. Las Vegas, Nevada: Sandia National Laboratories.

Sandia National Laboratories, 2008. "Features, Events, and Processes for the Total System Performance Assessment: Analyses." ANL-WIS-MD-000027. Rev. 00. Las Vegas, Nevada: Sandia National Laboratories.

#### Exclusion of FEP 2.1.11.06.0A Thermal Sensitization of Waste Packages

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

The FEP 2.1.11.06.0A Thermal Sensitization of Waste Packages is excluded from the performance assessment model based on low consequence (Safety Analysis Report Section 2.2, Table 2.2-5; Sandia National Laboratories, 2008). The technical basis to support this screening decision relies in part on a model abstraction for long-term thermal aging and phase stability of Alloy 22 (Safety Analysis Report, Section 2.3.6.7). The staff considers that the technical bases of the screening argument are not sufficient to support exclusion of the FEP from the performance assessment model.

**RAI #16:** Provide additional support for the thermal aging model used to conclude that insignificant aging and phase instability would occur in Alloy 22 under repository thermal conditions. This support should include an assessment of the capability of the thermodynamic and diffusion mobility databases to model the stability of tetrahedrally close-packed phases and long-range ordering in Alloy 22, under repository thermal conditions. This information is needed to verify compliance with 10 CFR 63.114 (e), (f).

Basis: DOE conducted theoretical modeling to predict the rate of precipitation of tetrahedrally close-packed phases and long-range ordering in Alloy 22 using a simplified alloy system (Bechtel SAIC Company, 2004, Sections 6.3.2 and 6.6.4). Based on the calculated time-temperature-transformation diagrams, DOE concluded that precipitation of these phases to a transformation extent greater than 2 percent will not occur under the repository thermal conditions.

Two databases were used in the thermal aging model: the thermal-chemical database and the MOB database (Bechtel SAIC Company, 2004, Section 6.7.1.2). The thermal-chemical database that was extracted from the SSOL database contains the thermodynamic properties of phases of Ni-base alloys, and the MOB database contains kinetic information on diffusion mobilities. The applicant stated that these databases have been validated for Ni-base alloys by comparing the calculated results against literature data (Bechtel SAIC Company, 2004, Section 7). However, the report (Bechtel SAIC Company, 2004) did not include assessment of the capability of the databases to model the tetrahedrally close-packed phases and long-range ordering specifically for Alloy 22.

**RAI #17:** Provide a technical basis for the assertion that the planned solution-annealing operation could minimize phase instabilities in Alloy 22. Provide the technical basis for the selection of solution-annealing and quenching conditions for the waste package outer container. This information is needed to verify compliance with 10 CFR 63.112 (f) and 63.114 (b), (e), (f).

Basis: Fabrication of the waste package outer container will include a solution-annealing heat treatment (Safety Analysis Report, Section 1.5.2.7.1). The Alloy 22 outer container will be solution annealed at 2050 °F for a minimum of 20 minutes, followed by quenching at a rate greater than 275 °F per minute to below 700 °F. Solution-annealing heat treatment is intended to minimize potential phase instabilities in Alloy 22 (Safety Analysis Report, Sections 2.3.6.2.2 and 2.3.6.7.4). However, no information was provided to support this assertion, nor a technical basis for the planned solution-annealing and quenching conditions for the waste package outer

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

container. Existing literature data suggest that solution-annealing heat treatment at temperatures substantially above the temperature of 2050 °F may be required to eliminate the formation of secondary phases (NRC, 2004). Information about the implementation of the solution annealing heat treatment and its effects on the phase stability and corrosion resistance is necessary for assessing performance of the waste package.

#### References

Bechtel SAIC Company, LLC. "Aging and Phase Stability of Waste Package Outer Barrier." ANL-EBS-MD-000002. Rev. 02. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004.

NRC. "NRC Review of the DOE KTI Agreement Response to CLST.2.04, 2.05, and PRE.7.03, 7.05." December 22, 2004. ML043410129.

Sandia National Laboratories. "Features, Events, and Processes for the Total System Performance Assessment: Analyses." ANL-WIS-MD-000027. Rev. 00. Las Vegas, Nevada: Sandia National Laboratories. 2008.

#### Exclusion of FEP 2.2.08.03.0B Geochemical Interactions and Evolution in the Unsaturated Zone

The FEP 2.2.08.03.0B Geochemical Interactions and Evolution in the Unsaturated Zone is excluded from the performance assessment model based on low consequence (Safety Analysis Report Section 2.2, Table 2.2-5; Sandia National Laboratories, 2008a). The staff considers that the technical bases of the screening argument are not sufficient to support exclusion of the FEP from the performance assessment model.

**RAI #18:** From the expected range of compositions of waste package effluent, provide a description of the changes to unsaturated zone water chemistry and Topopah Spring tuff that would be expected to result from geochemical interactions with the effluent from breached waste packages. Assess how these interactions could affect radionuclide transport processes in the unsaturated zone. This information is needed to verify compliance with 10 CFR 63.114 (e).

**Basis:** Water in a waste package will interact chemically with the metals and wasteform components inside the waste package. As a result, the evolved fluid in which the radionuclides are transported out of a breached waste package may differ chemically from the ambient waters of the unsaturated zone. The exclusion argument focused mainly on thermo-chemical interactions involving unsaturated zone water and drift seepage and the resulting effects on (i) the precipitation of secondary minerals in fractures and (ii) the stability of colloids transported in the unsaturated zone. A technical basis was not provided for excluding geochemical interactions involving waste package effluent and the effect of such reactions on radionuclide transport in the unsaturated zone or in the crushed tuff invert.

#### References

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

Sandia National Laboratories. “Features, Events, and Processes for the Total System Performance Assessment: Analyses.” ANL–WIS–MD–000027. Rev. 00. Las Vegas, Nevada: Sandia National Laboratories. 2008a.

#### Exclusion of Seismic FEPs

Some FEPs related to a potential response of the system to seismic events were excluded from the performance assessment model on the basis of low consequence (Safety Analysis Report Section 2.2, Table 2.2-2, p. 2.2-172–173; Sandia National Laboratories, 2008). The staff considers that technical bases of the screening arguments are not sufficient to support exclusion of the FEP from the performance assessment model.

**RAI #19:** Justify the apparent inconsistent treatment of low probability seismic ground motions in FEP screening arguments compared to the application of low probability seismic ground motions as inputs to the performance assessment model. This information is needed to verify compliance with 10 CFR 63.114(d), (e), and (f), and 63.21(c)(1) and (9).

**Basis:** The following FEPs related to a potential response of the system to seismic events (as identified in Table 2.2-2, p. 2.2-172–173, of the Safety Analysis Report) were excluded from the performance assessment model:

- 1.2.03.02.0B Seismic-Induced Rockfall Damages EBS Components
- 1.2.03.02.0E Seismic-Induced Drift Collapse Alters In-Drift Chemistry
- 1.2.10.01.0A Hydrologic Response to Seismic Activity
- 2.2.06.01.0A Seismic Activity Changes Porosity and Permeability of Rock
- 2.2.06.02.0A Seismic Activity Changes Porosity and Permeability of Faults
- 2.2.06.02.0B Seismic Activity Changes Porosity and Permeability of Fractures
- 2.2.06.03.0A Seismic Activity Alters Perched Water Zones

In general, the screening arguments in Sandia National Laboratories (2008) rely on the assumption that the total system would experience minor changes from the seismic events. However, seismic ground motions at low annual exceedence probabilities (below about  $10^{-6}$ ) resulting from the DOE probabilistic seismic hazard assessment (PSHA) are much larger than recorded ground motions from even the largest earthquakes anywhere on Earth, and it is not clear that the response of the system to such large ground motions would be minor. Some steps have been taken to condition the PSHA in order to develop ground motion inputs considered to be more consistent with site conditions. Nevertheless, even the conditioned ground motions lead to acceleration and velocity versus time inputs for the seismic abstraction in the performance assessment model with peak accelerations approaching 20 g and peak ground velocities of more than 1500 cm/sec (e.g., see figure II-171 of BSC, 2004). In comparison, the  $M_w$  7.9 Denali Earthquake in 2002 produced what was considered a very high peak ground velocity of 180 cm/sec at one station very near the fault rupture (e.g. Ellsworth et al., 2004).

### 2.2.1.2.1 Scenario Analysis – Set 2 RAIs

The rationale for exclusion of these FEPs is based in part on assumptions of how the repository will perform under seismic loads typically observed in large western United States earthquakes. While very large ground motions from the conditioned PSHA are used to develop inputs to the seismic abstraction in the performance assessment model, the impacts of such large ground motions on the total system are neglected, and the large ground motions do not appear to be fully considered in the rationale to exclude the seismic related FEPs from the performance assessment model.

#### References

Ellsworth, W.L., M. Celebi, J. R. Evans, E. G. Jensen, R. Kayen, M. C. Metz, D. J. Nyman, J.W. Roddick, P. Spudich, and C. D. Stephens. "Near-Field Ground Motion of the 2002 Denali Fault, Alaska, Earthquake Recorded at Pump Station 10." *Earthquake Spectra, Volume 20, No. 3*, pp 597–615, August 2004.

BSC. "Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, NV." MDL–MGR–GS–000003. Rev. 01 ACN 01. Las Vegas, Nevada. 2004.

Sandia National Laboratories. 2008. "Features, Events, and Processes for the Total System Performance Assessment: Analyses." ANL–WIS–MD–000027. Rev. 00. Las Vegas, Nevada: Sandia National Laboratories.