U.S. NUCLEAR REGULATORY COMMISSION, OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS, REVIEW OF THE U.S. DEPARTMENT OF ENERGY AGREEMENT RESPONSES RELATED TO THE POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA: KEY TECHNICAL ISSUE AGREEMENTS TO EVOLUTION OF THE NEAR-FIELD ENVIRONMENT 4.06 ADDITIONAL INFORMATION NEED, AND TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION 3.17 ADDITIONAL INFORMATION NEED

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issue-resolution goal during the prelicensing period is to ensure that the U.S. Department of Energy (DOE) has assembled enough information about a given issue for NRC to accept a license application for review. NRC staff resolution of an issue during prelicensing does not preclude the raising of related issues during the licensing proceedings. Also, and equally important, NRC resolution of an issue during prelicensing does not prejudge NRC staff's evaluation of the issue during the licensing review. NRC staff considers an issue resolved during prelicensing when it has no further questions or comments about how DOE is addressing an issue. Pertinent new information could raise new questions or comments about a previously resolved issue.

This review addresses additional information DOE supplied in its September 29, 2006, letter, from Mark H. Williams, to the Director, Division of High-Level Waste Repository Safety, which responded to staff additional information needs (AINs) for Key Technical Issue (KTI) Agreements Evolution of the Near-Field Environment (ENFE) 4.06 and Total System Performance Assessment (TSPA) and Integration (TSPAI) 3.17 (Williams, 2006). These agreements were originally made between DOE and NRC during two Technical Exchange and Management Meetings (Reamer, 2001a,b) and relate to the DOE TSPA abstraction of radionuclide transport within the waste package and engineered barrier system.

In response to ENFE 4.06, DOE initially indicated that the "Total System Performance Assessment for Site Recommendation" (CRWMS M&O, 2000) would satisfy the agreement. In response, NRC issued a letter requesting additional information (Schlueter, 2002), to which DOE responded in an appendix to a technical basis document (Bechtel SAIC Company, LLC, 2003). A subsequent NRC request for additional information (Kokajko, 2005) led to the September 29, 2006, DOE letter and accompanying analysis model report (Bechtel SAIC Company, LLC, 2006).

The initial DOE response to TSPAI 3.17 was contained in an appendix to a technical basis document (Bechtel SAIC Company, LLC, 2003). NRC responded by expressing a need for additional information (Kokajko, 2005), which led to the September 29, 2006, DOE response.

2.0 WORDING OF THE AGREEMENTS

ENFE 4.06

> Provide documentation to demonstrate suitability of the bounding values used for colloid transport through the perturbed near-field environment. For example, consider sensitivity analyses to investigate the effects of varying colloid sorption parameters

(K_c)on repository performance. The DOE will evaluate the suitability of the colloid transport model under perturbed conditions as discussed in agreement #3 for this subissue. As part of this work, the DOE will consider sensitivity analyses to investigate the effects of varying colloid sorption parameters (K_c) on repository performance. The DOE will also provide the TSPA-SR (TDR–WIS–PA–000001), Rev 00 ICN 01, in January 2001. The TSPA-SR includes sensitivity studies in the form of barrier degradation and parameter sensitivity analyses that investigate the effect of sorption and colloid parameters on repository performance (Reamer, 2001a).

ENFE 4.06 AIN–01

Provide additional sensitivity analyses of colloid release and transport parameters as discussed in the agreement. Related issues are covered under TSPAI Agreements 3.17, 3.30, and 3.42 (Schlueter, 2002).

ENFE 4.06 AIN–02

In the model, plutonium and americium can sorb both reversibly and irreversibly onto the iron corrosion products in the waste package, thereby either slowing or preventing release. Previously, no credit was taken for sorption in the engineered barrier system (CRWMS M&O, 2000). The new model is described only briefly in the available reports. To evaluate DOE's abstraction, which could potentially result in reduced dose from colloid-facilitated plutonium, the NRC staff needs to understand how the model and parameters were developed. Some of the required information may be contained in the analysis model report, EBS Radionuclide Transport Abstraction, Revision 1; however, this report was unavailable at the time this review was conducted (Kokajko, 2005).

Staff considers Agreement ENFE.4.06 to be open because the technical basis for the new engineered barrier system transport abstraction was not provided (Kokajko, 2005).

TSPAI 3.17

[NOTE: ENG 4.4.1 in this agreement refers to Item 4.4 of NRC integrated subissue ENG 4 Table 1.1-2 (NRC, 2002)].

Provide an uncertainty analysis of the diffusion coefficient governing transport of dissolved and colloidal radionuclides through the invert. The analysis should include uncertainty in the modeled invert saturation (ENG 4.4.1) (Reamer, 2001b).

DOE will provide an uncertainty analysis of the diffusion coefficient governing transport of dissolved and colloidal radionuclides through the invert. The analysis will include uncertainty in the modeled invert saturation. The uncertainty analysis will be documented in the EBS Radionuclide Transport Abstraction AMR (ANL–WIS–PA–000001) expected to be available to NRC in FY 2003 (Reamer, 2001b).

TSPAI 3.17 AIN–01

In Bechtel SAIC Company, LLC (2003) and other available reports, DOE has not satisfied the intent of Agreement TSPAI.3.17. Although this agreement has been rated as having a low risk significance (Travers, 2003), DOE: (i) has not yet provided the data supporting model parameters and uncertainties; (ii) has not made clear what set of parameters will be used; and (iii) has not supported the assertion that the invert is an insignificant barrier. This agreement is, therefore, open (Kokajko, 2005).

3.0 SIGNIFICANCE TO PERFORMANCE

A discussion of the importance of agreements ENFE 4.06 and TSPAI 3.17 in assessing repository performance is given in Kokajko (2005). In Travers (2003), NRC staff described the basis for risk-ranking the KTI agreements. NRC's preliminary analyses indicated that ENFE 4.06 has a medium significance to risk calculations, whereas TSPAI 3.17 has a low significance (Travers, 2003).

DOE has indicated the level of importance it has assigned to the abstractions that are the subjects of these agreements in Bechtel SAIC Company, LLC (2006, page 7-1). The engineered barrier system transport model was judged to require a Level II validation, indicating that this is a model "...whose variation could lead to moderate effect on the estimate of mean annual dose (less than 1 mrem yr^{-1}, but greater than 0.1 mrem yr^{-1})...." The invert transport model was assigned a Level I validation, requiring a lower level of validation confidence because of lesser importance in estimating mean annual dose. These classifications correspond well with the medium- and low-risk rankings assigned by NRC to ENFE 4.06 and TSPAI 3.17, respectively.

4.0 EVALUATION AND COMMENT

4.1 Agreement ENFE 4.06, AIN–02

The second ENFE 4.06 AIN was concerned with the technical basis for the most recent DOE engineered barrier system radionuclide transport abstraction for performance assessment. In particular, the AIN was prompted by the new approach that allows for radionuclide retention on stationary steel-corrosion products inside the waste package. This modeled mechanism has the potential to significantly lower the release rate of dose-significant plutonium isotopes and inventory-significant americium.

4.1.1 Technical Basis for Radionuclide Transport Abstraction

The analysis model report (Bechtel SAIC Company, LLC, 2006) clearly describes the structure and function of the engineered barrier system radionuclide transport abstraction within the TSPA model. In the abstraction, the waste package is the source of dissolved and colloidal radionuclides and is capable of reducing radionuclide flux to the invert by irreversibly retaining a portion of radionuclides at limited sorptive sites in the corrosion-products domain. The major assumptions underlying the conceptual model are presented in Sections 5 and 6.3.4.2, with particular emphasis on: (i) reversible and irreversible sorption of radionuclides onto mobile and immobile collector surfaces; (ii) negligence of film straining at air-water interfaces; (iii) existence of radionuclide and colloid transport through continuous film flows at in-drift temperatures below 100 °Centigrade [212 °Farenheit]; and (iv) negligence of physical filtration and gravitational settling of colloids. A complete description of the mathematical model is discussed in Section 6.5.1.2 (including mass-balance equations for waste-form colloids and radionuclides, and estimated masses of corrosion products, given in Table 6.3-4), and additional assumptions are underlined in Section 6.5.1.2 (e.g., use of the same-rate constant for irreversible sorption of plutonium and americium onto mobile and stationary iron-oxyhydroxide corrosion products).

In this review, NRC staff focused on those aspects of Bechtel SAIC Company, LLC (2006) that addressed irreversible attachment of radionuclides onto stationary and mobile surfaces in a breached waste package and in the invert. Some of the key attributes of the abstraction that were significantly different from previous descriptions (Bechtel SAIC Company, LLC, 2003) include: (i) eliminating reversible sorption of radionuclides onto stationary corrosion products in the waste package; and (ii) limiting the sites on stationary corrosion products in the waste package available for irreversible radionuclide sorption, resulting in an increase in the quantity of released dissolved radionuclides. These changes were implemented by: (i) reducing the upper bounds for K_d values for colloid sorption of plutonium and americium by a factor of 100, to promote their irreversible sorption onto stationary corrosion products, at the expense of sorption onto mobile colloids; and (ii) calculating the capacity of irreversible sorptive sites on stationary corrosion, via the product of an available surface area, adsorbed site densities, and the percentage of high-affinity sites (Bechtel SAIC Company, LLC, 2006, p. 6-96). The forward rate constant for irreversible attachment was treated as a fitting parameter, the value of which was calculated from the mass-outflux ratio of the colloid-associated radionuclides to the total radionuclides at the exit end of the corrosion-product domain (Bechtel SAIC Company, LLC, 2006, Eq. B–72). Although this seems to be a reasonable approach, treatment of the irreversible rate constant as a fitting parameter does not directly use the conceptual model for irreversible sorption discussed in Section 6.3.4.2.3.2 of Bechtel SAIC Company, LLC (2006). The conceptual model proposed calculating the limited irreversible sites in the corrosion-product domain, in terms of the product of an available surface area, adsorbed site densities, and the percentage of high-affinity sites. However, because these factors may not be determined with high confidence in heterogeneous flow systems at the field scale, bounding the capacity of irreversible sorptive sites *a priori*, based on findings from controlled experiments, appears reasonable. If field-scale information on these factors is made available, the abstraction has the flexibility to replace the fitted irreversible rate constant with the product of the aforementioned factors, in calculating the mass of irreversibly sorbed radionuclides.

The rationales for neglecting reversible or irreversible sorption/attachment of radionuclides onto corrosion products in the invert (mainly because of localized and widely separated distribution of corrosion products in this zone) and reversible sorption of radionuclides (uranium, neptunium, plutonium, americium, protactinium, cesium, strontium, radium, and thorium) onto the crushed tuff in the invert, have been clearly addressed. Partition coefficient (K_d) values reported in Bechtel SAIC Company, LLC (2006; Tables 8.2-3 and 6.5-6) are consistent with the model assumptions regarding reversible and irreversible sorption of radionuclides onto colloidal particles, and the technical bases for parameter selections are clearly presented.

Corrosion rates of carbon steel in Table 4.1-1 of Bechtel SAIC Company, LLC (2006) seem to be higher than typical open literature values. Use of these rates may lead to model underestimation of radionuclide release by providing, over a relatively short period of time, abundant sorption sites on corrosion products. However, future performance assessments may reflect waste package design changes (DOE, 2006) that limit or eliminate the use of carbon steel and, consequently, the mass of early-formed corrosion products.

4.1.2 ENFE 4.06 AIN–02 Summary

In Williams (2006) and the accompanying analysis model report (Bechtel SAIC Company, LLC, 2006), DOE has provided a transparent description of the engineered barrier system radionuclide transport abstraction, including those aspects of the abstraction simulating in-package radionuclide retention. NRC staff has no further questions on this abstraction at this time.

4.2 Agreement TSPAI 3.17, AIN–01

The TSPAI 3.17 AIN arose from the unavailability of a report detailing the technical basis for invert diffusion model parameters, and the DOE conclusion that the invert is an insignificant barrier to radionuclide release from the engineered barrier system. DOE addressed, in turn, the three listed aspects of the invert diffusion model cited in the NRC AIN (see Section 2.0).

4.2.1 Technical Basis for Diffusion Model Parameters and Uncertainties

As discussed in summary form in Williams (2006) and in more detail in Section 6.3.4.1 of Bechtel SAIC Company, LLC (2006), the invert diffusion submodel supplies an effective diffusion coefficient that TSPA uses to simulate diffusive transport through the invert. For radionuclides, the submodel uses the bulk self-diffusion coefficient of water, which is an upper bound for dissolved species. The diffusion coefficient is then modified to account for the porosity and water saturation (also expressed as the volumetric moisture content) of the crushed tuff that makes up the invert, and for the modeled temperature in the invert. The technical bases for these modifications are detailed in Section 6.3.4.1 of Bechtel SAIC Company, LLC (2006) and rely on cited laboratory and theoretical studies. In particular, the moisture content dependence involves a statistical fit to laboratory measurements of electrical conductivity on granular materials over a broad range of moisture contents. An uncertainty bound on the water-saturation dependence of the effective diffusion coefficient (Bechtel SAIC Company, LLC, 2006, Figure 6.3-4) accounts for variation in the laboratory data and bounds uncertainty in invert porosity. A comparison with diffusion coefficient data obtained independently of the model development data shows that the model exceeds all comparison data points over a range of moisture contents (Bechtel SAIC Company, LLC, 2006; Figure 7.2-3). DOE concludes that this comparison validates the model development, including the method used for measurements of diffusion coefficient.

4.2.2 Clarification of Model Diffusion Coefficients

The AIN noted some lack of clarity in discussing which particular set of diffusion coefficients would be used in the TSPA invert diffusion abstraction. Williams (2006) stated that the electrical conductivity data over a range of volumetric moisture contents from Conca and Wright (1992) and Conca, et al. (1993), listed in Table 4.1-17 of Bechtel SAIC Company, LLC (2006), were used to develop the abstracted functional relationship between diffusion coefficient and moisture content. The values in Tables 4-2 and F–1 of Bechtel SAIC Company, LLC (2003) are independent of the model development and equivalent to the values used for model validation in Bechtel SAIC Company, LLC (2006).

4.2.3 Invert Barrier Capability

DOE had previously stated that invert diffusion properties are not important to repository performance, but a detailed basis for that assertion was not provided (Bechtel SAIC Company, LLC, 2003). As stated in Williams (2006), the supporting rationale is in Section 7.2.2 of Bechtel SAIC Company, LLC (2006). DOE states that, in the nominal scenario, waste package breaches have such low probability that any radionuclide releases, whether diffusion-related or not, will be unimportant to system performance. Under disruptive scenarios, DOE states that waste package breaches will be more significant and that advective conditions will be present, such that advective releases will dominate diffusive releases. Although TSPAI 3.17 is concerned chiefly with invert diffusion, Williams (2006) also points out that the short transport pathway of the invert means it is an insignificant barrier under advective conditions relative to the unsaturated zone.

4.2.4 TSPAI 3.17, AIN–01 Summary

In Williams (2006) and the accompanying analysis model report (Bechtel SAIC Company, LLC, 2006), DOE has addressed the three aspects of the NRC additional information request. The report discussed model conceptualization, assumptions, and governing equations for the invert radionuclide transport abstraction, including the diffusion model. NRC staff has no further questions on invert diffusion at this time.

5.0 SUMMARY

Staff evaluated the DOE responses to two additional information requests for KTI agreements ENFE 4.06 and TSPAI 3.17, concerned with the abstractions for radionuclide transport in the waste package and invert. Staff concludes that the information DOE provided in the Williams (2006) letter and accompanying report satisfies the AINs requested.

Staff is aware that simulations of the waste package internal environment may be modified in response to design changes resulting from the new transportation, aging, and disposal canister concept (DOE, 2006). The comments contained in this letter are relevant only to the model conceptions as presented in Bechtel SAIC Company, LLC (2006).

6.0 STATUS OF THE AGREEMENTS

Based on the preceding review, the information provided by DOE satisfies the intent of ENFE 4.06 and TSPAI 3.17. Therefore, NRC considers these agreements complete.

7.0 REFERENCES

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