APPENDIX A

EXCLUSION OF ENTRAINED COLLOIDS IN THERMAL-CHEMICAL ALTERATION (RESPONSE TO ENFE 1.06, ENFE 4.04, AND GEN 1.01 (COMMENT 35))

This appendix provides a response for Key Technical Issue (KTI) agreement Evolution of the Near-Field Environment (ENFE) 1.06, agreement ENFE 4.04, and general agreement (GEN) 1.01, comment 35. These KTI agreements relate to providing the technical basis for the screening of entrained colloids in its analysis of features, events, and processes (FEPs) and for new transport parameter distributions.

A..1 KEY TECHNICAL ISSUE AGREEMENTS

A.1.1 ENFE 1.06, ENFE 4.04, and GEN 1.01 (Comment 35)

Agreements ENFE 1.06 and ENFE 4.04 were reached during the U.S. Nuclear Regulatory Commission (NRC)/U.S. Department of Energy (DOE) Technical Exchange and Management Meeting on Evolution of the Near-Field Environment held January 9 through 12, 2001, in Pleasanton, California. ENFE KTI subissues 1, 2, 3, and 4 were discussed at that meeting (Reamer 2001). ENFE 1.06 and ENFE 4.04 are identical agreements.

Agreement GEN 1.01 was reached during the NRC/DOE Technical Exchange and Management Meeting on Range of Thermal Operating Temperatures held September 18 through 19, 2001. At that meeting, NRC provided an additional comment relating to ENFE 1.06 (GEN 1.01, comment 35), and DOE provided an initial response (Reamer and Gil 2001).

The wording of these agreements and of DOE's initial response to the general agreement comment is as follows:

ENFE 1.06 and ENFE 4.04

> 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.

GEN 1.01 (Comment 35)

> The SSPA recommends new values for EBS colloid transport parameters. If these are adopted by TSPA in the future, the technical basis for the new distributions will require close scrutiny. Relevant KTI agreements are RT 3.07, ENFE 4.03, ENFE 4.04, and ENFE 4.06.

DOE Initial Response to GEN 1.01 (Comment 35)

The new values for EBS colloidal transport parameters were designed to evaluate unquantified uncertainty for the SSPA. DOE understands that prior to any potential LA, a stronger technical basis must be provided for EBS colloidal transport parameter values carried forward to the base case analysis.

A.1.2 Related Key Technical Issue Agreements

ENFE 4.06

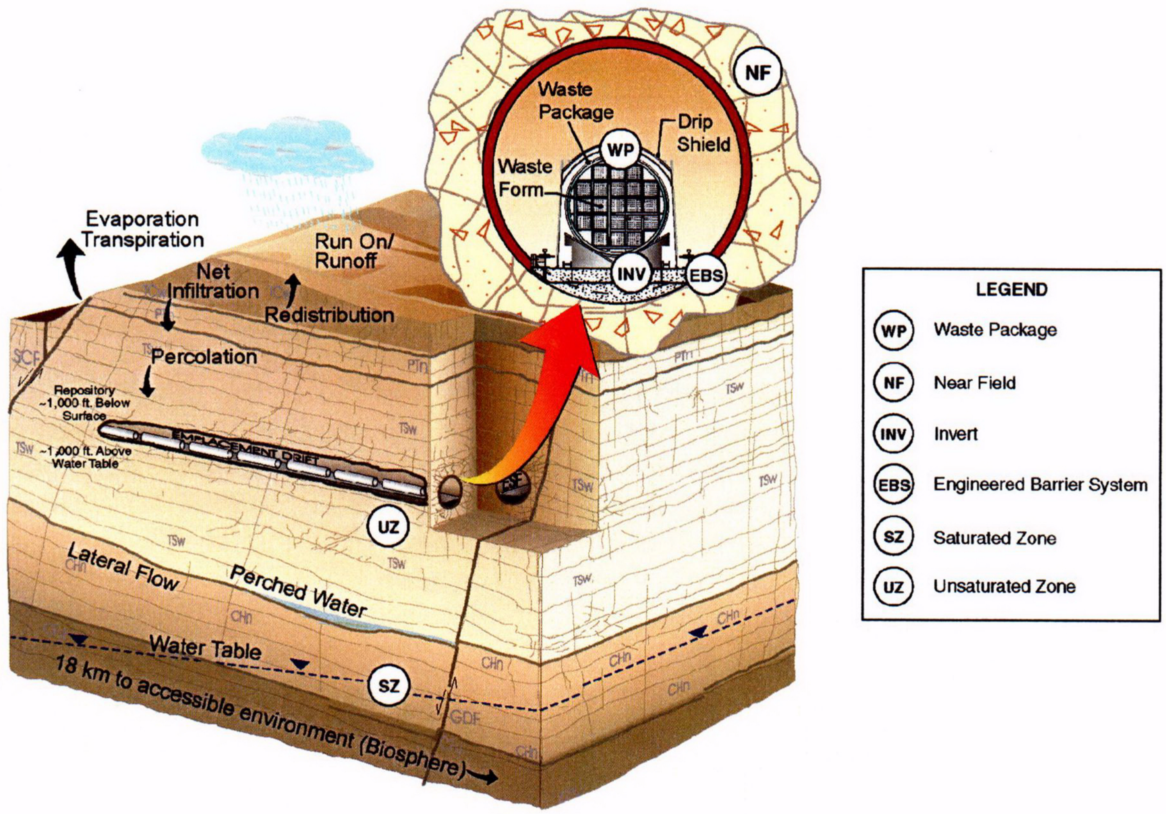
Provide documentation to demonstrate suitability of the bounding values used for colloid transport through the perturbed near-field environment. For example, consider sensitivity analysis to investigate the effects of varying colloid sorption parameters (K_c) on repository performance. The DOE will evaluate 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.

KTI agreements ENFE 4.03 and RT 3.07 have been grouped with KTI agreements ENFE 1.06 and ENFE 4.04 through this technical basis document. Responses to KTI agreements ENFE 4.03 and RT 3.07 appear respectively in Appendix C and Appendix E of this technical basis document.

A.2 RELEVANCE TO REPOSITORY PERFORMANCE

Radioactive colloids, when entrained in groundwater flow, could provide a potentially faster means for the release of radionuclides to the accessible environment relative to the transport of dissolved radionuclides. For colloids to represent such a faster transport means, colloids must remain entrained in the flow (i.e., stable) for tens of kilometers and thousands of years. Effects of changes in the thermal and chemical environment on the formation and stability of colloids is addressed in *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003a). The near-field thermal-chemical analysis indicates only small changes in hydrologic properties and mineralogy as a result of these coupled processes (BSC 2003b, Section 6). Far-field changes are likewise expected to be small, including mineral precipitation/dissolution and alteration of minerals such as zeolites and clays. Therefore, this FEP is excluded from TSPA on the basis of low consequence.

Therefore, excluding entrained colloids in the analysis of the thermal-chemical alteration FEP will not be significant to repository performance. The KTI agreements addressed in this appendix are related to the engineered and near-field environment as shown in Figure A-1.



SYSTEM COMPONENTS	KEY TECHNICAL ISSUE AGREEMENT
NF	ENFE 1.06 and ENFE 4.04: Provide the technical basis for excluding entrained colloids in the analysis of FEP 2.2.10.06.00 (Thermo-Chemical Alteration).
NF	ENFE 4.03: Provide the technical basis for screening out coupled THC effects on radionuclide transport properties and colloids- dissolved and colloids.
NF	ENFE 4.06: Provide documentation to demonstrate suitability of the bounding values used for colloid transport through the perturbed near-field environment.
WP	ENFE 4.05: Provide the screening criteria for the radionuclides selected for PA. Provide the technical basis for selelction of radionuclides that are transported via colloids in the TSPA.
WP	RT 1.03: Provide the screening criteria for the radionuclides selected for PA. Provide the technical basis for selection of the radionuclides that are transported via colloids in the TSPA.
WP	ENFE 3.05: Provide the technical basis for selection of radionuclides that are released via reversible and irreversible attachment to colloids for different waste forms in the TSPA.
INV	TSPAI 3.17: 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 (ENG4.41). DOE will provide an uncertainty analysis of the diffusion coefficient governing transport of dissolved and colloidal radionuclides through the invert.
EBS UZ SZ	TSPAI 3.30 and RT 3.07: Provide the technical basis for the contrasting concentrations of colloids available for reversible attachment in the 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 Kc.
INV UZ SZ	TSPAI 3.42: 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.
SZ	RT 3.08: Provide justification that microspheres can be used as analogs for colloids (for example, equivalent ranges in size, charge, etc.).

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Figure A-1. Mapping of Colloid-Related Key Technical Issues Agreement to Repository System Components

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A.3 RESPONSE

FEP 2.2.10.06.00 considers thermal-chemical alteration effects in the unsaturated zone, specifically solubility, speciation, phase changes and precipitation/dissolution. This FEP was revised and is now discussed as FEP 2.2.10.06.0A in Section 6.8.13 of *Features, Events and Processes in UZ Flow and Transport* (BSC 2003c). This FEP is conservatively ignored with respect to solubility reduction in the far-field; the effects of radionuclide precipitation are ignored in the far-field unsaturated zone transport problem for TSPA. The effects of colloid formation are accounted for in the colloid source term. Colloids are expected to form from the degradation of the HLW glass (with an insignificant contribution from SNF waste forms), engineered barrier system materials, and rock (see Section 3 of this technical basis document). Radionuclides associated with colloids are modeled as either irreversibly or reversibly attached to colloids (CRWMS M&O 2000a, Section 6; CRWMS M&O 2000b, Section 6). The near-field thermal-chemical analysis indicates only small changes in hydrologic properties and mineralogy as a result of these coupled processes (BSC 2003b, Section 6). Therefore, far-field changes are likewise expected to be small, including mineral precipitation/dissolution and alteration of minerals such as zeolites and clays. Therefore, this FEP is excluded from TSPA on the basis of low consequence.

An issue regarding this FEP discussed at the NRC/DOE Technical Exchange and Management Meeting on Evolution of the Near-Field Environment held January 9 through 12, 2001, in Pleasanton, California (Reamer 2001) was the consideration of colloid entrainment due to boiling. At that time, DOE stated that, while colloid entrainment due to boiling had not been considered, this process was not expected to have a significant adverse impact on system performance. The specific statements regarding colloid entrainment due to boiling contained in the documented meeting summary are:

1. Under NRC Comments Related to TSPA Treatment of Engineered Barrier System Chemical Environments, Total System Performance "The NRC asked if the DOE considered colloid entrainment by vigorous water movement in the drift. The DOE answered that they had not considered this but would expect the effect on transport to be small due to (1) low flow rates in the drift and (2) the tendency of boiling-generated flow to be directed toward the source."

2. Under NRC Comments on Colloidal Transport in the Unsaturated Zone (Technical Discussions – Subissue 4, Effects of Coupled Thermal-Hydrologic-Chemical Processes on Radionuclide Transport "... the NRC asked whether the DOE had considered possible entrainment of colloids and particulates in convection/advection fluids during boiling. The DOE said that they had not, but that low fluid fluxes made it unlikely that this effect would be significant."

As discussed below, boiling conditions may enhance the instability of colloid suspensions, rather than enhance colloid entrainment. Therefore, exclusion of colloid entrainment due to boiling is a conservative assumption.

A revision to FEP 2.2.10.06.0A to include entrainment of colloids due to boiling is being addressed. As will be discussed in more detail in Section A.4, it is not believed that colloid entrainment due to thermal-chemical alteration will enhance radionuclide transport.

GEN 1.01 (Comment 35) calls for new values of engineered barrier system colloid transport parameters. Within the engineered barrier system, the main transport mechanism for colloid transport is diffusion through the invert without colloid retardation (see Section 4 of this technical basis document). Therefore, the only relevant parameter for colloid transport through the engineered barrier system is the colloid diffusion coefficient. New values for the diffusivity of dissolved species through the invert are presented in Section 6.3.4.1 of *EBS Radionuclide Transport Abstraction* (BSC 2003d). Diffusivities for colloids are estimated from the dissolved species diffusivity values. These values for colloid diffusion coefficients through the invert are provided in Section A.4.

The information in this report is responsive to agreements ENFE 1.06, ENFE 4.04, and GEN 1.01 (Comment 35) made between the DOE and NRC. The report contains the information that DOE considers necessary for the NRC to review for closure of these agreements.

A.4 BASIS FOR THE RESPONSE

Section 6.8.13 (FEP 2.2.10.06.0A) of *Features, Events and Processes in UZ Flow and Transport* (BSC 2003c) presents the screening argument for excluding the effects of thermal-chemical alteration in the unsaturated zone (solubility, speciation, phase changes, and precipitation/dissolution). This FEP is conservatively excluded with respect to solubility reduction in the far field, and the effects of radionuclide precipitation are excluded in the unsaturated zone transport for TSPA. If solubility limits increase in the geosphere compared with the waste emplacement drift, there is no effect on transport because all available radionuclides from the source at the waste emplacement drift already exist as aqueous species. The thermal-chemical alteration effects on colloid formation have already been accounted for in the colloid source term (BSC 2003a). Therefore, any impact from thermal-chemical alteration on colloid entrainment will be insignificant with respect to total repository system performance.

This screening argument is reasonable because in the rock mass around the repository the temperature may be relatively high compared to ambient host-rock temperature even at 10,000 years. For example, in part (a) of Figure 3-2 of this technical basis document, it is shown that after 10,000 years the temperature is 45° to 50°C, which is significantly higher than the initial temperature of around 25°C. This higher temperature increases the instability of the colloids due to Brownian deposition, as discussed in *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003a).

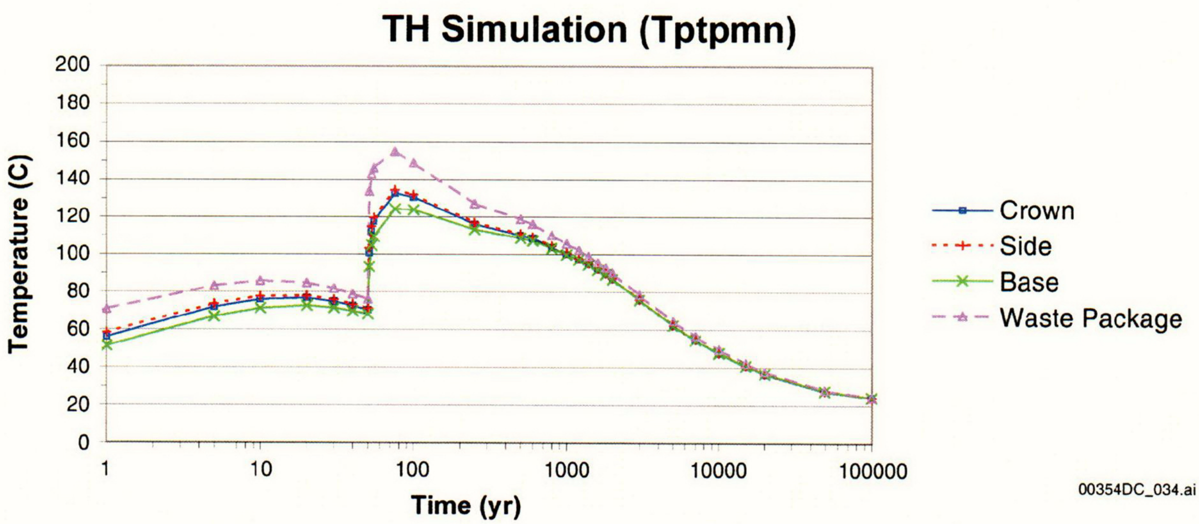
An issue regarding this FEP discussed at the NRC/DOE Technical Exchange and Management Meeting on Evolution of the Near-Field Environment held January 9 through 12, 2001, in Pleasanton, California (Reamer 2001) was the consideration of colloid entrainment due to boiling. As discussed herein, the effect of boiling on entrainment of colloids would be transient restricted to the first 200 years following waste emplacement and extending a few meters away from the drift. The issue raised at the aforementioned meeting was the possibility of boiling-induced detachment of colloids that are already attached to immobile rock. A revision of

this FEP to include this process is being addressed. As discussed below, the exclusion of colloid entrainment has no significant impact on total repository system performance.

Boiling is the result of increased temperature and increased temperature contributes to the instability of colloid suspensions due to Brownian deposition. Also, boiling results in evaporation and this tends to increase the ionic strengths of colloid suspensions leading to instability as discussed in *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003a). In addition, the boiling front is a transient phenomenon, which is expected to happen only for a few hundred years over a scale of meters (BSC 2003b) (see Figures A-2 and A-3). Colloids suspended due to the boiling process, if there are any, will settle out after the physical condition becomes quiescent. Therefore, it is concluded that colloid entrainment as a result of boiling is not a plausible effect under expected repository conditions. Actually, boiling will be a contributor to the instability and settling of colloids out of suspension. Therefore, excluding colloid entrainment due to boiling from consideration in TSPA is a conservative assumption.

In response to GEN 1.01 (Comment 35), the diffusion coefficient for dissolved species has been determined specifically for crushed tuff invert materials as a function of volumetric moisture content (m^3 water/m^3 bulk rock), using electric conductivity measurements (BSC 2003d).

Figure A-4 presents the uncertainty in the statistical fit for the diffusion coefficient.



Source: BSC 2003b.

Figure A-2. Thermal-Hydrologic Simulation (Tptpmn Model): Time Profiles of Modeled Temperatures and Liquid Saturations in Fractures and Matrix at Three Drift-Wall Locations and in the Waste Package

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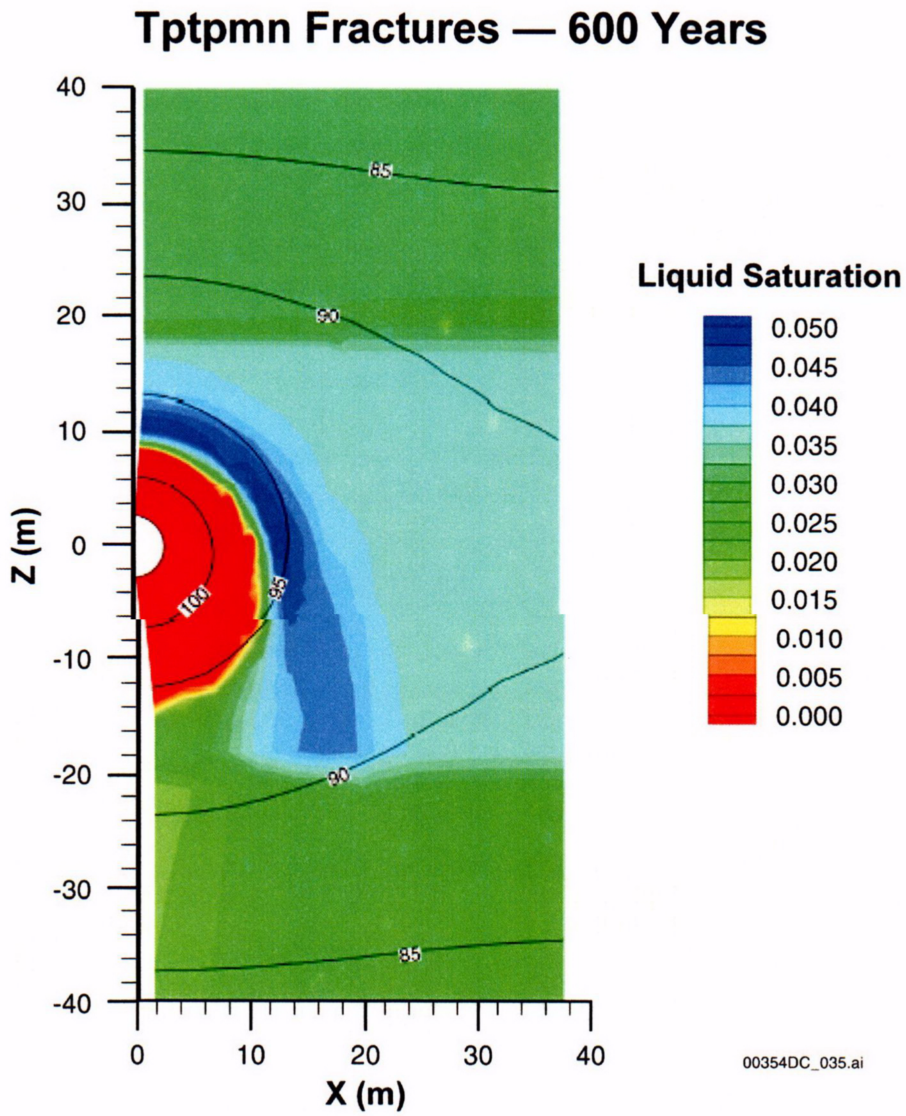
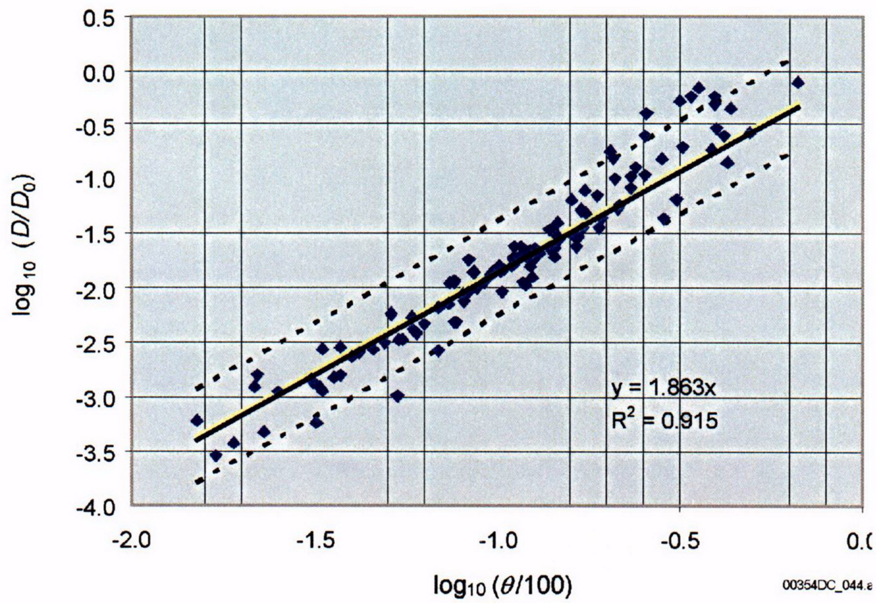


Source: BSC 2003b.

Figure A-3. Thermal-Hydrologic Simulation (Tptpmn Model): Contour Plot of Modeled Temperatures (°C) and Liquid Saturations in Fractures at 600 Years (near Maximum Dryout—Mean Infiltration)



Source: BSC 2003d, Figure 7.

NOTE: The dashed lines correspond to two standard deviations above and below the statistical fit to the data. *D* is the diffusion coefficient of the crushed invert materials, D_0 is the diffusion coefficient of the fully saturated crushed invert materials, and θ is the percentage of saturation.

Figure A-4. Uncertainty in the Statistical Fit for the Diffusion Coefficient

The colloidal diffusion coefficient can be estimated from the following Stokes-Einstein relationship (BSC 2003d):

$$D_{coll} = D_{ion}\left(\frac{r_{ion}}{r_{coll}}\right) \quad \text{(Eq. A-1)}$$

where D_{coll} is the diffusion coefficient for a colloidal particle of radius r_{coll} and D_{ion} is the diffusion coefficient of an ion of radius r_{ion}. Given a typical ion radius and colloidal particle radius of 0.1 and 1 nm, respectively, the diffusion coefficient of a colloidal particle is generally 100 times smaller than that of a dissolved ion.

A.5 REFERENCES

BSC (Bechtel SAIC Company) 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. ACC: DOC.20030626.0006.

BSC 2003b. *Drift-Scale Coupled Processes (DST and THC Seepage) Models.* MDL-NBS-HS-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030804.0004.

BSC 2003c. *Features, Events and Processes in UZ Flow and Transport.* ANL-NBS-MD-000001 REV 02B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030922.0198.

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BSC 2003d. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 01F. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030922.0199.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 2000a. *Particle Tracking Model and Abstraction of Transport Processes.* ANL-NBS-HS-000026 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000502.0237.

CRWMS M&O 2000b. *UZ Colloid Transport Model.* ANL-NBS-HS-000028 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000822.0005.

Reamer, C.W. 2001. 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 from C.W. Reamer (NRC) to S. Brocoum (DOE/YMSCO), January 26, 2001, with enclosure. ACC: MOL.20010810.0033.

Reamer, C.W. and Gil, A.V. 2001. Summary Highlights of NRC/DOE Technical Exchange and Management Meeting of Range on Thermal Operating Temperatures, September 18-19, 2001. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20020107.0162.

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APPENDIX B

SENSITIVITY ANALYSIS OF COLLOID TRANSPORT PARAMETERS (RESPONSE TO ENFE 4.06 AIN-1 AND GEN 1.01 (COMMENTS 35 AND 37))

Note Regarding the Status of Supporting Technical Information

This document was prepared using the most current information available at the time of its development. This Technical Basis Document and its appendices providing Key Technical Issue Agreement responses that were prepared using preliminary or draft information reflect the status of the Yucca Mountain Project's scientific and design basis at the time of submittal. In some cases this involved the use of draft Analysis and Model Reports (AMRs) and other draft references whose contents may change with time. Information that evolves through subsequent revisions of the AMRs and other references will be reflected in the License Application (LA) as the approved analyses of record at the time of LA submittal. Consequently, the Project will not routinely update either this Technical Basis Document or its Key Technical Issue Agreement appendices to reflect changes in the supporting references prior to submittal of the LA.

APPENDIX B

SENSITIVITY ANALYSIS OF COLLOID TRANSPORT PARAMETERS (RESPONSE TO ENFE 4.06 AIN-1 AND GEN 1.01 (COMMENTS 35 AND 37)

This appendix provides a response for additional information needed (AIN) request for Key Technical Issue (KTI) agreements Evolution of the Near-Field Environment (ENFE) 4.06 and general agreement (GEN) (1.01), comments 35 and 37. These KTI agreements relate to providing more information regarding colloid transport parameters and their bounding values.

B.1 KEY TECHNICAL ISSUE AGREEMENTS

B.1.1 ENFE 4.06 AIN-1 and GEN 1.01 (Comments 35 and 37)

Agreement ENFE 4.06 was reached during the U.S. Nuclear Regulatory Commission (NRC)/U.S. Department of Energy (DOE) Technical Exchange and Management Meeting on Evolution of the Near-Field Environment held January 9 through 12, 2001, in Pleasanton, California. ENFE KTI subissues 1, 2, 3, and 4 were discussed at that meeting (Reamer 2001).

In evaluating the response to this agreement, NRC reviewed *Total System Performance Assessment for the Site Recommendation* (CRWMS M&O 2000), which contained sensitivity analyses of the effects of colloid parameters on repository performance. NRC staff noted that the analyses in the total system performance assessment (TSPA) for the site recommendation did not include values for parameters outside the adopted uncertainty range and, therefore, provided insufficient information regarding uncertainties in colloidal behavior (Schlueter 2002). They commented that "Future sensitivity studies should address the substantial uncertainties regarding colloidal behavior during waste corrosion and radionuclide release." NRC requested specific additional information needed to complete KTI agreement ENFE 4.06, and added that information provided by DOE in response to ENFE Agreement 4.03 would also be used in the evaluation of ENFE 4.06.

During the NRC-DOE technical exchange and management meeting on thermal operating temperatures, held September 18 through 19, 2001, the NRC provided additional comments that are related to ENFE 4.06 (Reamer and Gil 2001). These comments (GEN 1.01, comments 35 and 37) related to colloidal transport parameters for the engineered barrier system and thermal chemical effects on transport in the unsaturated zone. DOE provided initial responses to these comments (Reamer and Gil 2001).

The wording of these agreements and of DOE's initial response to the general agreement comments is as follows:

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.

ENFE 4.06-AIN

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.

GEN 1.01 (Comment 35)

The SSPA recommends new values for EBS colloid transport parameters. If these are adopted by TSPA in the future, the technical basis for the new distributions will require close scrutiny. Relevant KTI agreements are RT 3.07, ENFE 4.03, ENFE 4.04, and ENFE 4.06.

DOE Initial Response to GEN 1.10 (Comment 35)

The new values for EBS colloidal transport parameters were designed to evaluate unquantified uncertainty for the SSPA. DOE understands that prior to any potential LA, a stronger technical basis must be provided for EBS colloidal transport parameter values carried forward to the base case analysis.

GEN 1.01 (Comment 37)

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.

DOE Initial Response to GEN 1.01 (Comment 37)

DOE acknowledges this comment and notes that some limited studies were documented in Section 11.3.5.4.2 of SSPA 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.

B.1.2 Related Key Technical Issues

ENFE 1.06

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.

GEN 1.01

For NRC comments 3, 5, 8, 9, 10, 12, 13, 15, 16, 18, 21, 24, 27, 36, 37, 41, 42, 45, 46, 50, 56, 64, 69, 75, 78, 81, 82, 83, 93, 95, 96, 97, 98, 102, 103, 104, 106, 109, 110, 111, 113, 116, 118, 119, 120, 122, 123, 124, and 126, DOE will address the concern in the documentation for the specific KTI agreement identified in the DOE response (Attachment 2). The schedule and document source will be the same as the specific KTI agreement.

NRC Comment 37

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.

DOE response to Comment 37

DOE acknowledges this comment and notes that some limited studies were documented in Section 11.3.5.4.2 of SSPA 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.[1], [2]

TSPAI 2.02

Provide the technical basis for the screening argument, as summarized in Attachment 2, for the highlighted FEPs. The technical basis will be provided in the referenced FEPs AMR and will be provided to the NRC in FY2003.

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[1] The information presented in this document does not, at this time, represent a commitment to perform additional work. DOE is currently considering and scoping the appropriateness of a lower-temperature operating mode for potential LA, should the site be approved.

[2] Should the site be approved, DOE will, as appropriate, re-evaluate the impact of a lower-temperature operating mode upon existing KTIs, which were established on the basis of the higher-temperature operating mode.

B.2 RELEVANCE TO REPOSITORY PERFORMANCE

Colloid concentrations released from the engineered barrier system will travel through the near-field region of the unsaturated zone. The perturbed thermal and chemical conditions in the near-field region could affect the stability of the colloid suspension and therefore the concentration of colloids available to carry radionuclides through the unperturbed region of the unsaturated zone.

This KTI agreement is related to the near-field environment as shown in Figure B-1. The technical basis for the response to this KTI agreement appears in Section 5 of this technical basis document.

B.3 RESPONSE

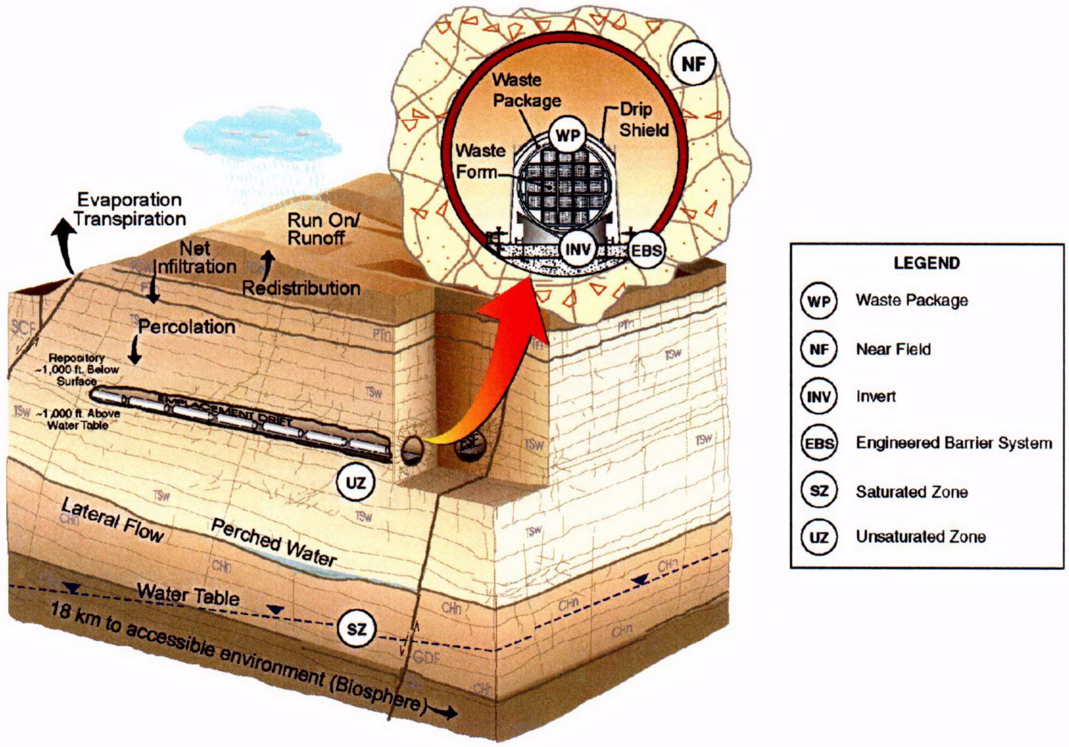
Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary (BSC 2003a) presented and summarized the results of experiments related to colloid formation during waste corrosion and release of radioactive colloids from the waste package. Values of colloid parameters, including the sorption coefficient, are provided in Section B.4. Uncertainty in colloid distribution coefficient, K_c, has been captured by sampling both colloid concentration and the sorption coefficient, K_d, and multiplying the sampled values.

As discussed in Sections 3.1.1, 3.2.5, 4.1.3, and Appendix C of this technical basis document, the thermal and chemical perturbations in the near-field during much of the 10,000-year regulatory period are likely to destabilize colloid suspensions by increasing Brownian motion and particle collision caused by higher temperature and increasing ionic strength of solution. Therefore, parameter ranges provided in *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003a) are still suitable for the perturbed near-field environment. In addition, any perturbed colloid concentration inside the drift will ultimately attenuate to the background concentration in the Yucca Mountain groundwater as the colloidal solution percolates through the invert and the unsaturated zone into the saturated zone, and the water chemistry converges to the ambient groundwater.

For small K_d values, the colloid concentrations in the Yucca Mountain environment are not high enough to compete with dissolved species. The distribution coefficient (K_c), a product of the sorption coefficient K_d and colloid concentration, is calculated based on the distributions of both K_d values and colloid concentrations. The colloid concentration used in the TSPA for the license application (LA) is sampled over the range of 0.001 to 200 ppm, as compared to the single mean value of 3×10^{-2} ppm used in the TSPA for the site recommendation (BSC 2001, p. 60). The wide ranges of both colloid concentrations and K_d values constructed for TSPA-LA are expected to capture all potential uncertainties associated with K_c.

New values for the diffusivity of dissolved species through the invert documented in Section 6.3.4.1 of *EBS Radionuclide Transport Abstraction* (BSC 2003b) and the related sensitivity analysis are summarized in Section 4 of this technical basis document. From the dissolved species diffusivity values, diffusivities for colloids are estimated.

The information in this report is responsive to agreements ENFE 4.06 AIN-1 and GEN 1.01 (comments 35 and 37) made between the DOE and NRC. The report contains the information that DOE considers necessary for the NRC to review for closure of these agreements.



SYSTEM COMPONENTS	KEY TECHNICAL ISSUE AGREEMENT
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NF	ENFE 4.03: Provide the technical basis for screening out coupled THC effects on radionuclide transport properties and colloids- dissolved and colloids.
NF	ENFE 4.06: Provide documentation to demonstrate suitability of the bounding values used for colloid transport through the perturbed near-field environment.
WP	ENFE 4.05: Provide the screening criteria for the radionuclides selected for PA. Provide the technical basis for selelction of radionuclides that are transported via colloids in the TSPA.
WP	RT 1.03: Provide the screening criteria for the radionuclides selected for PA. Provide the technical basis for selection of the radionuclides that are transported via colloids in the TSPA.
WP	ENFE 3.05: Provide the technical basis for selection of radionuclides that are released via reversible and irreversible attachment to colloids for different waste forms in the TSPA.
INV	TSPAI 3.17: Provide an uncertainty analysis of the diffustion coefficient governing transport of dissolved and colloidal radionuclides through the invert. The analysis should include uncertainty in the modeled invert saturation (ENG4.41). DOE will provide an uncertainty analysis of the diffusion coefficient governing transport of dissolved and colloidal radionuclides through the invert.
EBS UZ SZ	TSPAI 3.30 and RT 3.07: Provide the technical basis for the contrasting concentrations of colloids available for reversible attachment in the 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 Kc.
INV UZ SZ	TSPAI 3.42: 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.
SZ	RT 3.08: Provide justification that microspheres can be used as analogs for colloids (for example, equivalent ranges in size, charge, etc.).

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Figure B-1. Mapping of Colloid-Related Key Technical Issue Agreements to Repository System Components

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B.4 BASIS FOR THE RESPONSE

Estimation of typical colloid concentrations in the engineered barrier system and unsaturated zone are discussed in *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003a) and summarized below:

- The static-saturated tests at Argonne National Laboratory indicated that colloids developed and increased in concentration with time, up to the point where the colloid concentration reached a maximum value and then the colloidal suspension became less stable. This is due to colloid agglomeration and settling because of high ionic strengths (BSC 2003a). The maximum colloid concentration from experimental degradation of the high-level radioactive waste glass is estimated to be 5 ppm (BSC 2003a, Figure 3).

- The concentration range of iron oxyhydroxide colloids generated from the defense high-level radioactive waste glass values are estimated based on experiments performed at the University of Nevada, Las Vegas. In these experiments, scaled-down miniature waste packages were exposed to J-13 groundwater in either a bath-tub mode or a flow-through mode. The cumulative results have yielded average concentrations of colloidal size materials in the range of 20 mg/L within the initial four weeks of the experiments (BSC 2003a, p. 56).

- The range of colloid concentration in seepage/groundwater was derived based on literature data and groundwater sampling from the Yucca Mountain area and Idaho National Engineering and Environmental Laboratory (BSC 2003a, Figures 11 and 12). Practically no colloids were detected for ionic strengths above 0.05 M. The upper limit of colloid concentration is about 200 ppm, with average values of approximately 0.1 ppm.

Features, Events and Processes in UZ Flow and Transport (BSC 2003c, Section 6.8.13) presents the screening argument for excluding coupled thermal-hydrologic-chemical effects on radionuclide transport properties and colloids in the unsaturated zone (solubility, speciation, phase changes, and precipitation/dissolution). This FEP is conservatively ignored with respect to solubility reduction in the far field, and the effects of radionuclide precipitation are ignored in the unsaturated zone transport for TSPA. If solubility limits increase in the geosphere compared with the waste emplacement drift, there is no effect on transport because all available radionuclides from the source at the waste emplacement drift are already aqueous species. The thermal-chemical effects on colloid formation have already been accounted for in the colloid source term (BSC 2003a). Therefore, any impact from thermal-chemical alteration on colloid entrainment will be insignificant with respect to total repository system performance.

This screening argument is reasonable because in the rock mass around the repository the temperature may be relatively high even at 10,000 years. For example, in *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (BSC 2003d, Section 6.5.2) it is shown that after 10,000 years, the temperature is 45° to 50°C, which is significantly higher than the initial temperature of around 25°C. This higher temperature tends to decrease the stability of a colloidal suspension, as discussed in *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003a).

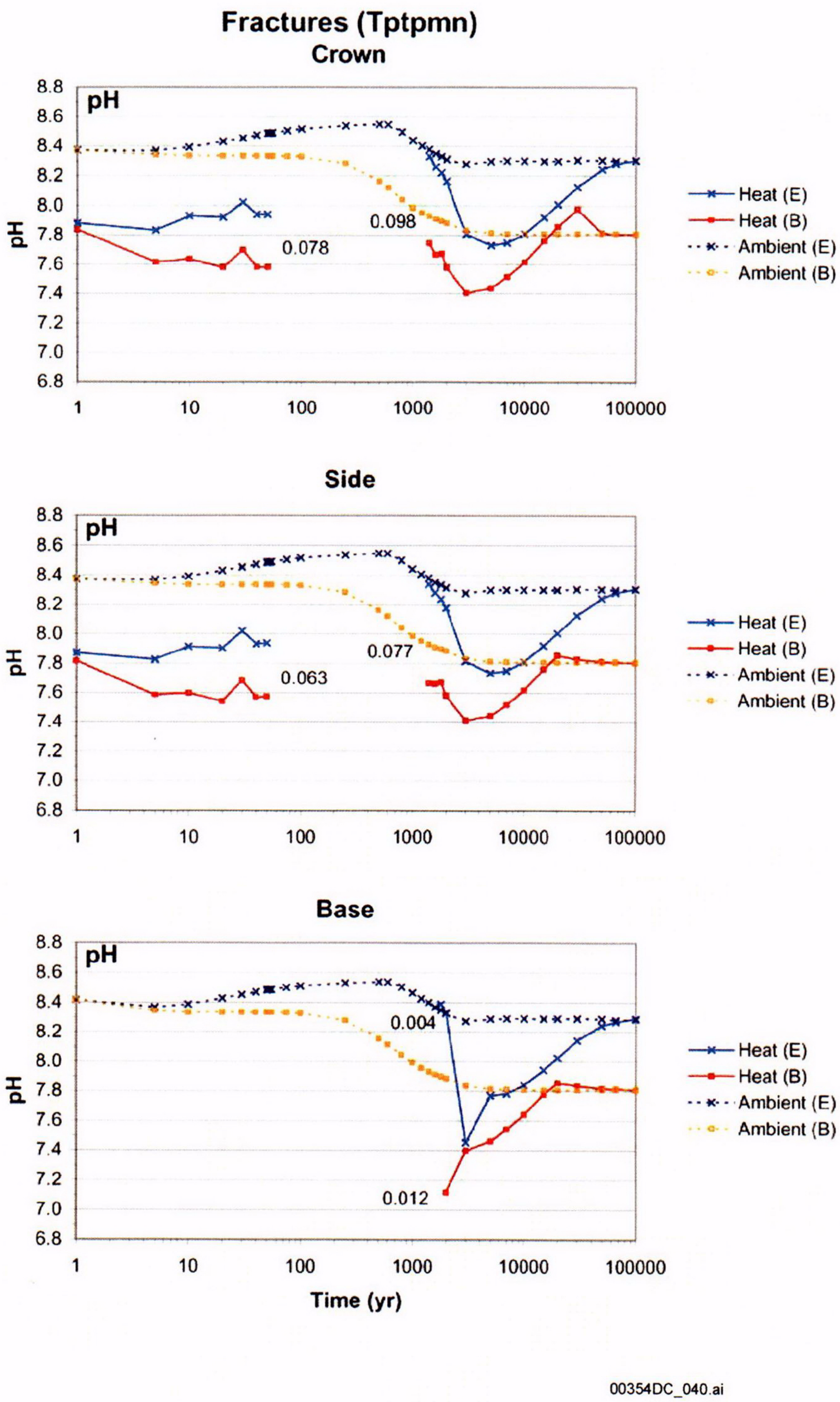
The thermal-hydrologic-chemical model simulations have been performed for both the base case and the extended case and for both Tptpmn and Tptpll geologic formations (BSC 2003d). The extended case includes the major solid phases (minerals and glass) encountered in geologic units at Yucca Mountain, together with a range of possible reaction product minerals, CO_2 gas, and the aqueous species necessary to include these solid phases and the pore-water composition within the thermal-hydrologic-chemical model. The base case is a subset of the extended case excluding aluminum silicate minerals, which form or dissolve much less easily than minerals such as calcite or gypsum. The results for the Tptpmn rock unit are shown in Figures B-2 and B-3. The pH in fracture waters varies within 7.4 to 8.6 but still remains alkaline over the 10,000-year regulatory time period (Figure B-2), and thus its effect on colloid stability is expected to be negligible. The concentrations of soluble components (e.g., Na and Cl) and therefore the ionic strength in the waters are predicted to increase over the time period of thermal event (Figure B-4), which will reduce colloid stability. The thermal-hydrologic-chemical effect may also change the transport properties of rock. However, Figure B-3 shows that this change is small and can be negligible for colloid transport.

In addition to colloid concentration, which is determined by colloid stability and filtration, the partitioning coefficient of radionuclides between colloids and solution (denoted as K_c) is another factor controlling colloid-facilitated transport. K_c is the product of K_d and colloid concentration. The updated K_d values are tabulated in Table B-1. These K_d values are used to calculate K_c together with the sampled colloid concentrations (Figure B-5). Note that in the TSPA-LA the same concentration distribution of groundwater (i.e., smectite) colloids is used for the engineered barrier system, the unsaturated zone, and the saturated zone, except that in the engineered barrier system the concentration changes due to a potential shift in colloid stability is explicitly taken into account. The colloid concentration used in the TSPA-LA is sampled over 0.001 to 200 ppm, as compared to the single mean value of 3×10^{-2} ppm used in the TSPA-SR (BSC 2001, p. 60). These wide ranges of both colloid concentrations and K_d values constructed for TSPA-LA are expected to capture all potential uncertainties associated with K_c

In response to the GEN 1.01 (comment 35) agreement, data on diffusion coefficients have been provided (BSC 2003b). The remainder of this section provides the technical basis in response to this agreement.

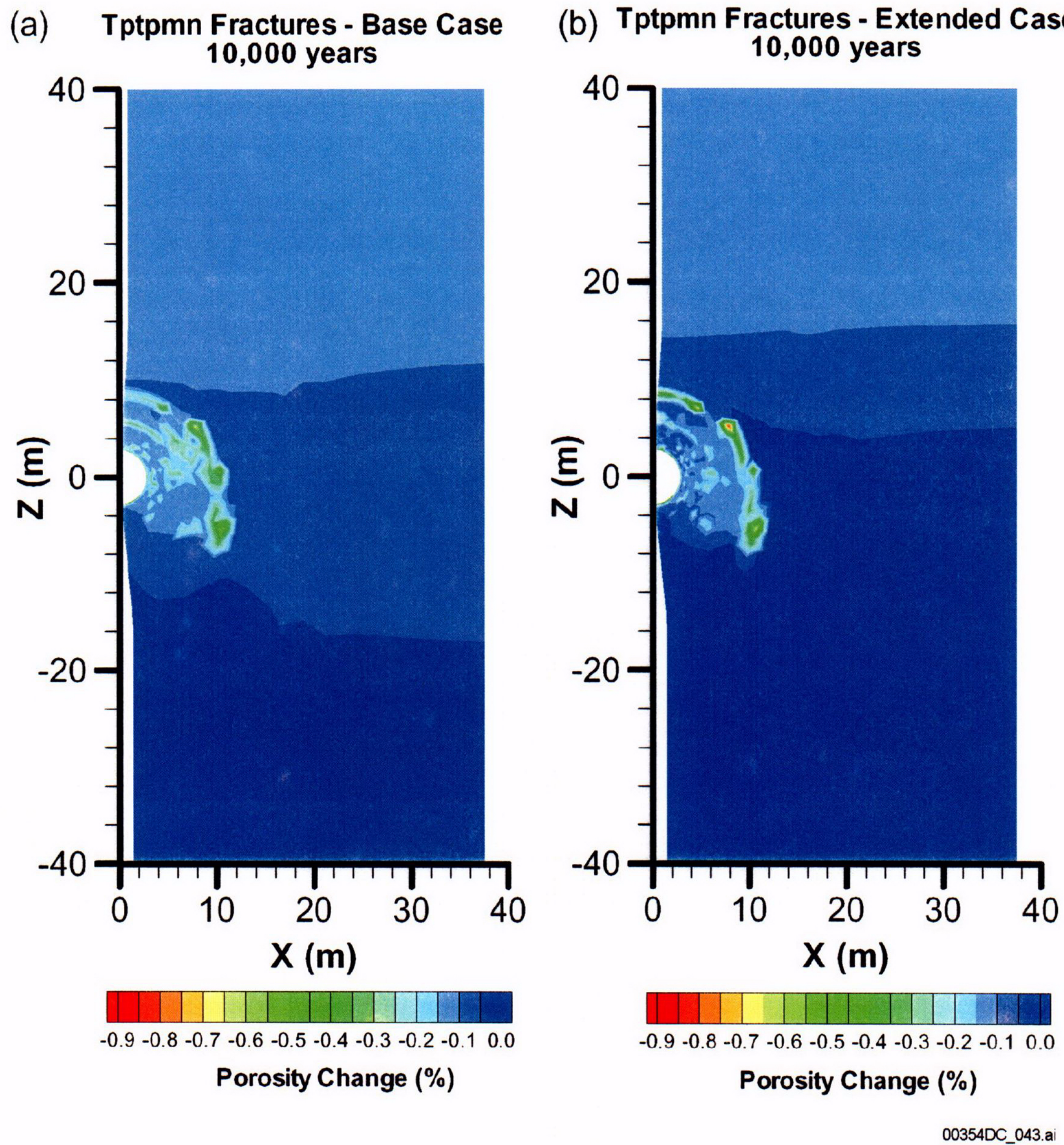
The diffusion coefficient for dissolved species has been determined specifically for crushed tuff invert materials as a function of volumetric moisture content (m^3 water/m^3 bulk rock), using electric conductivity measurements (BSC 2003b).

Figure B-6 presents the uncertainty in the statistical fit for the diffusion coefficient.



Source: BSC 2003d.

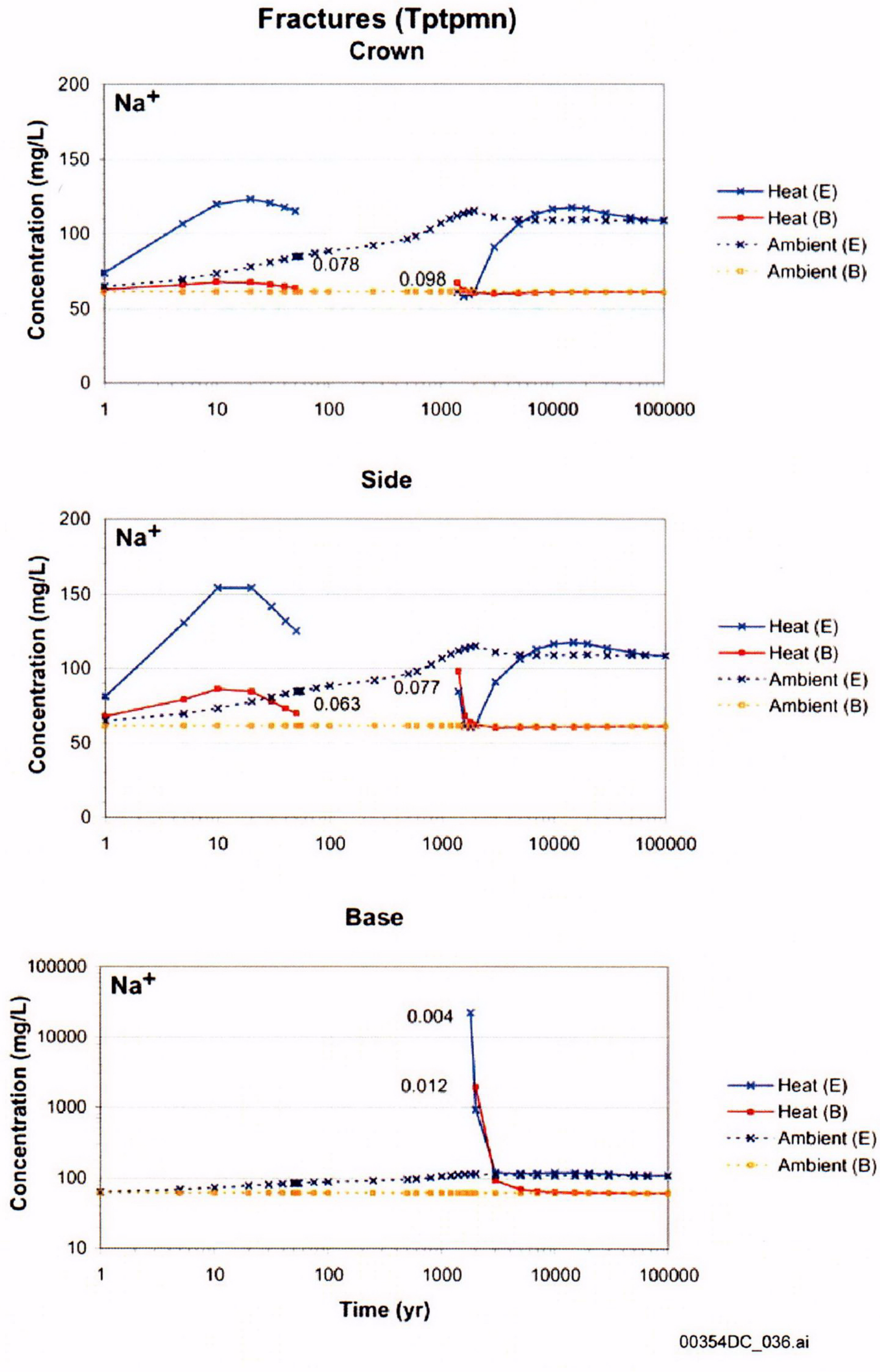
Figure B-2. Thermal-Hydrologic-Chemical Simulation (Tptpmn Model): Time Profiles of the Modeled pH of Fracture Water at Three Drift-Wall Locations under Heating (Heat) and Nonheating (Ambient) Conditions for the Extended (E) and Base-Case (B) Geochemical Systems



Source: BSC 2003d.

NOTE: Decrease in porosity is primarily due to the precipitation of calcite and amorphous silica.

Figure B-3. Thermal-Hydrological-Chemical Model Simulation (Tptpmn Model): Contour Plot of Modeled Fracture Porosity Change at 10,000 Years for (a) Base-Case and (b) Extended Geochemical Systems



Source: BSC 2003d.

Figure B-4. Thermal-Hydrologic-Chemical Simulation (Tptpmn Model): Time Profiles of Modeled Total Aqueous Sodium Concentrations in Fracture Water at Three Drift-Wall Locations under Heating (Heat) and Nonheating (Ambient) Conditions for Extended and Base-Case Geochemical Systems

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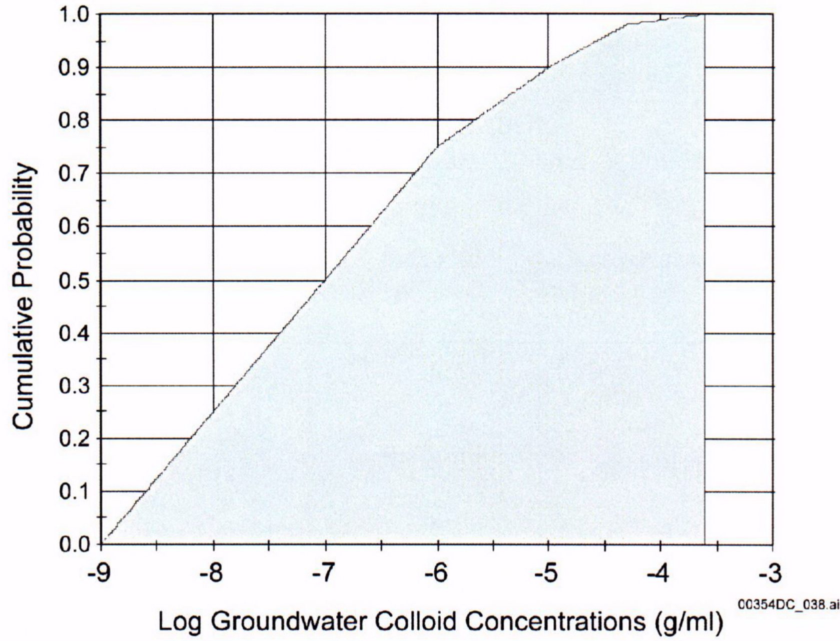
Table B-1. K_d Values (mL/g) Used for Reversible Radionuclide Sorption on Colloids in Total System Performance Assessment-License Application Calculations

Radionuclide	Colloid	K_d Value Range (mL/g)	K_d Value Intervals (mL/g)	K_d Value Interval Probabilities
Pu	Iron Oxyhydroxide	10^4 to 10^6	$<1 \times 10^4$ 1×10^4 to 5×10^4 5×10^4 to 1×10^5 1×10^5 to 5×10^5 5×10^5 to 1×10^6 $> 1 \times 10^6$	0 0.15 0.2 0.5 0.15 0
	Smectite	10^3 to 10^6	$< 1 \times 10^3$ 1×10^3 to 5×10^3 5×10^3 to 1×10^4 1×10^4 to 5×10^4 5×10^4 to 1×10^5 1×10^5 to 5×10^5 5×10^5 to 1×10^6 $> 1 \times 10^6$	0 0.04 0.08 0.25 0.2 0.35 0.08 0
Am, Th, Pa	Iron Oxyhydroxide	10^5 to 10^7	$< 1 \times 10^5$ 1×10^5 to 5×10^5 5×10^5 to 1×10^6 1×10^6 to 5×10^6 5×10^6 to 1×10^7 $> 1 \times 10^7$	0 0.15 0.2 0.55 0.1 0
	Smectite	10^4 to 10^7	$< 1 \times 10^4$ 1×10^4 to 5×10^4 5×10^4 to 1×10^5 1×10^5 to 5×10^5 5×10^5 to 1×10^6 1×10^6 to 5×10^6 5×10^6 to 1×10^7 $> 1 \times 10^7$	0 0.07 0.1 0.23 0.2 0.32 0.08 0
Cs	Iron Oxyhydroxide	10^1 to 10^3	$< 1 \times 10^1$ 1×10^1 to 5×10^1 5×10^1 to 1×10^2 1×10^2 to 5×10^2 5×10^2 to 1×10^3 $> 1 \times 10^3$	0 0.13 0.22 0.55 0.1 0
	Smectite	10^2 to 10^4	$< 1 \times 10^2$ 1×10^2 to 5×10^2 5×10^2 to 1×10^3 1×10^3 to 5×10^3 5×10^3 to 1×10^4 $> 1 \times 10^4$	0 0.2 0.25 0.5 0.05 0

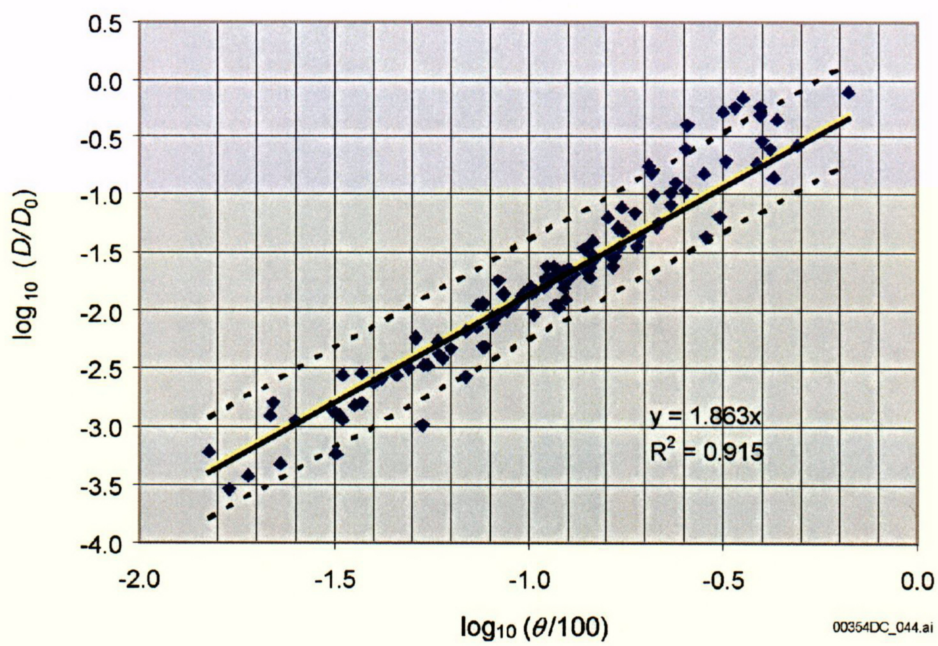
Source: BSC 2003a, Table 10.

NOTE: The K_d values for Tc and I are very low and not listed here.



Source: BSC 2003e.

Figure B-5. Cumulative Distribution Function of Uncertainty in Groundwater Colloid Concentrations



Source: BSC 2003b, Figure 7.

NOTE: The dashed lines correspond to two standard deviations above and below the statistical fit to the data.

Figure B-6. Uncertainty in the Statistical Fit for the Diffusion Coefficient, D, of Solute as a Function of Log Percent Moisture, θ, where D_0 is the Solute Diffusion Coefficient in Bulk Water

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The colloidal diffusion coefficient can be estimated from the following Stokes-Einstein relationship (BSC 2003b):

$$D_{coll} = D_{ion}\left(\frac{r_{ion}}{r_{coll}}\right) \qquad \text{(Eq. B-1)}$$

where D_{coll} is the diffusion coefficient for a colloidal particle of radius r_{coll} and D_{ion} is the diffusion coefficient of a ion of radius r_{ion}. Given a typical ion radius and colloidal particle radius of 0.1 and 1 nm, respectively, the diffusion coefficient of a colloidal particle is generally 100 times smaller than that of a dissolved ion.

B.5 REFERENCES

BSC (Bechtel SAIC Company) 2001. *Uncertainty Distribution for Stochastic Parameters.* ANL-NBS-MD-000011 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020506.0917.

BSC 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. ACC: DOC.20030626.0006.

BSC 2003b. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001 REV 01F. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030922.0199.

BSC 2003c. *Features, Events and Processes in UZ Flow and Transport.* ANL-NBS-MD-000001 REV 02B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030922.0198.

BSC 2003d. *Drift-Scale Coupled Processes (DST and THC Seepage) Models.* MDL-NBS-HS-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030804.0004.

BSC 2003e. *SZ Flow and Transport Model Abstraction.* MDL-NBS-HS-000021 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030612.0138.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 2000. *Total System Performance Assessment for the Site Recommendation.* TDR-WIS-PA-000001 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001220.0045.

Reamer, C.W. 2001. 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 from C.W. Reamer (NRC) to S. Brocoum (DOE/YMSCO), January 26, 2001, with enclosure. ACC: MOL.20010810.0033.

Reamer, C.W. and Gil, A.V. 2001. Summary Highlights of NRC/DOE Technical Exchange and Management Meeting of Range on Thermal Operating Temperatures, September 18-19, 2001. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20020107.0162.

Schlueter, J. 2002. "Evolution of the Near-Field Environment Key Technical Issue Agreements" Letter from J. Schlueter (NRC) to S. Brocoum (DOE/YMSCO), February 14, 2002, 0225021620, with enclosure. ACC: MOL.20020607.0086.