# THE U.S. NUCLEAR REGULATORY COMMISSION OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS REVIEW OF THE U.S. DEPARTMENT OF ENERGY'S KEY TECHNICAL ISSUE AGREEMENT RESPONSES RELATED TO THE POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA: COLLOID-RELATED AGREEMENTS FOR EVOLUTION OF THE NEAR-FIELD ENVIRONMENT 1.06, 4.03, 4.04, and 4.06, TOTAL SYSTEM PERFORMANCE ASSESSMENT AND INTEGRATION TSPAI.3.17, 3.30, AND 3.42, AND GENERAL 1.01, COMMENTS 35, 36, 37, AND 38

## 1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issue resolution goal during this interim pre-licensing period is to ensure the U.S. Department of Energy (DOE) has assembled sufficient information on a given issue for NRC to accept a potential License Application for review. It is important to note that closure of an issue by NRC staff during the pre-licensing period does not prejudge the NRC staff evaluation of the issue during the licensing review. Issues are closed by the NRC staff during pre-licensing when the staff have 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. The NRC licensing decision will be based on information provided as part of a potential License Application.

By letter dated October 3, 2003, DOE submitted a report, Technical Basis Document No. 8: Colloids (Bechtel SAIC Company, LLC, 2003a), to satisfy the informational needs for numerous key technical issue (KTI) agreements pertaining to colloid-associated release and transport at the potential repository at Yucca Mountain. Among the agreements addressed in the appendices to that document were the following, categorized according to three different key technical issues:

- Evolution of the Near-Field Environment (ENFE) Agreements 1.06, 4.03, 4.04, and 4.06;
- Total System Performance Assessment and Integration (TSPAI) Agreements 3.17, 3.30, and 3.42; and
- General (GEN) Agreement 1.01, Comments 35, 36, 37, and 38.

The other agreements and comments addressed in the appendices to Bechtel SAIC Company, LLC (2003a) are not discussed in this report. For one of these agreements (ENFE.4.06), DOE previously submitted documents with a response to the information needs. However, NRC judged the agreement was not closed and replied with an additional information needs request (Schlueter, 2002). For all agreements and comments listed previously, DOE stated in Appendices A, B, C, D, F, and H of the technical basis document (Bechtel SAIC Company, LLC, 2003a) that it had satisfied the NRC information needs regarding the agreements and that all agreements should be considered closed. Finally, it should be noted that GEN.1.01, Comments 35 and 38, were only to be addressed by DOE if DOE were to adopt a "low temperature" operating mode in a potential License Application (Reamer, 2001c). Since a "low temperature " operating mode is not currently planned by DOE, NRC staff did not evaluate the adequacy of DOE's response to GEN.1.01, Comments 35 and 38. These will not be discussed further in this report.

The purpose of this enclosure is to report the results of a staff review of the DOE bases for agreement closure. The agreements are grouped according to similarity in the aspect of colloid release and transport being addressed, corresponding to their grouping in the Bechtel SAIC Company, LLC (2003a) appendices. The GEN.1.01 Comment 37 was addressed in more than one appendix. To avoid duplication, this comment was categorized into the most appropriate group for evaluation.

## 2.0 AGREEMENTS

### ENFE.1.06

The agreement reads (Reamer, 2001a):

"Provide the technical basis for excluding entrained colloids in the analysis of FEP 2.2.10.06.00 (Thermo-Chemical Alteration) or an alternative FEP. The DOE will provide the technical basis for screening entrained colloids in the analysis of FEP 2.2.10.06.00 in a future revision of the *Features, Events, and Processes in UZ Flow and Transport* AMR (ANL–NBS–MD–000001), expected to be available in FY 02."

### ENFE.4.03

The agreement reads (Reamer, 2001a):

"Provide the technical bases for screening out coupled THC effects on radionuclide transport properties and colloids. The DOE will provide the technical bases for screening out coupled THC effects on radionuclide transport properties and colloids in a new AMR or in a revision to an existing AMR, expected to be available in FY 02."

### ENFE.4.04

The agreement reads (Reamer, 2001a):

"Provide the technical basis for excluding entrained colloids in the analysis of FEP 2.2.10.06.00 (Thermo-Chemical Alteration) or an alternative FEP. The DOE will provide the technical basis for screening entrained colloids in the analysis of FEP 2.2.10.06.00 in a future revision of the *Features, Events, and Processes in UZ Flow and Transport* AMR (ANL–NBS–MD–000001), expected to be available in FY 02."

### ENFE.4.06

The agreement reads (Reamer, 2001a):

"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."

ENFE.4.06 AIN (Additional Information Need)–1

The AIN request reads (Schlueter, 2002):

"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."

TSPAI.3.17

The agreement reads (Reamer, 2001b): [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)."

"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."

TSPAI.3.30

The agreement reads (Reamer, 2001b): [NOTE: SZ 2.3.1 in this agreement refers to Item 2.3 of NRC integrated subissue SZ 2, Table 1.1-2, (NRC, 2002)]

"Provide the technical basis for the contrasting concentrations of colloids available for reversible attachment in the engineered barrier system and the saturated zone. Sensitivity analyses planned in response to RT Agreement 3.07 should address the effect of colloid concentration on $K_c$. Update, as necessary, the $K_c$ parameter as new data become available from the Yucca Mountain region (SZ 2.3.1).

"DOE will provide the technical basis for the contrasting concentrations of colloids available for reversible attachment in the engineered barrier system and the saturated zone. The sensitivity analyses planned in response to RT Agreement 3.07 will address the effect of colloid concentration on the $K_c$ parameter. The technical basis will be documented in the Waste Form Colloid Associated Concentration Limits: Abstractions and Summary (ANL–WIS–MD–000012) in FY 2003. The $K_c$ parameter will be updated as new data become available from the Yucca Mountain region in the Uncertainty Distribution for Stochastic Parameters AMR (ANL–NBS–MD–000011) in FY2003."

TSPAI.3.42

The comment reads (Reamer, 2001b):

“DOE should provide a sensitivity analysis on the potentially abrupt changes in colloid concentrations due to shifts in modeled pH and ionic strength across uncertain stability boundaries. This analysis may be combined with plans to address ENFE Agreement 4.06 and RT Agreement 3.07.”

“DOE will complete sensitivity analyses to investigate the effects of varying colloid concentration due to shifts in model predicted pH and ionic strength across uncertain stability boundaries. These analyses will be documented in TSPA for any potential License Application expected to be available to NRC in FY 2003.”

GEN.1.01, Comment 36

The comment reads (Reamer, 2001c):

“The discussion of uncertainty in the saturation level of the invert does not consider the possibility of higher saturation. This comment is related to KTI agreement TSPAI.3.17.”

The DOE initial response reads (Reamer, 2001c):

“Studies with the MSTH model, as reported in Chapter 5 of the SSPA Volume 1, investigated the sensitivity of invert liquid saturation to a variety of repository parameters. These parameters included bulk permeability, host-rock thermal conductivity, lithophysal porosity, and invert thermal conductivity. Predicted liquid saturation remained within a narrow range, between four percent and 10 percent, for all parameter variations. In addition, the diffusive breakthrough time for the invert is already relatively rapid, so any increase in saturation levels is expected to have a negligible impact. DOE will provide an uncertainty analysis of diffusion in the invert. This analysis will include uncertainty in invert saturation per KTI agreements TEF.2.05 and TSPAI.3.17.”

GEN.1.01, Comment 37

The comment reads (Reamer, 2001c):

“The discussion of THC effects on UZ transport does not address chemical effects of the repository. This concern is related to KTI agreements ENFE.4.03 and ENFE.4.06 and TSPAI FEPs item J–8.”

The DOE initial response reads (Reamer, 2001c):

“DOE acknowledges this comment and notes that some limited studies were documented in Section 11.3.5.4.2 of SSPA [Site suitability Performance Assessment] Volume 1. Work is underway, consistent with the cited agreements, to study the effects of alkaline plumes generated by the cement-seepage interactions on rock properties (such as porosity and permeability) and thereby effects on radionuclide transport from the waste placement drifts, with preliminary results expected in FY03.”

## 3.0 RELEVANCE TO OVERALL PERFORMANCE

Colloids can form from the aqueous degradation of nuclear wasteforms, and dissolved radionuclides released from those wasteforms also can attach to colloids of natural or synthetic material, especially iron oxyhydroxides formed from corrosion of the steel in the waste package and ground-support materials. Because colloids can be transported in water, they can potentially provide a means for mobilizing radionuclides to a degree in excess of limits placed by solubility and sorption. Analyses suggest colloids can affect system performance, particularly with respect to how they affect plutonium and americium release and mobility (NRC, 2004). For example, a performance assessment calculation that assumed no retardation of plutonium, americium, and thorium yielded doses at least ten times larger than the basecase (Mohanty, et al., 2004). The potential importance of colloids was also evident in DOE's TSPA-SR (CRWMS M&O, 2000), which indicated colloidal plutonium is the second highest dose contributor at times when a significant number of waste packages have failed, allowing release of radionuclides. For colloids to affect performance, however, they must form in substantial quantities and be transported out of the engineered barrier system. Because colloids can enhance the release of radionuclides beyond their solubility limits, and can enable groundwater transport at velocities greater than predicted using retardation factors for the corresponding dissolved species, the NRC staff has concluded that the effects of colloids on waste package releases and radionuclide transport have medium significance to waste isolation (NRC, 2004).

Considerable uncertainties remain regarding the concentration and mobility of colloids that would form in the perturbed near-field environment. Concentrations will be sensitive, in part, to the pH and ionic strength of the waters interacting with the various engineered materials in the drift and waste package and to temperature. Modeling the water chemistry is uncertain with respect to thermodynamic and kinetic processes, as well as the nature of materials encountered by the in-drift and in-package waters. These uncertainties extend to how DOE models colloid stability and transport once colloids have been released from the waste package and are transported through the invert to the unsaturated zone.

A significant change in DOE's abstraction for release of plutonium and americium is the addition of retention of plutonium and americium on stationary iron corrosion products within the waste package, which has the effect of greatly reducing the masses available for transport to groundwater (Bechtel SAIC Company, LLC, 2003a, Section 3.4.3; 2003b, pp. 73–77). The model is implemented such that a large fraction of total plutonium is sorbed to [stationary] corrosion products, a small fraction to colloids, and a small fraction remains dissolved in the fluid (Bechtel SAIC Company, LLC, 2003b, p. 75). Clearly, adding retention (of plutonium and americium) to this new abstraction, while more realistic, will result in lower plutonium and americium release from the engineered barrier system compared with past abstractions that took no credit for retention. Overall system performance will be improved if this mechanism occurs, because groundwater doses from plutonium and americium will be lower than if there were no in-package retention. It is likely, therefore, that any new DOE performance assessment that takes credit for plutonium and americium retention will calculate doses that are lower, all other factors being equal. Although this retention mechanism was not originally included in the technical content of the agreements addressed in Bechtel SAIC Company, LLC (2003a) (because it was not included in DOE's abstractions), discussion of the retention of plutonium and americium within the drift is directly relevant to evaluations of how colloids affect in-drift transport of these radionuclides.

Also, during the thermal period, when temperatures are above boiling in the walls of the repository drifts, the physical and chemical characteristics of fluids in this fractured medium are uncertain. In the extreme, these fluids could be devoid of colloids and particulate, or entrain a significant quantity of these solids, depending on solid-liquid interactions and fracture geometries and connections. The physical properties of the fluids that could be affected by the presence of colloids and particulate are specific gravity, viscosity, boiling point, and surface tension. Uncertainty in these parameters can impact modeling of seepage, which has been rated as of medium risk significance.

Finally, of the seven agreements addressed in this review, the NRC staff has rated three as having medium significance to risk: ENFE.4.06, TSPAI.3.30, and 3.42 (Travers, 2003). Agreements ENFE.1.06, 4.03, 4.04, and TSPAI.3.17 were assigned a low risk significance (Travers, 2003). Although Agreement ENFE.4.03 was assigned a low risk rating (Travers, 2003), its importance may be enhanced by the changes in the abstraction for radionuclide transport through the engineered barrier system that have been only summarized in available documents. These are the agreements most directly relevant to the selection of uncertain parameters that govern the quantity, radionuclide attachment, and mobility of colloids in the repository system performance assessment. The requested information, therefore, may have some influence on risk estimates. In addition, these agreements are related to two of the six most risk-significant technical areas: (i) effects of in-package chemistry on the dissolution of the waste form and (ii) radionuclide transport in the saturated zone (Travers, 2003). Finally, the individual comments within GEN.1.01 were not separately categorized within the significance framework. The information requested in these agreements is not expected to be significant for estimating repository risk, but is necessary to understand DOE’s bases for simulating how colloids will behave in the system.

## 4.0 RESULTS OF THE NRC REVIEW

### 4.1 Agreements Pertaining to Entrained Colloids and Thermo-Chemical Alteration

#### 4.1.1 Agreements ENFE.1.06 and 4.04

Appendix A of Bechtel SAIC Company, LLC (2003a) dealt with the technical basis for exclusion of entrained colloids in the analysis of features, events, and processes associated with thermal-chemical alteration (FEP 2.2.10.06.00). The DOE envisioned that on heating, colloids experience increased Brownian deposition caused by increased collisions with solid surfaces. Additionally, DOE suggested evaporation will result in a fluid with increasing ionic strength, further destabilizing colloids. These processes remove colloids from fluids of the repository. The staff considers DOE’s response to entrained colloids adequate and the Agreements ENFE.1.06 and 4.04 are closed.

### 4.2 Agreements Pertaining to Bounding Values of Colloid Transport Parameters in the Near-Field Environment

#### 4.2.1 Agreement ENFE.4.06

In response to ENFE.4.06, DOE described the technical bases for colloid-relevant parameters affecting radionuclide transport in the near field (Bechtel SAIC Company, LLC, 2003a,

Appendix B). The key parameters addressed were colloid concentration (total mass of colloids available) and the sorption coefficient, or $K_d$, governing radionuclide attachment to colloids. These parameters were developed in a related analysis model report using laboratory, field, and literature data (Bechtel SAIC Company, LLC, 2003b, Sections 6.3.2.5 and 6.3.3.1). The DOE also argued that conditions in the perturbed near-field environment will not affect colloid or flow characteristics to a degree that colloid-facilitated transport will be underestimated in their models, and that probability distributions for colloid concentration and $K_d$ are broad enough to capture any variability in the near field. The DOE consequently has provided sufficient information on near-field colloid transport parameters.

As discussed in Section 3.0, DOE, now has a new approach to modeling plutonium and americium transport from the waste package that takes credit for retention onto stationary iron oxyhydroxide corrosion products, resulting in a significant decrease in released radionuclide mass. This model is directly related to concerns about colloid release and transport in the near field because it involves similar technical bases for the stability of the corrosion products and the irreversibility of attachment of plutonium and americium onto this substrate. Because this new conceptual model was introduced in the colloids technical basis document (Bechtel SAIC Company, LLC, 2003a) and involves transport of colloid-enhanced radionuclides in the perturbed near-field environment, it is appropriate to consider this model in the context of Agreement ENFE.4.06.

In the new 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.

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

### 4.3 Agreements Pertaining to Screening Out Coupled Thermal-Hydrological-Chemical Effects

#### 4.3.1 Agreement ENFE.4.03

Appendix C of Bechtel SAIC Company, LLC (2003a) contained DOE’s response to Agreement ENFE.4.03. The intent of the agreement was for DOE to provide the technical basis for neglecting the effects of coupled thermal-hydrological-chemical processes on radionuclide transport properties and colloids. In the appendix, supported by Bechtel SAIC Company, LLC (2003b), DOE argued that excluding these near-field effects is conservative with respect to solubility and colloid stability and that transport-relevant properties of rock surrounding and underlying the drift (e.g., permeability and mineralogy) are altered only slightly during the thermal period. The latter issue has been evaluated separately as part of the NRC staff review of Agreement ENFE.1.03, which is considered closed (Kokajko, 2005). The exclusion of these effects relies directly on the screening argument for FEP 2.2.10.06.0A [Thermo-Chemical

Alteration in the UZ (Solubility, Speciation, Phase Changes, Precipitation/Dissolution)] (Bechtel SAIC Company, LLC, 2004a). In addition, the abstraction of colloid stability and concentration relies directly on simulations of near-field chemistry.

One aspect of this agreement not fully discussed in the appendix is engineered barrier system transport of both colloidal and dissolved radionuclides. Rather, DOE chiefly discussed thermal-hydrological-chemical conditions in the waste package and the geosphere. The only reference to in-drift transport properties was a figure and brief discussion of diffusion coefficients for the invert. The appendix, however, did not justify the neglect of thermal-hydrological-chemical effects for invert transport. This agreement cannot be closed until the NRC staff evaluates the relevant transport abstraction reported in the recently released analysis model report EBS Radionuclide Transport Abstraction, Revision 1. Staff needs to be able to evaluate any arguments in that report for the neglect of thermal-hydrological-chemical effects, particularly in light of changes in DOE's approach to modeling engineered barrier system transport (see Section 4.2.1). The transport abstraction would be expected to rely on near-field thermal and chemical conditions or to provide a basis for neglecting them.

In addition, DOE based the response to Agreement ENFE.4.03, in part, on the screening argument for FEP 2.2.08.03.0B [Geochemical Interactions and Evolution in the Unsaturated Zone] (Bechtel SAIC Company, LLC, 2004a, Section 6.8.7). This features, events, and processes database item superseded, among others FEP 2.2.08.02.00, [Radionuclide Transport Occurs in a Carrier Plume in Geosphere]. It should be noted that FEP 2.2.08.02.00 is also the subject to Agreement TSPAI.2.02 Comment J-8 (which is currently "open," and awaiting additional rationale regarding the chemistry of water leaving the drift, and its possible effects on sorption below the drift). The new item includes the descriptive language, "Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may change through time, as a result of the evolution of the disposal system or from mixing with other waters" (Bechtel SAIC Company, LLC, 2004a, pp. 6–95). The screening argument focused on changes to transport-relevant characteristics of rock surrounding the drift, but it did not address the transport effects of potential changes to water chemistry below the drift because of interaction of that water with engineered materials. In other words, a basis has not been clearly provided for neglecting the fact that waters carrying radionuclides from the drift may be chemically different from ambient unsaturated zone waters. In the response to Agreement ENFE.4.03 (Bechtel SAIC Company, LLC, 2003a, Appendix C), DOE did argue that chemical effects on solubility and thermal effects on sorption can be conservatively neglected and stated that waters leaving the drift will not be strongly alkaline. The DOE, however, did not discuss how radionuclide sorption below the drift may be affected by the water chemistry, whether it is alkaline or not. This plume effect was a component of the original FEP 2.2.08.02.00 (as well as TSPAI 2.02 Comment J-8) that was apparently not inherited by FEP 2.2.08.03.0B.

The NRC staff finds that DOE, in its response to Agreement ENFE.4.03, has not yet provided a technical basis for: (i) screening out repository groundwater chemical effects on radionuclide transport properties and colloids in the unsaturated zone; or (ii) the engineered barrier system transport abstraction. This agreement is, therefore, considered open.

### 4.3.2 Agreement GEN.1.01, Comment 37

Comment 37, to which DOE responded in Bechtel SAIC Company, LLC (2003a, Appendices B,C), is directly related to Agreements ENFE.4.03, 4.06, and TSPAI.2.02 Comment J–8. It should be noted that each of these comments remain open. Also, NRC staff notes that Comment 37 does not add to the technical content of these other agreements, which are discussed either in this report (Sections 4.3.1 and 4.2.1) or in a separate report evaluating Agreement TSPAI.2.02 responses. Therefore, the NRC staff finds GEN.1.01, Comment 37 should also be considered open.

## 4.4 Agreement Pertaining to Contrasting Colloid Concentrations in the Engineered Barrier System and Saturated Zone

### 4.4.1 Agreement TSPAI.3.30

Appendix D of Bechtel SAIC Company, LLC (2003a) contains DOE's response to Agreement TSPAI.3.30, which concerns how colloid concentrations are calculated and tracked across multiple barriers in DOE's total system performance assessment (TSPA). These colloids are available for reversible attachment of solutes, enhancing radionuclide transport. The DOE abstraction now also includes irreversible attachment of plutonium and americium to iron oxyhydroxide colloids (Bechtel SAIC Company, LLC, 2003a, Section 3.4.3); previously, only reversible attachment was modeled. In Appendix D and a supporting analysis model report (Bechtel SAIC Company, LLC, 2003b), DOE presented the technical basis for the model abstraction of colloid concentrations in the waste package and invert. The concentration parameters were developed from a combination of field and laboratory studies, supported by literature citations. The performance assessment abstraction calculates colloid concentration as a function of solution pH and ionic strength modeled for the waste package and for the two invert porosity fractions. The DOE also presented the basis for partition coefficients used for modeling reversible radionuclide attachment to colloids, as well as colloid concentrations used in the saturated zone transport abstraction. The appendix also included the technical basis for neglecting wasteform and corrosion-product colloids in calculating colloid concentrations for the reversible attachment model in the saturated zone. The NRC staff provided comments about those aspects of Agreement TSPAI.3.30 that consider how colloid-facilitated transport is modeled for the unsaturated and saturated zones in a separate review of Agreements RT.3.07, GEN.1.01, Comment 43 and 46. The NRC staff considers Agreement RT.3.07, and GEN.1.01, Comment 43 and 46, closed (Reamer, 2004)

In DOE's response, one important source of information on colloid stability in near-field waters was not fully explained in evaluating the colloid model abstraction. In a DOE-sponsored project, Zarrabi et al. (2003), measured water chemistry and colloid contents in waters that had interacted with corroding miniature steel waste packages. Data packages from this project were cited in Bechtel SAIC Company, LLC (2003a, Sections 3.3.2 and 3.4.3; 2003b, Section 6.3.1.3) as the basis for the range of iron corrosion product colloid concentrations generated in the waste package. Zarrabi, et al. (2003) also reported chemical data on the waters bearing these colloids from the miniature waste packages at concentrations of 10 mg/L [10 ppm] and higher. The waters have some chemical characteristics that, according to DOE's abstraction (Bechtel SAIC Company, LLC, 2003a, Figure 3-7), would render colloids unstable and limit them to very low concentrations. These chemical characteristics include pH between 8 and 9 (Zarrabi, et al., 2003, Figure 26) and high ionic strengths (Zarrabi, et al., 2003, pp. 14–15 and

45). In fact, the study concludes, “High salinity of incoming solution increases solid transport out of MWP [miniature waste packages]” (Zarrabi, et al., 2003, p. 51). Although the results have not been fully evaluated and interpreted, it is clear the water chemistry data are relevant to DOE’s model of iron oxyhydroxide colloid generation and stability. The model concentration of these particular colloids is especially important for release of plutonium and americium, which attach both reversibly and irreversibly to iron oxyhydroxide colloids (Bechtel SAIC Company, LLC, 2003a, Section 3.4.3).

In summary, the NRC staff considers Agreement TSPAI.3.30 open because DOE has not addressed the potential inconsistency between the iron oxyhydroxide colloid abstraction and the results of DOE-sponsored studies by Zarrabi, et al. (2003).

## 4.5 Agreements Pertaining to Transport of Dissolved and Colloidal Radionuclides through the Invert

### 4.5.1 Agreement TSPAI.3.17

The DOE responded to Agreement TSPAI.3.17, which concerns uncertainty in the diffusion coefficient for dissolved and colloidal radionuclides in the invert, in Appendix F of Bechtel SAIC Company, LLC (2003a). The response consisted of: (i) a presentation of invert diffusion coefficient values and associated uncertainties; (ii) an argument that diffusion of solutes and, particularly, colloids through the invert will be slow because of low moisture contents; and (iii) a statement that transport through the invert is insignificant relative to transport through the unsaturated zone. The central argument appears to be that uncertainty in the invert diffusion coefficient, which is highly sensitive to volumetric moisture content, is accounted for and is not significant to performance.

The NRC staff has not been able to evaluate the diffusion data used in the appendix because the report in which they were developed, Revision 1 of EBS Radionuclide Transport Abstraction, was not available at the time this review was conducted. In addition, staff has not been able to confirm that uncertainty from variability in conditions affecting radionuclide transport (e.g., water content, invert physical characteristics, and colloid sizes) was incorporated into the diffusion coefficient used for dissolved or colloidal species. Although sensitivity of the diffusion coefficient to the volumetric water content was shown and the standard deviation of the measured diffusion coefficients for dissolved species was provided, Bechtel SAIC Company, LLC (2003a) did not provide information about how the volumetric moisture content, from which the diffusion coefficients are apparently calculated, is modeled. The argument that invert transport characteristics are not significant relative to the unsaturated zone was not presented in detail. Therefore, it is not clear that invert diffusion provides a barrier significantly less effective than fractured unsaturated tuff, which may accommodate advection.

Furthermore, Bechtel SAIC Company, LLC (2003a) was not clear about the set of diffusion coefficients actually used in the TSPA abstraction. Section 4.2 of that document indicated that diffusion coefficients for granular materials are used by DOE to model diffusion in the invert (Bechtel SAIC Company, LLC, 2003a, Table 4-1). In Appendix F, it was implied that diffusion in the invert is modeled with new diffusion coefficients derived from experiments with crushed tuff

(Bechtel SAIC Company, LLC, 2003a, Tables F–1 and 4-2), and the granular materials data set was not discussed. Because the difference between diffusion coefficients in the two data sets is approximately two orders of magnitude at the low volumetric moisture contents predicted by DOE for the invert, DOE should specify which set of diffusion coefficients are being used to model diffusion in performance assessment.

In Bechtel SAIC Company, LLC (2003a) 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.

### 4.5.2 Agreement GEN.1.01, Comment 36

The DOE response to Agreement GEN.1.01, Comment 36 was implicitly included in the response to Agreement TSPAI.3.17 in Appendix F of Bechtel SAIC Company, LLC (2003a). As discussed in Section 4.5.1, the appendix showed uncertainty in the invert diffusion coefficient for a wide range of saturation levels. The NRC staff finds that DOE response satisfies Agreement GEN.1.01, Comment 36, associated with TSPAI.3.17, and is therefore, closed.

## 4.6 Agreement Pertaining to Changes in Colloid Concentrations Due to Shifts in pH and Ionic Strength

### 4.6.1 Agreement TSPAI.3.42

The DOE response to Agreement TSPAI.3.42 was presented in Appendix H of Bechtel SAIC Company, LLC (2003a). The motivation for this agreement was a desire for confidence that colloid concentration would not be underpredicted in performance assessment abstractions (Bechtel SAIC Company, LLC, 2003a, Figure 3-11), given the high degree of sensitivity of colloid concentrations to uncertain water chemistry parameters modeled in the waste package and drift. A small change in calculated pH or ionic strength can lead to a decrease in the abstraction output colloid concentration by a factor of 1,000 or more. The DOE did not provide the requested sensitivity analysis. Rather, the DOE stated that on the basis of in-package chemistry modeling for a codisposal package containing high-level waste glass and N-Reactor fuel (Bechtel SAIC Company, LLC, 2003c), solutions that are stable with respect to colloids are possible only during the first 300 years after closure; and, even then, have a probability of less than 6 percent. The appendix also stated that the chemistry models do not account for evaporation, which would further destabilize colloids because of rising ionic strength. Finally, DOE pointed to elevated temperatures, also unfavorable for colloids, in the drift during the first 1,000 years.

The DOE technical basis did not discuss water chemistry for other waste package types, such as the dominant commercial spent nuclear fuel type or other combinations of DOE spent nuclear fuel and glass waste. The NRC staff reviewed the cited analysis model report on in-package chemistry abstraction (Bechtel SAIC Company, LLC, 2003c) to try to evaluate more generally the probabilities of colloid-favorable water chemical conditions and associated uncertainties. In DOE's abstraction of in-package chemistry for commercial spent nuclear fuel under dripping conditions, for example, after 40 years, the ionic strength is dependent only on seepage flux (Bechtel SAIC Company, LLC, 2003c, p. 101). There was insufficient information in the analysis model report to evaluate the probabilities of specific ranges of seepage flux and, thus, ionic strength. Therefore, staff did not gain understanding of how probable in-package colloid stability is in the overall abstraction. In ionic strength abstractions for all waste types, an uncertainty range of ± 60 percent or ± 99 percent (depending on temperature) is added to the sampled value (Bechtel SAIC Company, LLC, 2003c).

The DOE response relied principally on the assertion that in-package conditions are dominantly unfavorable for colloids. The information provided, however, did not demonstrate that calculated chemical conditions are consistently within fields of colloid instability, for the broad range of scenarios, given the substantial model and data uncertainties. In addition, staff has learned from another technical basis document (Bechtel SAIC Company, LLC, 2004b) that

Bechtel SAIC Company, LLC (2003c) has been revised, and significant changes have been made to the in-package chemistry abstraction. The revision had not been released at the time this review was conducted.

A related concern is the effect of assumptions that may be conservative with respect to degradation and solubility considerations, but are nonconservative for determining colloid stability and concentration. Model assumptions from Bechtel SAIC Company, LLC (2003c) that may be conservative with respect to dissolved radionuclides, but are nonconservative for colloid modeling include:

- In the in-package chemistry models, assumed water film thickness values were minimized "...because they result in conservative in-package chemistry estimates." With respect to colloid stability, however, the higher ionic strengths resulting from a lower water volume are not conservative (Bechtel SAIC Company, LLC, 2003c, p. 29).

- The commercial spent nuclear fuel dripping model ionic strength regression against seepage flux employs the maximum ionic strength, which biases against colloid stability (Bechtel SAIC Company, LLC, 2003c, Figure 23).

There were other, less specific references to the conservatism of assumptions and approaches in this now-superseded version of the in-package chemistry abstraction. Because the abstraction has changed (Bechtel SAIC Company, LLC, 2004b), staff should review the new abstraction when it becomes available to ensure any nonconservative model approaches will not significantly affect modeled colloid release.

In TSPA, colloid stability and concentration also are evaluated in the invert (Bechtel SAIC Company, LLC, 2003a, Section 4). Staff, therefore, has the same concerns about calculated colloid stability in the in-drift environment below the waste package. Appendix H of Bechtel SAIC Company, LLC (2003a) did not address invert chemical conditions, and the information in Chapter 4 of that report did not provide sufficient detail about uncertainties and probabilities. For example, Section 4.4.1 of Bechtel SAIC Company, LLC, (2003a) discussed the conceptual basis for the invert water chemistry abstraction. Details about the abstraction, however, such as model results and chemical characteristics of the five water groups chosen to reflect uncertainty, are presented in an analysis model report— Revision 2 of Engineered Barrier System: Physical and Chemical Environment Model—that was not available when this review was conducted. The NRC staff was not able to evaluate how DOE abstracts pH, ionic strength, and temperature in the invert for comparison with colloid stability relationships.

In summary, staff found that DOE response: (i) did not provide comprehensive information about modeled in-package conditions to support the conclusion that colloids are unlikely to be stable; and (ii) did not address invert chemical conditions in detail. In addition, a new DOE report about the in-package chemistry abstraction was not available at the time this review was conducted. Staff, therefore, considers Agreement TSPAI.3.42 to be open.

## 5.0 SUMMARY STATUS OF THE AGREEMENTS

The NRC staff reviewed DOE's KTI agreement responses within Bechtel SAIC Company, LLC (2003a) to Agreements ENFE.1.06, 4.03, 4.04, 4.06 (and associated Additional Information Needed); TSPAI.3.17, 3.30, and 3.42; and GEN.1.01, Comments 36 and 37. On the basis of this review, the NRC staff consider that Agreements ENFE.1.06 and 4.04 are closed. Agreements ENFE.4.06, 4.03, and TSPAI.3.30, 3.42 are considered open. The staff considers GEN.1.01, Comment 37 open. For GEN.1.01, Comment 36, the NRC staff finds the intent of this agreement has been satisfied by DOE's response and is considered closed.

## 6.0 REFERENCES

Bechtel SAIC Company, LLC. "Features, Events, and Processes in UZ Flow and Transport." ANL–NBS–MD–000001. Rev. 2. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004a.

———. "Technical Basis Document No. 7: In-Package Environment and Waste Form Degradation and Solubility." Rev. 1. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004b.

———. "Technical Basis Document No. 8: Colloids." Rev. 2. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2003a.

———. "Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary." MDL–EBS–PA–000004. Rev. 00. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2003b.

———. "In-Package Chemistry Abstraction." ANL–EBS–MD–000037. Rev. 2. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2003c.

CRWMS M&O. "Total System Performance Assessment for the Site Recommendation." TDR–WIS–PA–000001. Rev. 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. 2000.

Kokajko. Pre-Licensing Evaluation of “Evolution of the Near-Field environment” Key Technical Issue Agreements ENFE.1.03, 1.04, 1.05, 1.07, qnd 4.02. Letter (February 4) to Mr. Joseph Ziegler, ML043440184, Washington D. C.: NRC. 2005.

Mohanty, S., R. Codell, J.M. Menchaca, R. Janetzke, M. Smith, P. LaPlante, M. Rahimi, and A. Lozano. “System-Level Performance Assessment of the Proposed Repository at Yucca Mountain Using the TPA Version 4.1 Code.” CNWRA 2002-05. Rev. 2. San Antonio, Texas: CNWRA. 2004.

NRC (Nuclear Regulatory Commission) 2002. Integrated Issue Resolution Status Report.: NUREG-1762 (Revision 0). Nuclear Regulatory Commission, Office of Nuclear Material safety and Safeguards, Washinton, D.C..

NRC (Nuclear Regulatory Commission) 2003. Yucca Mountain Review Plan: NUREG-1804 (Revision 2), Nuclear Regulatory Commission, Office of Nuclear Material safety and Safeguards, Washinton, D.C.

NRC. “Risk Insights Baseline Report.” ML040560162. Washington, DC: NRC. April 2004. <www.nrc.gov/ waste/hlw-disposal/reg-initiatives/resolve-key-tech-issues.html>

Reamer, C.W. “U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Evolution of the Near-Field Environment (January 9–12, 2001).” Letter (January 26) to S. Brocoum, DOE. ML010300165 and ML010290320. Washington, DC: NRC. 2001a. <www.nrc.gov/waste/hlw-disposal/public-involvement/mtg-archive.html#KTI>

———. “U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Total System Performance Assessment and Integration (August 6–10, 2001).” Letter (August 23) to S. Brocoum, DOE. ML012410199 and ML012400030. Washington, DC: NRC. 2001b. <www.nrc.gov/waste/hlw-disposal/public-involvement/mtg-archive.html#KTI>

———. “U.S. Nuclear Regulatory Commission/U.S.Department of Energy Technical Exchange and Management Meeting on Range of Operating Temperatures (September 18–19, 2001).” Letter (October 2) to S. Brocoum, DOE. ML012820043 and ML012700285. Washington, DC: NRC. 2001c. <www.nrc.gov/waste/hlw-disposal/public-involvement/mtg-archive.html#KTI>

Reamer. Pre-Licensing evaluation of “Evolution of the Near-Field environment” Key Technical Issue Agreements 3.05 and 4.05 [Status Complete], “Radionuclide Transport” Key Technical Issue Agreements 1.03 and 3.07 [Status complete], and General Agreement 1.01, Comments 43 and 46 [Status Complete]. Letter (December 20) to Mr. Joseph Ziegler, ML043360345, Washington D. C.: NRC. 2004

Integrated Issue Resolution Status Report.: NUREG-1762. Nuclear Regulatory Commission, Office of Nuclear Material safety and Safeguards, Washinton, D.C. NRC (Nuclear Regulatory Commission) 2002.

Schlueter, J. “Evolution of the Near-Field Environment Key Technical Issue Agreements.” Letter (February 14) to S. Brocoum, DOE. ML020460110. Washington, DC: NRC. 2002.

Travers, W.D. “Final Staff Response to March 19, 2003, Requirements Memorandum on the Waste Arena Briefing–M030303A.” Letter (June 5) to Chairman Diaz and Commissioners Dicus, McGaffigan, and Merrifield. Washington, DC: NRC. 2003. <www.nrc.gov/reading-rm/adams.html>

Zarrabi, K., S. McMillan, S. Elkonz, and J. Cizdziel. “Corrosion and Mass Transport Processes in Carbon Steel Miniature Waste Packages.” TR–03–003. Rev. 0. Las Vegas, Nevada: University and Community College System of Nevada. 2003.