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Subissue 1: Effects of Coupled Thermal-Hydrologic-Chemical Processes on Seepage and Flow

Importance to System Performance: The integrated subissue on flow paths in the unsaturated zone is concerned with flow paths above and below the repository horizon, as well as seepage into the emplacement drifts. All of these processes could be altered by persistent THC-induced changes to rock properties. A calibrated, three-dimensional, mountain-scale flow model was developed. This model is based on the dual-permeability formulation for fracture/matrix flow with the active-fracture model. The active-fracture model formulation has been used to describe the reduced coupling between fractures and matrix that is expected under unsaturated conditions. Partitioning between the matrix and the fracture system is important because flow through the fractures is rapid compared to flow through the matrix. In addition, sorption on minerals is expected to retard radionuclide movement in the matrix but not in the fractures. Data used in the model were obtained for the ambient system, which has not been altered by repository-induced THC effects.

The NRC maintains that DOE has generally neglected the effects of THC alteration on fracture and rock properties that affect unsaturated zone flow and transport. However, DOE has not yet provided an adequate technical basis for neglect of thermal alterations that are expected to develop under expected repository conditions.

Acceptance Criterion (AC) 1—Integration for Evolution of the Near-Field Environment Subissue 1: Important design features, physical phenomena and couplings, consistent and appropriate assumptions have been incorporated into the abstraction of flow paths in the unsaturated zone in the total system performance assessment and the technical bases are provided. The total system performance assessment abstraction identifies and describes aspects of flow paths in the unsaturated zone and seepage that are important to waste isolation and includes the technical bases for these descriptions. Specifically (see numbered items below),

1-1. DOE provides adequate technical bases, including activities such as independent modeling, laboratory or field data, or sensitivity studies, for exclusion of any thermal-hydrologic-mechanical-chemical (THMC) couplings and FEPs.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. In the audit review of Pickett and Leslie, it was determined that 15 of the excluded 17 FEPs have inadequate or missing screening arguments. (ENFE IRSR, Rev. 3, Sect. 5.4.1.2.1.1) DOE should provide adequate screening arguments for those FEPs identified by Pickett and Leslie (1999) or in Section 5.4.1.2 as having inadequate or missing screening arguments. The two FEPs on dehydration reactions identified as missing from the preliminary DOE FEP database should also be addressed [IRSR 5.0.2 (5)]	CLOSED PENDING. The revised THC AMRs and PMRs adequately identify and describe aspects of flow paths in the UZ and seepage important to waste isolation and include the technical bases for FEPs included and excluded for TSPA-SR. The document reviewed by the NRC had placeholders for screening arguments that were never intended for review. The placeholder information was intended only to show how the information in the database would be portrayed. Revision 01 of the FEPs database includes new screening arguments for primary and secondary FEPS [CRWMS M&O 2000af and CRWMS M&O	

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	2000bg]. Section 2.1 of the NFE PMR (CRWMS M&O 2000ad) describes the process of analysis used to determine which couplings need to be considered in PA, and which were excluded, and the technical justification for that determination. Section 2.1 identifies and describes the weak couplings as second or third order effects for the NFE processes. Analysis is presented that demonstrates that weak coupled processes are second or third order effects and may be neglected in TSPA calculations. This reduces the computer computational effort required to compute coupled problems. Sections 3.3 and 3.4 of the NFE PMR (CRWMS M&O 2000ad) describe the process level models, model abstractions and supporting analyses that address the NFE processes. The THC Process AMR and THC Abstraction AMR (CRWMS M&O 2000 and 2000) describe the inputs and assumptions that underlie the modeling. Detailed justification is provided as the basis for each assumption.(NFE PMR CRWMS-M&O 2000ad) It should also be noted that Section 2.5 of the NFE PMR (CRWMS M&O 2000ad) describes the FEPs included in this PMR. The NFE FEPs AMR (CRWMS M&O 2000ai) provides the technical bases and documentation for TSPA. Documentation includes justification for each excluded FEP, including the criterion on which it was excluded and the technical basis for the screening argument. The coupling of THC to seepage and flow is	

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	analyzed in the UZ F&T PMR (CRWMS M&O 2000ab). The approach used to resolve Subissue 1, acceptance criterion 1, is also documented in Appendix A of EBS PMR (CRWMS M&O 2000aa). The above described will continue through LA.	
1-2. DOE provides the bases and justification for modeling assumptions and approximations where simplifications for modeling coupled THMC effects on percolation and seepage and used for performance assessment.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Modeling Reports and Process and Modeling Reports is needed. (ENFE IRSR, Rev. 3, Sect. 5.4.1.2.1.1) No technical bases were provided for neglecting the potential alterations to the Paintbrush Tuff. DOE should provide a technical basis for neglecting thermal alteration of the Paintbrush Tuff, demonstrate that thermal alteration of this unit is unimportant to performance, or include the effects in abstracted models [IRSR 5.0.2 (2)].	CLOSED PENDING. Sections 3.3 and 3.4 (CRWMS M&O 2000aa) describe the process level models, model abstractions and supporting analyses that address the NFE processes. The THC Process AMR and THC Abstraction AMR (CRWMS M&O 2000ba and 2000bb) that support development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption.(ENFE PMR R0ICN2, S1IAC3) The coupling of THC to seepage and flow is described in the UZ F&T PMR (CRWMS M&O 2000ab). This acceptance criterion is also discussed in Appendix A of the EBS PMR (CRWMS M&O 2000aa). Data exist for the PTn temperature. Importance of the Paintbrush Tuff will be verified prior to LA. Flow to the repository horizon is modeled as vertical. The model takes no credit for repository-scale lateral attenuation in the Paintbrush	No additional work is required beyond that already planned.

	nonwelded hydrogeologic unit. The PTn is modeled as a layered unit with resulting variable hydrogeologic properties (CRWMS M&O 2000ab, Section 3.7.2). DOE has modeled mineralogic variability and the resulting effects of that variability on flow properties in the episodic flow models. Transient episodic flows are not explicitly modeled because of attenuation (of vertical flow) in the PTn, which tends to transform flow from fracture dominated to matrix dominated. Porosity in the PTn is so great that changes associated with thermal alteration of the unit are not expected to be important to TSPA modeling. This preliminary conclusion will be verified prior to LA. The THC Process AMR and THC Abstraction AMR (CRWMS M&O 2000ba and 2000bb) and the UZ FEPs AMR are scheduled for completion in FY 2001.	
1-3. DOE temporal abstractions of the flow paths in the unsaturated zone appropriately incorporate the physical couplings if sufficient justification is provided for exclusion of these couplings. The DOE abstraction incorporates or conservatively bounds coupled processes based on, for example, independent models, laboratory and field analyses, literature reviews, natural analog data, and other available information.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Coupled THC processes that might affect flow paths in the UZ and seepage into drifts were omitted without technical justification in the TSPA-VA. DOE should provide an improved basis for neglecting mineral precipitation in a highly localized zone at the interface between fractures and matrix. [IRSR 5.0.2 (4)] Data justification, data uncertainty, model uncertainty, and model support were not reviewed because the supporting	CLOSED PENDING. Also see discussion the for acceptance criterion 4-1. Discussions of TOUGHREACT and other codes are discussed under criterion 2-4a. Temporal abstractions of flow fields are limited to climate change (CRWMS M&O 2000am, Section 3.7.5.1). Changes in hydrologic properties related to THC changes are negligible based on an initial fracture porosity of 1% and the calculational limit of uniform distribution of precipitate within a	

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Analysis and Model Report was not available prior to May 15, 2000. (ENFE IRSR, Rev. 3, Sect. 5.4.1.2.1.1)	computational element. Sensitivity studies of these issues are under way. These studies include consideration of highly localized mineral precipitation. (CRWMS M&O 2000ab, Section 5.2.4) Section 2.1 of the NFE PMR (CRWMS M&O 2000ad describes the process of analysis used to determine which couplings need to be considered in PA, and which were excluded, and the technical justification for that determination. Section 2.1 identifies and describes the weak couplings as second or third order effects for the NFE processes. Weak coupled processes may be **neglected in the initial calculations as second or third order effects. This reduces the computer** computational effort required to compute coupled problems. Sections 3.3 and 3.4 describe the process level models, model abstractions and supporting analyses that address the NFE processes. The THC Process AMR and THC Abstraction AMR (CRWMS M&O 2000ba and 2000bb) that support development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justification are provided for the basis for each assumption. The Repository Safety Strategy (RSS) describes the factors that contribute strongly to performance (CRWMS M&O 2000al). Coupled processes are described in the RSS as factors that do not contribute strongly to performance (NFE PMR CRWMS-M&O 2000ad). It should also be noted that Section 2.5 of the NFE PMR (CRWMS M&O 2000ad) describes the FEPs included in this PMR. The NFE FEPs AMR (CRWMS M&O 2000ad) supporting this section provides documentation and justification for	

	screening arguments and TSPA dispositions. Documentation includes a statement of the screening decision for each FEP. Justification is provided for each excluded FEP, including the criterion on which it was excluded and the technical basis for the screening argument. The coupling of THC to seepage and flow is described in the UZ F&T PMR (CRWMS M&O 2000ab). This acceptance criterion is also discussed in Appendix A of the EBS PMR (CRWMS M&O 2000aa). Importance of the thermal alteration of the Paintbrush Tuff will be verified prior to LA.	
1-4. DOE estimates of performance are not over-optimistic, given the excluded set of phenomena and the implementation of coupled THMC processes in the total system performance assessment.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further reviews of Analysis and Model Reports and Process Model Reports is needed. Data justification, data uncertainty, model uncertainty, and model support were not reviewed because the supporting Analysis and Model Report was not available prior to May 15, 2000. (ENFE IRSR, Rev. 3, Sect. 5.4.1.2.1.1) An evaluation of the potential for cementitious materials to alter repository performance by altering hydrological properties below the repository is required before the ENFE Subissue 1 can be resolved. DOE should evaluate the potential for cementitious	CLOSED PENDING. DOE's estimates of performance are reasonable.. Based on the current waste package degradation model, and assuming that the waste packages perform as expected, THMC processes have negligible effects on performance (CRWMS M&O 2000ae, Section 3.1.3, 3.1.5, 3.1.6, and 3.1.7). DOE's current design does not include concrete liners for emplacement drifts; however DOE recognizes the potential for interactions between cementitious materials in ventilation shafts, grout and rock bolts, and the host rock. Effects of cementitious materials on water leaving the repository have not been examined. Until the ventilation shaft designs are complete, bounding analyses will be performed. The abstraction of	

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materials (in ventilation shafts and tunnels) to interact with tuff host rock, thereby altering hydrological properties and flow paths below the repository [IRSR 5.0.2 (6)] NRC will review the information when it becomes available in the SR	cementitious material in rock bolts shows that effects from limited use of cement grout for rockbolts and the effects on CO_2 fugacity and water composition are minor. (EBS AMR, ANL-EBS-MD-000043) Calcite will be deposited in the EBS, such as on the rock roof and drip shield. These effects are documented in the EBS Degradation, Flow, and Transport PMR (CRWMS M&O 2000aa) and summarized in the Executive Summary. Effects of limited amounts of cementitious materials used in ventilation systems will be verified prior to LA.	

1-5. For estimates of the amount of seepage flux, the DOE must (i) demonstrate the coupled THC changes in rock mass properties will not focus percolation into drifts, and (ii) rigorously justify estimated diversion of percolation away from the waste package footprints. Model calculations that account for drift collapse and coupled THMC changes to rock properties could provide such support. If these alteration processes are not accounted for, a technical basis for neglecting them must be provided.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
CLOSED-PENDING. The approach of the Site Recommendation is to use the auxiliary analysis to demonstrate that THC effects will not alter hydrological properties beyond the range used in performance assessment abstractions. In broad terms, the staff agrees this is an appropriate plan for addressing this subissue. (ENFE IRSR, Rev. 3, Sect. 5.4.1.2.1.1)	CLOSED- DOE agrees with the status as described by the NRC.	No additional work required.

1-6. DOE peer reviews follow the guidance in NUREG-1297 and NUREG-1298 or other acceptable approaches		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Supporting Analysis and Model Reports and Process Model Reports were unavailable prior to May 15, 2000. Staff will review the Analysis and Model Reports and supporting material as they become available. (ENFE IRSR, Rev. 3, Sect.	CLOSED PENDING. Peer reviews, expert elicitation, and qualification of data, when utilized, were conducted and documented in accordance with QARD requirements (DOE 2000a), which are consistent with guidance in NUREG-1297 and NUREG-1298,	No additional work required.

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5.4.1.2.1.1)	and NUREG-1563.	

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Acceptance Criterion (AC) 2—Data and Model Justification for Evolution of the Near-Field Environment Subissue 1. Sufficient data (field, laboratory, and/or natural analog data) that are consistent with site characteristics are available to define relevant parameters and conceptual models necessary for developing the total system performance assessment abstraction of flow paths in the unsaturated zone, including the distribution of mass flux between fractures and matrix. The data are sufficient to assess whether FEPs related to flow paths in the unsaturated zone have been adequately characterized, and whether the technical bases provided for exclusion of those FEPs affecting flow paths in the unsaturated zone are adequate. Specifically (see numbered items below),		
2-1. If potentially affected flow pathways due to hydrothermally driven geochemical reactions such as zeolitization of volcanic glass are excluded from the total system performance assessment abstraction of flow paths in the unsaturated zone, the reviewer should examine the adequacy of the technical basis for the exclusion and also examine the sufficiency of the transparency and traceability of the data used in defining the technical bases for the exclusion in the abstraction.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2) DOE dismisses the possibility for further hydrothermal alteration of the Calico Hills nonwelded unit by calculating temperatures there and arguing that these are below the critical temperature needed for significant alteration. No supporting data for the reaction rates at the calculated temperatures are provided or cited. DOE should provide a technical basis for neglecting thermal alteration of zeolites in the Calico Hills unit, demonstrate that thermal alteration of this unit is unimportant to performance, or include the effects in abstracted models [IRSR 5.0.2 (1)]	CLOSED PENDING. Also see the discussion under criterion 4-1. DOE addresses alteration of the CHn in the UZ FEPs AMR (CRWMS M&O 2000aj) and uses information from the mountain-scale TH model (CRWMS M&O 2000ab, Section 3.12). The top of the CHn predicted maximum temperature rises to 75 - 85 degrees between 2000-7000 yr. (MDL-NBS-HS-000007). These temperatures are in the lower range of alternation susceptibility. (Carey et al 1996). The near-field model has looked at alteration along fractures and has found negligible effects in terms of alteration of glass. Since the near-field effects are shown to be minimal, DOE believes that adequate basis has been established to support assumptions that far-field effects are also minimal to non-existent. DOE has also added a FEP (CRWMS M&O 2000aj) to examine far-field effects. Studies by Bish have been completed and will be documented in an AMR.	
2-2a. DOE thermohydrologic tests are designed and conducted with the explicit objective of testing conceptual and numerical models so that critical thermohydrologic processes can be observed and measured		

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OPEN. Staff agrees that the DOE's stated plan to use the results of the Drift Scale Heater Test to test and refine the models and parameters in the THC models is an appropriate approach. The Analysis and Model Reports describing this effort will be reviewed when it becomes available. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED TH processes affecting flow and transport are described in the UZ F&T PMR (CRWMS M&O 2000ab) Sections 3.10 and 3.12. These processes include spatial patterns and rates of flow close to waste emplacement drifts, mountain-scale flow patterns and rates above waste emplacement drifts, seepage into waste emplacement drifts, and mountain-scale flow patterns and rates between the potential repository and the water table.	No additional work required.
2-2b. DOE thermohydrologic tests are designed and conducted with explicit consideration of thermohydrologic, thermal-chemical, and hydrological-chemical couplings.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. Section 3.6 of the NFE PMR (CRWMS M&O 2000ad describes in situ and field thermohydrologic testing, including the LBT and the DST. Section 6.1 of the Thermal Test AMR (CRWMS M&O 2000bc) describes the objectives of the LBT. The objective of the LBT was to create a planar, horizontal region of boiling in a block of fractured TSW to observe coupled thermal-hydrological-mechanical-chemical (THMC) behavior in a representative rock unit. The THC Process AMR (CRWMS M&O 2000ba) Section 6.2 describes the DST. The purpose of the DST is to evaluate the coupled thermal, hydrological, chemical, and mechanical processes that take place in unsaturated, fractured tuff over a range of temperatures from approximately 25°C to	

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	nearly 200°C. The EBS PMR (CRWMS M&O 2000aa) reports quarter-scale testing at the Atlas Test Facility. The quarter scale tests are being conducted with J-13 groundwater, but are principally thermal-hydrologic in their focus. These tests have demonstrated the relative importance of radiation, conduction, and convection in heat and mass transport in the emplacement drifts and will be documented in the Water Distribution and Removal AMR (CRWMS M&O 2000as) Rev. 01.	
2-2c. DOE thermohydrologic tests are designed and conducted at different scales to discern scale effects on observed phenomena.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED Mountain-scale TH (CRWMS M&O 2000ab, Section 3.12) and drift-scale THC (CRWMS M&O 2000ab, Section 3.10) models address the effects of heat and mass transfer processes at different scales. The mountain-scale model considers the effects of faults, perched water, and condensate drainage between drifts. The drift-scale THC model addresses effects of heat and mass transfer at the drift scale, including chemical reactions, mineral alteration, precipitation, and dissolution. The testing program discussed in Section 3.6 of the NFE PMR (CRWMS M&O 2000ad) was designed to continue the testing at different scales. The scale dimension was extended from laboratory scale (core samples) to bench scale (small block tests) to the LBT and SHT and then to the large scale DST. Bench scale tests were succeeded by field tests which the results were provided as input to the	No additional work required.

	SHT, LBT, DST and Cross-Drift testing. Section 3.6 of the NFE PMR (CRWMS M&O 2000ad) also provides a description of the thermal tests. The SHT, DST, and LBT are all different scale tests. The SHT is a small to intermediate sized field test. The DST is geometrically more complex and larger scale than the SHT or LBT. The scale of the DST allows investigation of the NFE and associated coupled thermal, hydrological, chemical, and mechanical processes on an emplacement drift scale. The size of the LBT was chosen so that the block of rock to be heated was large enough to contain several fractures, but small enough so that boundary conditions and rock heterogeneity could be adequately controlled and/or characterized. Finally, quarter-scale testing at the Atlas Facility has been used to investigate heat and mass transfer processes, and to confirm relationships for transfer of test results to the repository scale.	
2-2d. DOE thermohydrologic tests are designed and conducted for temperatures ranges expected under repository operations conditions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED Section 3.6 in the NFE PMR (CRWMS M&O 2000ad) describes the thermal tests, including the DST. The planned temperatures for the DST are consistent with an 85 MTU thermal load. The quarter scale tests simulate waste package heating with a waste package heater and repository heating through peripheral heaters. Various temperature ranges have been used, up to 90°C (the approximate upper limit of the test) which is	No additional work required.

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	representative of repository conditions throughout much of the cooldown period, after the few hundreds to thousands of years. Quarter-scale testing will be described in Rev. 01 of the EBS PMR.	
2-2e. DOE thermohydrologic tests are designed and conducted to determine if water refluxes back to the heaters during either the heating or cool-down phases of the tests.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED The LBT and DST field tests reported in Section 3.6 of the NFE PMR (CRWMS M&O 2000ad) were specifically designed to look at reflux issues. The LBT was an integrated test designed to maximize the conditions under which refluxing could occur. A specific goal of the LBT was observation of condensate refluxing above the boiling zone. The temperatures were maintained at the surface to a point that would allow for condensation within the rock, and the heater temperatures were maintained above boiling. The LBT had controlled or monitored side boundaries to account for all mass and energy losses/gains. These boundaries consisted of an impermeable membrane glued to the side-rock surface to prevent loss of water mass through the sides, with insulation and heat-flux monitoring outside the membrane to account for the energy losses/gains. Further, there was a temperature control system installed at the top of the block to maintain constant surface temperature. The power input from this system was monitored. There were no controls on water mass-movement through the top and bottom of the block, although measurements were made below the	No additional work required.

	block. The wing heaters in the DST were also designed to create conditions that would be favorable to condensate buildup (i.e., to create a thermal barrier that could potentially impair condensate drainage and thus allow for both reflux and "thermal perching" of condensate) by creating a horizontal plane above the boiling point approximately 1/3 of the way up on the block and by maintaining below boiling temperatures on the top of the block. At elevated temperatures in the DST on borehole 79, there is evidence of vapor flow heat-up about 10-m into the drift. Later on a reduction is seen as temperatures approach $T_{boiling\ point}$. In borehole 79, at 39-m from the bulkhead and the temperature below $T_{boiling\ point}$, there is evidence of condensate penetrating the thermal zone. Similar responses are seen in borehole 80. From each test, many different types of data were collected. The list of test measurements include the following: moisture distribution in rock/fractures monitored by neutron, logging, radar, and electrical resistive tomography. Temperatures monitored by permanently installed and movable RTDs,Heat flux through boundaries is monitored by RTDs within the ultra-temperature insulation. Refluxing was determined from a suite of data results in lieu of direct measurements Water is collected from several hydrology boreholes. In SHT, closely spaced temperature measurements indicated small-scale variability in the refluxing process.	

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2-2f DOE thermohydrologic tests are designed and conducted to account for mass and energy losses/gains in the model system.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED. Section 3.6 of the NFE PMR (CRWMS M&O 2000ad) indicated that the DST was heavily monitored to account for mass and energy losses within the measurement sections. There was only partial control or accounting for energy losses from the ends, as discussed in the Thermal Test AMR (CRWMS M&O 2000bc). The DST was neither **designed nor conducted to account for all mass and energy losses/gains in the thermal test system.** Evaluation of impacts of heat and moisture losses in the DST concludes that the test is acceptable and heat losses do not invalidate the test. (ANL-NBS-TH-000001) DOE does not believe that it is necessary to account for all mass and energy losses/gains. Heat and mass loss through the bulkhead is accounted for in the numerical simulations. Currently it appears total heat loss is between 20 and 30 kW and the mass/water loss is approximately 25 to 50 kilograms (liters) per hour. • The bulkhead was intended to provide a protective and primary thermal barrier to allow personnel to observe the heated drift and to work in close proximity to the bulkhead/heated drift with minimal risk. Based on extensive discussions within the thermal test team and on scoping analyses of potential heat loss measurement approaches, it was concluded that more accurate characterization of the heat loss through the bulkhead is not necessary To	No additional work required.

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	analyze overall test results. • Analyses indicate that an assumed convective boundary condition results in good comparative agreement between measured and simulated temperatures. Thus, the lack of accurate measurements of heat loss can be offset by measures taken in numerical modeling. This will be documented in revisions to the thermal test AMR prior to LA. • In a large-scale, open system test like the DST, assumptions on many factors are unavoidable. **Despite these shortcomings, calculated results can be compared to corresponding measurements to allow acceptable evaluation** of conceptual models. (Thermal Test AMR)	
2-2g. DOE thermohydrologic tests are designed and conducted such that the model environment is sufficiently characterized so that the level of uncertainty in property values does not result in unacceptable uncertainty in thermal test interpretation.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED One of the objectives of the DST was to evaluate the impacts of different property sets on model results. Section 3.6 of the NFE PMR (CRWMS M&O 2000ad) describes the thermal tests, including the SHT, LBT and the DST. Section 1 of the Thermal Test AMR (CRWMS M&O 2000bc) describes how comparative analyses are performed of measurements from the thermal tests to results from the numerical simulations. These analyses form the bases for the conclusions presented in the AMR. Section 6.2 of the Thermal Test AMR (CRWMS M&O 2000bc) describes the results of the comparative analyses in sufficient detail to conclude that the environment is sufficiently	No additional work required beyond that already planned.

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	characterized, so that the level of uncertainty in property values does not result in unacceptable uncertainty in thermal-test interpretation. Evaluation of impacts of heat and moisture losses in the DST concludes that losses do not invalidate the test.	
2-2h. DOE thermohydrologic tests are designed and conducted such that accuracy in the measurement of the test environment saturation is sufficient to discern the relative capability of different conceptual models to represent the thermohydrologic processes in heated, partially saturated fractured porous media.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. Saturation histories in the heated blocks were deduced from three geophysical methods: neutron logging, electrical resistivity tomography and the ground penetrating radar. Measurements were conducted during heating and cooling phases of the LBT and SHT using these complementary techniques. The DST is a continuing test and the planned Cross Drift Thermal Test will use geophysical methods to measure saturation. These test results to date are consistent with dual permeability models (DKM), but not with an equivalent continuum model. The test results are part of the basis for the project's movement from ECM to DKM. Section 3.6 of the NFE PMR (CRWMS M&O 2000ad) describes the thermal tests, including the SHT, the DST, and the LBT. The Thermal Test AMR (CRWMS M&O 2000bc) compares model results using a number of property sets to measured temperature and liquid saturation data obtained from a known thermal perturbation for comparison.	

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	The AMR provides a comparison of simulated and measured water saturation distributions to determine the accuracy of NFE and EBS TH models. The LBT and DST were performed at saturation ranges that were representative of that expected for the repository (from nearly 95% for DST to near-total desaturation or dry-out).	
2-3. Accepted and well-documented procedures are adopted to construct and calibrate numerical models used.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. DOE's models are constructed and calibrated according to DOE procedures AP-3.10Q and AP-3.11Q Specifics are addressed in the UZ F&T PMR (CRWMS M&O 2000ab), and EBS PMR (CRWMS M&O 2000aa). See Table 4.3-1 of the UZ F&T PMR and Appendix A of the EBS PMR (CRWMS M&O 2000ab and 2000aa) for additional information regarding this acceptance criterion. The discussion of the THM model is documented in the NFE PMR (CRWMS M&O 2000ad).	
2-4a. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, models are abased on well-accepted principles of heat and mass transfer applicable to unsaturated geologic media.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. Based on a review of the preliminary draft unsaturated zone Process Model Report (CRWMS M&O, 2000e), staff agrees that the numerical software TOUGHREACT Version 2.2 used to simulate THC effects on flow and seepage is	CLOSED PENDING. There are three basic models that describe the near field environment. They are TH, THC, THM, which are also documented in the Near Field Environment PMR (CRWMS M&O 2000ad, Sections 3.3.1 and 3.6.4). Models are based on the physics of heat and mass transfer, and the numerical analyses are implemented for the TH by	

appropriate and was constructed using accepted and well-documented procedures. Staff will review this in more detail when the supporting Analysis and Model Report becomes available. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2) DOE should provide a description of the tests used to verify that TOUGHREACT Version 2.2 is producing correct solutions to the underlying mathematical models [ENFE IRSR Rev 3, Sect. 5.0.2 (3)].	the qualified version of NUFT, Version 3.0s and the qualified version of TOUGH2, Version 1.4 codes. For the THC, the TOUGHREACT, Version 2.2 code is applicable. TOUGHREACT has been calibrated to water and gas chemistry data from the heating phase of the DST. For the THMC the 3DEC, Version 2.0 code is applicable. NUFT, Version 3.0s, TOUGH2, Version 1.4, TOUGHREACT, Version 2.2, and 3DEC, Version 2.0 are qualified in accordance with Project QA procedures (DOE 2000a). The NRC has access to these codes. **A description of test to verify TOUGHREACT Ver. 2.2 will be made available to the NRC.**	
2-4b. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, models include, at a minimum, an evaluation of important thermohydrological phenomena, the processes of evaporation and condensation, and the effects of discrete geologic features.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. Current models described in the UZ F&T PMR (CRWMS M&O 2000ab) Section 3.10 include processes of evaporation and condensation. Figure 3.10-2 shows the relationship between TH and geochemical processes in zones of boiling, condensation and drainage in the rock mass outside of the drift and above the heat source. Seepage models described in the UZ F&T PMR (CRWMS M&O 2000ab) Section 3.9 include an active fracture model to describe fracture-matrix interactions. Comparison results between the discrete fracture model seepage and the continuum model will be documented in a future AMR. The	No further work required beyond that already planned.

	model is an isothermal, fracture only model. The EBS PMR (CRWWMS M&O 2000aa) relies on thermal-hydrologic models that incorporate evaporation and condensation as discussed above. The effects of seepage that could be caused by spatial heterogeneity in hydrologic properties have been addressed parametrically by introducing seepage directly into the models. The results are documented in the Water Distribution and Removal AMR Rev. 01 (CRWMS M&O 2000as). The effects of extreme seepage on drainage have also been evaluated.	
2-4c. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, important thermohydrologic phenomena such as (i) multi-drift dry-out zone coalescence and other multi-drift interactions, (ii) lateral movement of condensate, (iii) repository edge effects, and (iv) condensate drainage through fractures, at a minimum, are addressed.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED The current repository design has a lower thermal load than the VA design to eliminate dryout zone coalescence. Section 3.10 in the UZ F&T PMR (CRWMS M&O 2000ab) summarizes the evaluation of the extent of the dryout zone and time of rewetting for different calibrated property sets and climate scenarios. It also summarizes the TH mountain scale models and the effects of temperature changes over the mountain, including effects on flow around the drift, condensate formation and drainage in the pillars. The EBS Multiscale Thermal Hydrologic Model (CRWMS M&O 2000bd) provides analysis of repository thermohydrological phenomena throughout the repository area. This model	No additional work required.

	addresses the multi-drift dry-out zone coalescence and other multi-drift interactions, lateral movement of condensate, repository edge effects, and condensate drainage through fractures. The degree of multi-drift dry-out zone coalescence will be a function of the thermal load specified in the final design of the repository. CRWMS M&O 2000aa, Sections 3.1.1, 3.1.2 and 3.1.4). Durable changes to hydrologic properties have been evaluated. Thus, DOE understands the magnitude of effects of rock properties important to predicting fracture porosities. For example, calibrated rock properties used in TH models demonstrate that drainage though fractures does occur consistent with field scale test results. However, durable changes are believed to have negligible impact on repository performance and thus are not an important issue for the current design. (MDL-NBS-HS-000001), (THM AMR, CALC-NBS-MD-000002) In TSPA-SR, the average response of rock for predicting lateral movement of condensate was evaluated. In addition, current models in TSPA-SR indicate that heat transfer at the mountain is mostly conductive. (ANL-EBS-MD-000049) This approach is used in the models to represent repository edge effects. Ongoing work prior to LA is refining the models and improving the treatment of ventilation effects.	
2-4d. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, models are capable of accommodating variation in infiltration.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**

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OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED The TH model incorporates variations in infiltration as discussed in Sections 3.10 and 3.12 of the UZ F&T PMR (CRWMS M&O 2000ab). In addition, the models described in the EBS PMR (CRWMS M&O 2000aa) Section 3.1 have analyzed thermal-hydrological phenomena for the present day, monsoon, and glacial climates. The Multiscale TH (CRWMS M&O 2000bd) model fully addresses respository-scale variability in infiltration and mountain-scale thermal effects, as well as drift-scale and mountain-scale thermal effects.	No additional work required.
2-4e. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, mathematical models are consistent with conceptual models, based on consideration of site characteristics.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING The AP3.10Q process requires that detailed process models are consistent with conceptual models. Chapter 3 of the Near Field Environment PMR (CRWMS M&O 2000ad) discusses mathematical models used to represent conceptual models and are based on site characteristics. In each EBS process model, the mathematical models are consistent with conceptual models. The models will be refined as additional site characterization data are obtained in the lower lithophysal unit.	
2-4f. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, results from different mathematical models are compared to judge robustness of results.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**

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OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING The AP3.10Q process requires that detailed process models are consistent with conceptual models. Chapter 3 of the Near Field Environment PMR (CRWMS M&O 2000ad) discusses mathematical models used to represent conceptual models and are based on site characteristics. In each EBS process model, the mathematical models are consistent with conceptual models. Models are tested against all available ambient data and on thermal test results. In some cases, models are used to predict future test or site characterization results. The models are also tested on natural analog situations, where appropriate.	
2-4g. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, adequate technical bases for spatial and temporal variability of parameters and boundary conditions are provided.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further reviews of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. Mountain scale flow and TH models include large scale 3-D property variations. Seepage models include multiple realization finer scale variations. Refinement of the thermal seepage model is ongoing.	
2-4h. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, models used to predict shedding around emplacement drifts are shown to contain an adequate level of heterogeneity in media properties.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED Sections 3.10 and 3.12 in the UZ F&T PMR(CRWMS M&O 2000ab) summarize the approach to evaluating heterogeneities in the TH model. Seepage model calculations used by	No additional work required.

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	Performance Assessment have only been performed for unperturbed temperature because of the conservative assumptions that focused flow could overcome evaporation and imbibition in the near field. Evidence of two events in the LBT and from boreholes 79 and 80 of the DST, show that liquid water penetrated the thermal zone. Calculations have been performed that demonstrate shedding of percolating and condensate water around the drift during the boiling period (e.g. CRWMS M&O 2000ab, Section 3.10.5.2,See 2-2e of this table. **Monte Carlo simulations that include spatial heterogeneity, imbibition, and vaporation** are also being performed to directly assess thermal seepage and drainage of condensate in the pillars. The EBS Multi-scale TH Model (CRWMS M&O 2000bd) considers 31 chimney locations within the repository that captures an adequate level of heterogeneity in percolation rates at the repository horizon CRWMS M&O 2000aa, Section 3.1.4). This model has been validated against the drift scale test. [Sect 6.13 of the Multi-scale TH model (CRWMS M&O 2000bd)]. The drift scale modeling, which consider heterogeneous fracture property distribution, support the conclusions regarding condensate shedding and stochastic seepage models. Early pre-test TH-model simulations of the DST using the ECM predicted minimal shedding of condensate around the boiling zone, resulting in a thick zone of condensate buildup above the boiling	

	zone. These ECM TH-model calculations showed a very pronounced flattening of the vertical temperature profile, with temperatures close to 96°C in the zone of condensate buildup. More recent TH models of the DST, which use the DKM, predict much greater condensate shedding (than the ECM TH models) around the boiling zone, resulting in a much less pronounced zone of condensate buildup above boiling zone. The DKM TH-model calculations of the DST also predict a much thinner region of flattening (near 96°C) of the vertical temperature profile, corresponding to the very thin zone of condensate buildup above the boiling zone. Temperature measurements in the DST have a similar thin region of temperature flattening, indicating similar (efficient) condensate shedding behavior as is predicted by the DKM TH models. Based on the current models for corrosion resistance of the waste package and drip shield materials, the occurrence of seepage during the thermal period will be inconsequential to dose. (Waste Package PMR, Section 3.1)	
2-4i. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, thermohydrologic models are demonstrated to be appropriate for the temperature regime expected at the repository.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED The TH models incorporate the anticipated thermal load for the current repository design as described in Sections 3.10 and 3.12 in the UZ F&T PMR (CRWMS M&O 2000ab). Comparisons of the DST results and THC modeling are given in Section	No additional work required.

	3.10.4 of the UZ PMR. The thermal hydrologic calculations are appropriate for the expected temperature regime as discussed in EBS PMR (CRWMS M&O 2000aa) Section 3.1. The current EDA-II design is based upon an 81-m emplacement drift spacing with line loading. EBS models are based upon the NUFT thermal hydrological code, which has been validated for this temperature regime. (CRWMS M&O 2000aa, Section 3.1). **The drift scale modeling was conducted under conditions that caused thermal hydrologic behavior that is similar to that expected in the near field drift.** (See NFE PMR (CRWMS M&O 2000ad) and Sect. 6.13 of the multi-scale TH AMR) (CRWMS M&O 2000bd). The Thermal Test AMR (CRWMS M&O 2000bd) compares test results with model predictions using different codes and modeling approaches. Temperatures in the repository would be lower than in the DST heated drift. However, the same models would be used and the first stages of heating would be the same (e.g. warming, evaporation, near-boiling, dryout by ventilation, etc.).	
2-4j. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, media properties of a model contain an adequate level of heterogeneity such that mechanisms such as dripping are not neglected or misrepresented.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. The drift seepage model has been enhanced to account for heterogeneities as described in Section 3.9.3 of the UZ F&T PMR (CRWMS M&O	

	2000ab). The effects of heterogeneity on drift seepage have been found to be important, since the drift seepage results are sensitive to the presence of heterogeneous permeability. Model results for the drift-scale test have been validated against test results (CRWMS M&O 2000bd, Section 3.10.10). Based on available evidence, it has been demonstrated that dripping or seepage into the emplacement drifts under isothermal conditions is consistent with current scientific understanding. Based on available evidence, it has been demonstrated that the magnitude and time of the resulting expected annual dose would not be significantly changed by the omission of these mechanisms. Based on the current models described in the Waste Package Degradation PMR for corrosion resistance of the waste package and drip shield, the occurrence of seepage during the thermal period is inconsequential to dose. (CRWMS-M&O 2000ae) The Water Distribution and Removal Model (CRWMS M&O 2000as) Rev. 01 shows that the in-drift environment is not especially sensitive to seepage during the thermal period. The TSPA-SR (TDR-WIS-PA-000001) shows that seepage does not have a profound effect—rather it has little effect based on the current corrosion resistance of the waste package, drip shield, and other EBS components. Analysis of the influence of drift-scale heterogeneity is underway to determine whether drift-scale heterogeneity should be explicitly	

	represented in the Multiscale TH Model (CRWMS M&O 2000bd).	
2-4k. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, drift wall representations used in models contain sufficient physical detail such that processes predicted using a continuum model, such as capillary diversion, are appropriate for the geologic media at the proposed repository horizon.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE'IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. Dual permeability models that include capillary versions are used to predict seepage probabilities and volume. These models include partial drift collapse and multiple realizations of heterogeneous rock properties. These models are described in Sections 3.9.3.4 and 3.9.3.5 in the UZ F&T PMR (CRWMS M&O 2000ab). Higher rate flows generated by the proposed mechanism of film-flow and dripping from wall surface roughness features are captured in the Niche seepage calibration data. Some niche testing is conducted behind bulkheads to minimize the effects of ventilation and evaporation. The EBS multi-scale TH model (CRWMS M&O 2000bd) already includes a certain degree of drift wall irregularity. The TH submodel, which is used as the EBS multi- scale submodel, uses a stair step approximation of the cylindrical drift wall. Therefore, this model imposes drift wall irregularities.	
2-4l Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, physical mechanisms, such as penetration of the boiling isotherm by flow down a fracture, are not omitted from model predictions due to oversimplification of the physical medium of the conceptual model.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN.	CLOSED PENDING.	

Analysis of the Resolution Status for the Key Technical Issue on the Evolution of the Near Field Environment

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Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	Section 3.9 in the UZ F&T PMR (CRWMS M&O 2000ab) summarizes the drift seepage models, including enhancements, such as the evaluation of partial drift collapse and episodic percolation flux. Section 3.10 in the UZ F&T PMR (CRWMS M&O 2000ab) describes the THC models. Penetration of the boiling isotherm is currently overestimated in the PA model. The thermal seepage model is being refined to more accurately calculate the competing processes of capillary, gravity, and thermal effects on penetration of the boiling isotherm and potential seepage.Seepage from high-rate percolation flux has been adequately addressed and verified by field experiments. Lower-rate percolation flux and potential seepage (including film flow) are being addressed in current work. The EBS PMR (CRWMS M&O 2000aa) Rev. 01 and the Water Distribution and Removal Model (CRWMS M&O 2000as) present sensitivity studies that evaluate the importance of seepage during the thermal period. Seepage has little effect based on the current corrosion resistance of the waste package, drip shield, and other EBS components. Multiple failures will be required before thermally induced seepage could directly affect dose rates. (TDR-WIS-RL-000001) Analysis of the influence of drift-scale heterogeneity is underway to determine whether drift-scale heterogeneity should be explicitly represented in the Multiscale TH Model (CRWMS M&O 2000bd). Work is also in progress relative to stochastic model variability. Investigation of fault features is	

	proposed.	
2-24m. Process-level, conceptual and mathematical models used in the analyses are reasonably complete. In particular, models include changes in boundary conditions (e.g., drift shape and size) and hydrologic properties due to the response of the geomechanical system to thermal loading.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING In addition to Acceptance Criterion 2 Item 2-4l, above, THM models are being used that account for shear and normal displacement of fractures due to heating, and the consequent changes in permeability. The seepage model has been exercised for both as-built and degraded drift shapes.	
2-5. DOE demonstrates that the data on the geology, hydrology, and geochemistry of the unsaturated zone, including the influence of structural features and stratigraphy, used in the total system performance assessment abstraction are based on techniques that may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. The TSPA-SR models have been calibrated to all available site data. The models will be refined as additional lower lithophysal unit data becomes available.	
2-6. Sensitivity or uncertainty analyses are adequate to determine the possible need for additional data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. Sensitivity analyses related to ENFE are included in the TSPA-SR. Sensitivity analyses are conducted where appropriate in the EBS Process Models. Where appropriate, sensitivity and importance analyses have been performed as described by the parametric	No additional work required beyond that currently planned.

	studies in Sections 3.1.1 through 3.1.4 (CRWMS M&O 2000aa). Data on EBS processes currently being collected for the Water Distribution and Removal Model, (CRWMS M&O 2000as) and the Physical and Chemical Environment Model Abstraction (CRWMS M&O 2000ag) will be valuable in refining sensitivity studies.	
2-7. Some laboratory and field experiments used to support and verify total system performance assessment results may be designed for the postclosure period. In particular, if the testing program for coupled THC processes is not complete at the time of license application submittal, DOE explains why it is not necessary to complete the testing program for the license application and identifies specific plans for completion of the testing program as part of the postclosure program.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING. Arguments presented in the LA will be based on testing and analysis conducted before LA and considered in the licensing review. Testing contained in the performance confirmation program is confirmatory. The performance confirmation program addresses thermal-hydrologic effects on unsaturated zone flow and seepage into emplacement drifts during the pre-emplacement period, including assessment of the thermal hydrologic response of rock mass and cooling and seepage testing under heated environments. Longer term testing for seepage and NFE THC testing and monitoring around selected emplacement drifts and under simulated postclosure conditions is also addressed. Testing of the in-drift environments is included as well. See the Performance Confirmation Plan (CRWMS M&O 2000be, Sections 5.3.1.2, 5.3.1.4, 5.3.1.5, 5.3.2, and Appendix G) Data collected after LA in the PC program for example, will be considered in the	No additional work required beyond that currently planned.

	license amendment for waste emplacement. Performance Confirmation is not addressed in the EBS PMR. In the absence of performance confirmation, the EBS PMR provides bounding calculations in the absence of complete data and model uncertainties. For example, for the base case analysis for radionuclide transport, the calculations do not consider chemical retardation, which is a conservative assumption. (CRWMS M&O 2000aa, Section 3.1.3)	
2-8. Where sufficient data do not exist, the definition of parameters values and conceptual models is based on other appropriate sources such as expert elicitation conducted in accordance with NUREG-1563.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.2)	CLOSED PENDING Expert elicitations regarding seepage and flow were conducted in both the UZ and NF aspects. Peer reviews, expert elicitation, and qualification of data, when utilized, have been conducted in accordance with QARD requirements (DOE 2000a), which are consistent with guidance in NUREG 1563, NUREG 1297, and NUREG 1298. Section 2.4.5 of the NFE PMR addresses expert elicitation regarding those parts of the elicitation that relate to the NFE. For a complete discussion, refer to the UZ F&T Model PMR (CRWMS M&O 2000ab) and the Near Field PMR (CRWMS M&O 2000ad). Additional elicitations may be conducted prior to LA if warranted by modeling or testing results.	

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Subissue 1: Effects of Coupled Thermal-Hydrologic-Chemical Processes on Seepage and Flow

Acceptance Criterion (AC) 3—Data Uncertainty for Evolution of the Near-Field Environment Subissue 1. Parameter values, assumed ranges, probability distributions, and/or bounding assumptions used in the abstraction of flow paths in the unsaturated zone, including the distribution of mass flux between fractures and matrix, are technically defensible and reasonably account for uncertainties and variabilities. The technical basis for the parameter values used in the performance assessment is provided. Specifically (see numbered items below):

3-1. DOE appropriately adopted accepted and well-documented procedures to construct and test the numerical models used to simulate coupled THMC effects on percolation and seepage.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.3)	CLOSED Models (as well as assumptions, constraints, bounds, limits and values of input parameters) are identified and justified in accordance with the QARD (DOE 2000a) and procedure AP 3.10Q.	No additional work required.

3-2 The DOE evaluation of coupled THMC processes properly considered the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, and temporal and spatial variations, in establishing initial and boundary conditions for conceptual models and simulation of THMC coupled processes that affect percolation and seepage.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.3)	CLOSED PENDING. Section 3.10.6 of the UZ PMR (CRWMS M&O 2000ab) analyzes uncertainties in the characteristics of the natural system. Engineered materials are discussed in the EBS PMR. (CRWMS-M&O 2000aa). Mountain scale flow and TH models include large scale 3-D property variations. Seepage models include multiple realization finer scale variations. Refinement of the thermal seepage model is ongoing. Seepage modeling includes multiple realizations of heterogeneity, as a means to account for uncertainty as well as variability.	

3-3 DOE establishes that reasonable or conservative ranges of parameters or functional relations are used to determine effects of coupled THMC processes on percolation and seepage.

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NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.3)	CLOSED PENDING. Section 3.3 of NFE PMR (CRWMS M&O 2000ad) addresses the drift scale coupled processes (DSCP) models used to evaluate the potential effects of coupled THC processes on properties in the NFE, which are then used in evaluating UZ flow and transport. The parameter values used in this PMR were the values either provided by the UZ F&T AMRs or used in their evaluations. Section 3.10.3 of the UZ F&T PMR (CRWMS M&O 2000ab) discusses ranges in the characteristics of the natural system that were used to evaluate the effects of THC processes on seepage and flow, and the rationale for these ranges.(ENFE PMR R0ICN2 DUVAC1) DOE considers that ranges of parameters used to determine effects of coupled processes on percolation and seepage are adequate to support the evaluations specified.	

3-4. DOE shows that the parameters used to define initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THMC effects on percolation and seepage are consistent with available data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.3)	CLOSED PENDING. Sensitivity analyses are consistent with the range and variability of available data. See EBS, UZ, and NFE PMRs. (CRWMS-M&O 2000aa, 2000ab, and 2000ad)	

3-5. Coupling of processes has been evaluated using an acceptable methodology. Coupled processes may be uncoupled if it is shown that the uncoupled model results bound the predictions of the fully coupled model results.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN.	CLOSED PENDING.	

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Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.3)	NUREG-1466 (Nataraja and Brandshaug 1992) provides logical steps for the development of predictive models and their numerical representation of thermally induced THMC behavior of the host rock. Models of coupled processes in the UZFT PMR (CRWMS M&O 2000ab) Sections 3.10 and 3.12 present the current approach for modeling drift scale and mountain scale TH effects. The DOE agrees that coupled processes may be uncoupled if the models bound the effects of fully coupled processes (CRWMS M&O 2000aa, Section 3.1.4). See Appendix A of the EBS PMR for additional discussion. The NFE PMR (CRWMS M&O 2000ad, Sections 3.2, 3.3, 3.4, and 3.6) and two of its supporting AMRs, Thermal Test AMR (CRWMS M&O 2000ba and THC Abstraction AMR (CRWMS M&O 2000bb) discuss the evaluation of coupled process effects on the conditions or parameters (e.g., porosity and permeability) that are input to the TH models. In each case, the magnitude of the effect (such as THC or THM changes in permeability) is considered in the decision to include the change in follow-on TH calculations (maintain coupling) or to find the change to be negligible. That is if changes in flow patterns and volumes due to permeability change are small, the TH model for temperature and flow does not have to be coupled to the THC or THM result. (Here the "H" is included due to the change in hydrological properties rather than full coupling to change in flow field.	

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Subissue 1: Effects of Coupled Thermal-Hydrologic-Chemical Processes on Seepage and Flow

Acceptance Criterion (AC) 4—Model Uncertainty for Evolution of the Near-Field Environment Subissue 1. Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of flow paths in the unsaturated zone, including the distribution of mass flux between matrix and fractures. DOE has provided sufficient evidence that alternative data (e.g., field, laboratory, and natural analog) and current scientific understanding, and that the effect of these alternative conceptual models on total system performance assessment has been evaluated. Specifically (see following item) ,		
4-1. DOE provided a reasonable description of the mathematical models included in its analyses of coupled THMC effects on seepage and flow. The description should included a discussion of alternative modeling approaches not considered in its final analysis and the limitations and uncertainties of the chosen model.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of the DOE AMRs and PMRs is needed. Although the DOE THC model is appropriate for addressing the concern of bulky property modification caused by mineral precipitation and dissolution, it is not an appropriate model for addressing the matrix sealing process. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.4) DOE should provide an improved technical basis for neglecting mineral precipitation in a highly localized zone at the interface between fractures and matrix [ENFE IRSR 5.0.2 (4)]	CLOSED PENDING. DOE believes that issues related to alteration of the CHn and Acceptance Criterion 4 are thoroughly addressed. Modeling results indicate that only small amounts of zeolites will alter to other zeolites that are stable in a high silica environment. Total porosity and permeability changes will be modest. Alteration of clinoptilolite to analcime is not expected. (Carey, 1996), (E.Sonnenthal, J.Apps ENFE KTI Technical Exchange presentation, January, 2001). DOE's technical basis for excluding coupled THC effects on the CHn from TSPA-SR is as follows: THC processes that could adversely affect the natural barrier properties due to a transient thermal excursion to 70 °C include mineral alteration with adverse changes in the sorptive properties of radionuclides, consequent changes in porosity and permeability, release of zeolitic waters of hydration. Preliminary modeling estimates are that no more than 0.5 percent of the extant zeolites will alter to	

	other zeolites stable in a high silica activity environment. Effects on matrix sealing processes are expected to be minor. Total porosity changes will be less than one percent. Permeability changes will be negligible. Effect of temperature on the ion exchange properties of clinoptilolite and mordenite will be checked, but is expected to be relatively minor. Minor changes in the water of hydration of the principal zeolites will occur, but will not adversely affect radionuclide sorptive properties. The alteration of clinoptilolite to analcime will not take place. **References:** 1. Drift-scale Coupled processes (DST and Seepage) Models AMR U0110, MDL-NBS-HS-000001 REV01, (DIRS#: 152668, URN-0684 ACC: TB4) 2. Dibble, W. E., Jr. and Tiller, W. A., 1981. Non-equilibrium water/rock interactions - I. Model for interface controlled reactions. Geochimica et Cosmochimica Acta, vol. 45, p. 79-92. TIC: 240397 3. Dibble, W. E., Jr. and Tiller, W. A., 1981. Kinetic model of zeolite paragenesis in tuffaceous sediments. Clays and Clay Minerals, vol. 29, No. 5, p. 323-330. TIC: 22129 (DIRS#: 105386) 4. Duffy, C. J., 1993. Preliminary conceptual model for mineral evolution in Yucca Mountain. Los Alamos National Laboratory report LA-12708-MS, 45 p. ACC:NNA.19900117.0152., (DIRS#: 100740) DOE has evaluated the effects of loss of water from	

	the alteration of clinoptilolite to analcime as follows: The alteration of clinoptilolite to analcime is a kinetically controlled process described by the Ostwald Rule of Stages. (The reaction can be written as: sClinoptilolite + $t$$Na^+$ <=> vAnalcime +wK^+ = $x$$Ca^{2+}$ = $y$$SiO_2$ + $z$$H_2O$). Factors affecting the rate of transformation include: The solid state diffusive rate of ordering of opal-CT, nucleation and growth of secondary **quartz, advective removal of dissolved silica, extent of substitution of Na^+ and K^+ by Mg^{2+} and Ca^{2+} in clinoptilolite, stoichiometry of analcime,** composition and salinity of the aqueous phase, and temperature. The changes in percolation flux in the Calico Hills Formation will after emplacement of the repository be insufficient to materially affect advective removal of dissolved silica, even taking into account the increased solubility of opal-CT and clinoptilolite. The duration and magnitude of the thermal excursion in the Calico Hills Formation will be insufficient to cause alteration of more than 10 percent opal-CT to quartz. Therefore opal-CT will continue to control silica activity, and analcime formation will be inhibited. Silica dissolution in the repository horizon will tend to saturate some of the water percolating into the CH Formation with respect to amorphous silica. This water would inhibit recrystallization of opal CT to quartz, thereby further preventing analcime nucleation and growth in the CH Formation.	

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Subissue 1: Effects of Coupled Thermal-Hydrologic-Chemical Processes on Seepage and Flow

	References: 1. Drift-scale Coupled processes (DST and Seepage) Models AMR U0110, MDL-NBS-HS-000001 REV01, (DIRS#: 152668, URN-0684 ACC: TB4) 2. D. E. Broxton, D. E., Bish, D.L. and Warren, R. G., 1987. Distribution and chemistry of diagenetic minerals at Yucca Mountain, Nye County, Nevada. Clays and Clay Minerals, vol. 35, No. 2, p. 89-110. TIC: 203900, (DIRS#: 102004) 3. Chipera, S.J. and Bish, D.L., 1997. Equilibrium modeling of clinoptilolite-analcime equilibria at Yucca Mountain, Nevada. Clays and Clay Minerals, vol. 45, No. 2, p. 226-239. TIC: 233948, (DIRS#: 105079) 4. Dibble, W. E., Jr. and Tiller, W. A., 1981. Kinetic model of zeolite paragenesis in tuffaceous sediments. Clays and Clay Minerals, vol. 29, No. 5, p. 323-330. TIC: 22129 (DIRS#: 105386) 5. Duffy, C. J., 1993. Kinetics of silica phase transitions. Los Alamos National Laboratory report LA-12564-MS, 23 p. ACC:NNA.19900112.0346., (DIRS#: 105481) 6. Duffy, C. J., 1993. Preliminary conceptual model for mineral evolution in Yucca Mountain. Los Alamos National Laboratory report LA-12708-MS, 45 p. ACC:NNA.19900117.0152., (DIRS#: 100740)	

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Acceptance Criterion (AC) 5—Model Support for Evolution of the Near-Field Environment Subissue 1. Output from the TSPA abstractions of flow paths in the unsaturated zone and seepage, including the mass flux between matrix and fracture abstraction, is verified through comparison with detailed output from process-level models and/or empirical observations (e.g., laboratory testing, field measurements, and/or natural analogs). Specifically (see following items):

5-1. Abstractions of process-level models conservatively bound process-level predictions. In particular, DOE may use an abstracted model to predict seepage flux into an emplacement drift if the abstracted model is shown to conservatively bound process-level model predictions of the influx of water as liquid or vapor into an emplacement drift.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
CLOSED PENDING CONFIRMATION.	CLOSED PENDING. Section 3.9 in the UZ F&T PMR (CRWMS M&O 2000ab) summarizes the abstraction of seepage into drifts. As noted in Section 3.9.6.3, distributions for the amount of seepage as a function of percolation flux are derived directly from process models results and constrained by measurements of permeability around three niches in the ESF and calibration of seepage tests conducted in one niche in the ESF. A conservative model abstraction of drift seepage has been developed (Abstraction of Drift Seepage: ANL-NBS-MD-000005, CRWMS M&O 2000bf). The effects of heat on percolation flux intercepting the drift are included through a separate TSPA abstraction that provides a thermally-perturbed percolation flux input to the top of the seepage model domain.	No additional work required.

5-2. DOE appropriately adopts accepted and well-documented procedures to construct and test the numerical models used to simulate coupled THMC effects on percolation and seepage.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of AMRs and PMRs is needed. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.5)	CLOSED Procedures were followed consistent with the governing quality assurance requirements in the QARD (DOE 2000a) The following codes are	No additional work required.

	qualified: TOUGHREACT, Version 2.2, NUFT, Version 3.0s, TOUGH2, Version 1.4, and 3DEC, Version 2.0.	
5-3. Results of process-level models have been verified by demonstrating consistency with results/observations from field-scale, thermohydrologic tests. In particular, sufficient physical evidence should exist to support the conceptual models used to predict thermally driven flow in the near field		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The staff is unable to make a determination with respect to these acceptance criteria because supporting the AMR was not available prior to May 15, 2000. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.5)	CLOSED PENDING. The NFE PMR (CRWMS M&O 2000ad) Section 3 addresses process model confidence building or verification through comparisons with field tests. As described in that section, the DST THC model is used to predict THC processes prior to and during the DST. Measured data from the DST are used to evaluate the conceptual and numerical models. Results from DST THC simulations were compared to measured gas-phase CO_2 concentrations, and the chemistry of waters collected from hydrology boreholes during the test. The results of these comparisons provide indication of consistency with results and observations from field-scale thermal tests. The DST is continuing with the cooling phase scheduled to begin in December, 2001. Process level models have been calibrated against field data and observations as described in Sections 3.9.4.5, 3.10.4 and 3.12.4 in the UZ F&T PMR (CRWMS M&O 2000ab). See Table 4.3-1 and Appendix A of the referenced PMRs for additional discussion. Comparison of the EBS process models to field scale tests is in progress.	No additional work required beyond that currently planned.

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5-4. DOE demonstrates that abstracted models for coupled THMC effects on percolation and seepage are based on the same assumptions and approximations demonstrated to be appropriate for closely analogous natural or experimental systems.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The staff is unable to make a determination with respect to these acceptance criteria because supporting the AMR was not available prior to May 15, 2000. (ENFE IRSR Rev. 3, Sect. 5.4.2.1.5)	CLOSED PENDING. The DST was designed to generate THMC effects analogous to those possible in repository postclosure. The NFE PMR (CRWMS M&O 2000ad) addresses the process of changes to properties that would need to be considered within the UZ F&T PMR (CRWMS M&O 2000ab). Sections 3.3 and 3.4 describe the process-level models, model abstractions and analogous systems and supporting analyses that address the NFE processes and comparison of results. The THC Process AMR and THC Abstraction AMR (CRWMS M&O 2000ba and 2000bb) that support development of this section describe the inputs and assumptions that underlie the modeling. Detailed descriptions and justifications are provided for the basis for each assumption. In addition, the THC Abstraction AMR (CRWMS M&O 2000bb) provides explanations, documentation and justification for simplifications used in the abstractions described in that AMR.Modeling of seepage and flow, as well as abstractions of those models, is discussed in the UZ F&T PMR (CRWMS M&O 2000ab). The UZ F&T PMR (CRWMS M&O 2000ab, Section 3.10.11) documents the basis for the abstraction of coupled THC effects on seepage and flow. This acceptance criterion is also discussed in Appendix A of the EBS PMR (CRWMS M&O 2000aa).	

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Importance to System Performance: The number, location, and time when waste packages will be contacted and affected by dripping water will be influenced by the coupled processes that are partly addressed in the seepage and flow subissue. In addition, the chemistry of the water that contacts the waste packages will be the result of coupled THC processes that involve natural and engineered materials. Depending on the temperature of the waste packages and the drifts, and the flux of water contacting the waste packages, further evaporative concentration on the surface of the waste packages due to evaporative effects is possible. Description of the integrated subissues on quantity and chemistry of water and engineered barrier system degradation in a performance assessment must address the effects of coupled THC processes on the waste package chemical environment.		
Acceptance Criterion 1-Integration for Evolution of the Near-Field Environment Subissue 2. Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of the quantity and chemistry of water contacting waste packages and waste forms in the performance assessment and other related abstractions in the total system performance assessment, and the technical bases are provided. The features, phenomena and couplings, and assumptions used to abstract the quantity and chemistry of water contacting waste packages and waste forms have been provided. The total system performance assessment abstraction is consistent with the identification and description of those aspects of the quantity and chemistry of water contacting waste packages and waste forms that are important to waste isolation. The total system performance assessment abstraction is also consistent with the technical bases for these descriptions of barriers important to waste isolation. Specifically		
1-1. The DOE abstraction is consistent with the detailed information on waste package design and other engineered features.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED Abstraction of the quantity and chemistry of water contacting waste packages and waste forms are consistent with waste package design and EBS design. The EBS PMR (CRWMS M&O 2000aa, Executive Summary) identifies the following processes that relate to the chemistry of water contacting waste packages and eventually waste forms, especially: (1) seepage of water and its flow within the drift, (2) evaporation and condensation, (3) deposition of salts and precipitates within the drift, (4) chemical reactions between water, rock, and introduced materials, and (5) accumulation of corrosion products within the drifts and their effect on chemistry and flow. Section 5.3.2 of the EBS PMR summarizes the processes that control the	No additional work required

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	physical and chemical environment of the EBS, and Section 5.3.3 summarizes the modeled processes that control radionuclide transport. The Executive Summary notes that the EBS report demonstrates that EBS performance is sufficiently well understood to support reasonable predictions of the environmental conditions at drip shields and waste packages and of conditions that will affect radionuclide transport in the emplacement drifts.	
1-2. DOE evaluates the potential for focusing water flow into drifts caused by coupled THMC processes.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED This issue has been addressed in the TEF technical exchange, Open Item 7, Data Uncertainty. The chemical effects have received preliminary analysis. THC modeling is documented in the near-field PMR. The THMC work is in progress at LBL. The UZ PMR (CRWMS M&Oab, Section 3.10) discusses drift-scale thermal-hydrologic-chemical processes and models. Changes in hydrologic properties of fractures and the rock matrix are discussed in Section 3.10.2.4. Hydrologic property change relationships are discussed in Section 3.10.3.6, and the details of the THC seepage model are discussed in Section 3.10.5. The consequences of focusing have been captured in the TSPA, in the thermal seepage abstraction. (ANL-EBS-HS-000003)	No additional work is required beyond that already planned
1-3. DOE reasonably accounts for the chemical composition of the water in the environment surrounding the waste package and drip shield and its evolution with time.		

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NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. The individual in-drift submodels predict changes in water composition due to chemical interactions with a limited number of repository materials, and it is not yet clear how DOE will weigh the output from several different submodels and integrate it into a single RIP cell. It is not appropriate, for example, to assume that the initial water compositions for all submodels are similar to that of J-13 Well water, when each of the in-drift geochemical submodels describes changes in the infiltrating water composition due to chemical interactions with different types of engineered barrier materials. All DOE assumptions must be explicitly stated, and adequate technical bases must be provided. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED The current approach for representing the EBS in TSPA uses several GoldSim cells. The current design limits the number of materials that are present in the EBS (CRWMS M&O 2000aa, Section 1.6). Current models for the EBS capture the important aspects or water composition for performance (e.g., CRWMS M&O 2000aa, Executive Summary). Section 5.3.2 of the EBS PMR (CRWMS M&O 2000aa) summarizes the conceptual models of processes that control the physical and chemical environment of the EBS. Effects of TH processes (boiling, condensation, and drainage) on water and gas chemistry and mineral evolution are discussed in the UZ PMR (CRWMS M&O 2000ab, Section 3.10.2.2). Section 3.10.5 discusses the THC seepage model, and section 3.10.11 discusses the abstraction of the model for TSPA-SR. Effects of coupled THC processes on seepage and flow are discussed in Section 4.2.1.1. The current TSPA approach uses consistent set of water compositions, except for the waste form degradation model, which used a J-13 water composition. DOE believes this approach is adequate because the degradation products inside breached waste packages will dominate the water composition (CRWMS M&O 2000aa, Section	No additional work is required

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	3.1.2) and much of the mobilized radionuclide inventory will be colloidal (CRWMS M&O 2000ae, Section 3.8).	
1-4. DOE evaluates the effect of gamma-radiolysis of water contacting the waste packages and drip shield.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED. Preliminary scoping analyses (EBS PMR Rev 01, CRWMS M&O in prep.) and experiments documented in the Waste Package Degradation PMR (CRWMS M&O 2000ae, Section 3.1.6.6) show that gamma radiolysis will not be significant to corrosion of the drip shield or waste package. The Waste Form PMR (CRWMS M&O 2000an, Table 2.3-3) describes the basis for excluding radiolysis effects from TSPA as a mechanism for waste form degradation.	No additional work required
1-5. DOE identifies and adequately considers the effects of the drip shield and backfill on the quantity and chemistry of water contacting waste packages, including the potential for condensate formation and dripping from the underside of the shield.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED PENDING. An existing AMR (Water Distribution and Removal, Rev 1 CRWMS M&O 2000as) presents updated information on condensation under the drip shield. Based on observational data and modeling results, condensation is not likely until temperature differences are small. Even if condensation occurs, DOE expects a negligible effect on performance. Condensate water will be very dilute; hence, the chemistry of any condensate will be benign. Diffusion barrier performance is not effective	No additional work beyond that already planned.

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	according to current models in the long term when condensation could occur. Water diversion performance of the EBS without backfill is described in the EBS PMR, Rev 1 and supporting AMRs. Current models are based on the no- backfill repository concept.	
1-6. DOE provides analyses that demonstrate that no deleterious effects are caused by design or site features that DOE does not include in this abstraction.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1) DOE will need to provide a more thorough technical basis or supporting calculations to justify a number of FEPs exclusions, especially those based on low consequence. DOE also needs to revise the FEP database so that all the FEPs included in the in-drift geochemical model abstraction are also included in the FEP database. (IRSR 5.0.3.) DOE should conduct further studies to identify and characterize the conditions that could lead to enhanced drip shield degradation, in particular, take the potential impact of elevated fluoride concentrations into account, place reasonable constraints on the aqueous compositions at Yucca Mountain that might lead to drip shield	CLOSED PENDING. The EBS FEPs AMR (CRWMS M&O 2000af) is under revision (CRWMS M&O 2000as). Available documentation (e.g., CRWMS M&O 2000bg) supports the current FEPs screening. Currently available information indicates that the presence of Fl will not lead to premature failure of the drip shield, however, DOE has identified processes that could lead to accumulation of elevated concentrations of fluoride on the waste package CRWMS M&O 2000bj, Section 6.7). DOE has ongoing and planned laboratory testing to investigate chemical fractionation and related processes. (A CLST Agreement Item) Drainage capacity from the emplacement drifts is expected to be sufficient. (ANL-EBS-MD-000032, Rev.01)	

degradation, and use this information to define appropriate abstractions of engineered barrier degradation for performance assessment calculations. (IRSR 5.0.3)	Effects from steel and cement grout on the composition of seepage water have been evaluated. Evaluation of the effects of leaching of concrete in the ventilation shafts and other non-emplacement areas is being considered by the DOE. Gas generation and transport, chemical fractionation, and other chemical processes that could control the environments on the surfaces of the drip shield and the waste package outer barrier will be investigated in ongoing and planned work.	
1-7. DOE abstractions, including dimensionality of the abstractions, appropriately account for the various design features, site characteristics, and alternative conceptual approaches.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED PENDING. Current abstracted models for water diversion and radionuclide transport in the EBS have limited dimensionality, but these models closely represent the average response for all waste packages (EBS RN Transport Abstraction),(ANL-WIS-PA-000001, Rev.0 ICN 2) The multiscale thermal-hydrology model, described in the Near-Field Environment PMR (CRWMS M&O 2000ad, Section 3.2.2.1 and CRWMS M&O 2000aa, Section 3.1.4) uses 2-D TH models, and a 3-D model is being developed. The DOE model incorporates spatial variability and uncertainty in site characteristics (e.g., CRWMS M&O 2000ad, Section 3.3.4). Alternative conceptual approaches to handling TH,	

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	THC and THM processes have been considered (e.g., CRWMS M&O 2000ab, Section 3.10.7). See criterion 1-2 above.	
1-8. DOE spatial and temporal abstractions appropriately address the physical couplings (THMC).		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1) Coupled THC processes affect the two integrated subissues relevant to ENFE Subissue 2 and represent an integral part of DOE's conceptual model for performance assessment (CRWMS M&O, 1999a). Groundwater composition is sensitive to coupled THC conditions along the flow path and is expected to evolve as a function of time and space following waste emplacement. DOE's spatial and temporal abstractions must appropriately address physical couplings (THMC). If any THMC couplings are excluded from DOE's abstractions, then adequate technical bases must be provided. DOE therefore needs to provide adequate technical bases and justification for their major assumption (CRWMS M&O, 1999a) that THC processes can be decoupled, evaluated separately, and then recoupled without adversely affecting dose. Appropriate technical bases may stem from activities such as independent modeling, laboratory or field data,-or sensitivity studies	CLOSED PENDING. As in the TSPA-VA analysis, effects of spatial and temporal variations in the exposure conditions over the repository were modeled by incorporating explicitly relevant exposure conditions histories into the waste package degradation analysis. Spatial and temporal abstractions are handled by examining drift-scale and mountain-scale variability (CRWMS M&O 2000ab, Sections 3.10 and 3.12). For TH couplings, DOE models include the mountain-scale TH model (CRWMS M&O 2000bh, Section 3.12) and the multiscale TH model (CRWMS M&O 2000bd, Section 3.14). THM and THC couplings were discussed in TSPA presentations given by N. Francis and J. Nowak at the TEF and ENFE Technical Exchanges, respectively. DOE's technical bases and justification that THC processes can be decoupled, evaluated separately, and then recoupled without adversely affecting dose is addressed in the presentation "Treatment of Coupled Processes and Model Integration" (Ernest Hardin) in the ENFE Technical Exchange	No additional work required beyond that already planned.

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	Work is in progress to improve the modeling approaches for both THC and THM coupling.	
1-9. DOE provides the bases and justification for modeling assumptions and approximations where simplifications for modeling coupled THMC effects on seepage and flow and the waste package chemical environment are used for performance assessment.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1) **The Staff will evaluate the overarching impact of** DOE's approach to in-drift geochemical submodel integration on repository performance. A key aspect of this review will be an analysis of the reliability of DOE's major assumption (CRWMS M&O, 1999a) that coupled THC processes can be decoupled, evaluated separately, and then recoupled without adversely affecting predictions of repository performance. DOE must provide sufficient technical bases to support their treatment of coupled THC processes.	CLOSED Section 2.1 of the NFE PMR (CRWMS M&O 2000ad) describes the process of analysis used to determine which couplings that describe the host rock response need to be considered in TSPA, and the technical justification. The THC Process AMR and THC Abstraction AMR (CRWMS M&O 2000; 2000) describe the bases for these models. It is also noted that Section 2.5 of the NFE PMR (CRWMS M&O 2000ad) and the NFE FEPs AMR (CRWMS M&O 2000ai) describe the associated FEPs, and the justification for each excluded FEP. Coupling of THC processes to seepage and flow is analyzed in the UZ F&T PMR (CRWMS M&O 2000ab). DOE's current approach for modeling the host rock does not assume that all reactions proceed to equilibrium. Rather, THC simulations of the host rock are based on a kinetic rate-law formulation, although mineral selection and suppression are also used to represent the chemical system. Evolution of water composition in the EBS is modeled separately and differently from the host	No additional work required

	rock because the extent of evaporative concentration is greater, brines are formed, and the precipitated minerals and salts differ. Results from THC modeling of the host rock are used as the compositional boundary condition for equilibrium modeling with a Pitzer approach (reference In-Drift Precipitates and Salts AMR, CRWMS M&O 2000). TH couplings within the drift are included in the multiscale model (CRWMS M&O 2000bd) which provides temperature, humidity, and evaporation boundary conditions for the water composition model. Thermal effects on chemical equilibrium are included in the EQ3/6 Pitzer modeling approach. The minerals that are selected to form, and those that are suppressed, are chosen to conform to paragenetic relationships regarding the formation of calcite, sulfate and chloride salts, and silicates. The formation of soluble salts is justified by comparison with natural brine systems and laboratory test results (reference In-Drift Precipitates and Salts AMR, CRWMS M&O 2000; EBS Physical & Chemical Environment AMR, CRWMS M&O 2000). The potential for THC effects in the invert has been evaluated by considering the potential evaporation with and without Seepage (EBS Physical and Chemical Environment AMR Rev. 01 CRMWS M&O 2000). In addition, potential THC effects in the invert will be evaluated by planned modeling and testing activities (to be documented in revisions to the EBS PMR CRWMS M&O 2000).	

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	THC effects at a small scale, including scale and surface processes that could affect corrosion of the drip shields or waste packages, are addressed by ongoing and planned testing (*** current and future revisions to Environments on the Surface of the Drip Shield and Waste Package Outer Barrer CRWMS M&O 2000). Separation of processes in the EBS, for example at the drift wall, waste package surface, waste form, and invert, is justified because mass transfer is uni-directional. Modification of chemical conditions at each location is propagated to the next, while gas-phase conditions are considered uniform. Technical justification for this approach is document in the EBS PMR (Rev. 01 is work in progress) and supporting AMRs.	
1-10. DOE provides adequate technical bases, including activities such as independent modeling, laboratory or field data, or sensitivity studies, for exclusion of any THMC couplings and FEPs.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1) The NRC review of the DOE's FEPs database identified 26 FEPs related to Subissue 2. The NRC accepted screening arguments to exclude 2 FEPs: 2.1.04.03.00 Erosion or dissolution of backfill and 2.1.06.04.00 Flow through the liner. The NRC	CLOSED PENDING. The revised near field, waste package, and EBS FEP AMRs provide sufficient justification for inclusion and exclusion of FEPs in the current TSPA. The FEPs database has undergone major revisions that provide sufficient technical basis for the exclusions and inclusions of FEPs.	

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review showed that the staff either does not support DOE's preliminary screening or concluded that inadequate technical bases exist for exclusion of 24 FEPs that are described on pages 130-137 of the Evolution of the Near-Field Environment IRSR, Rev 3.		
1-11. DOE identifies and considers likely modes of corrosion for container materials, including dry-air oxidation, humid-air corrosion, and aqueous corrosion processes, such as general corrosion, localized corrosion, microbially induced corrosion, stress corrosion cracking, and hydrogen embrittlement, as well as the effect of galvanic coupling, in determining the quantity and chemistry of water entering the waste packages.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1) The following FEPs were screened by DOE: 2.1.06.06.00-Effects and degradation of drip shield. 2.1.09.02.00-Interaction with corrosion products. 2.1.09.07.00-Reaction kinetics in waste and engineered barrier system 2.1.09.09.00-Electrochemical effects in waste and engineered barrier system 2.1.10.01.00--Biological activity in waste and engineered barrier system 2.1.11.03.00 Exothermic reactions in waste and engineered barrier system 2.1.11.08.00--Thermal effects: chemical and microbiological changes in the waste and engineered barrier system DOE must commit to a screening stance and provide an adequate technical basis to support their	CLOSED PENDING. The revised near field, waste package, and EBS FEP AMRs provide sufficient justification for inclusion and exclusion of FEPs in the current TSPA. The FEPs database has undergone major revisions that provide sufficient technical basis for the exclusions and inclusions of FEPs.	No further work required than already planned

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screening decision		
1-12. DOE identifies the broad range of environmental conditions within the waste package emplacement drifts that may promote the corrosion processes of engineered barriers, taking into account the possibility of irregular wet and dry cycles and radiolysis that may enhance the rate of degradation.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED PENDING. DOE has addressed the items identified in the criterion in FEPs screening. Based on available information, the items specified do not appear to significantly increase the rate of waste package corrosion. Preliminary scoping analyses (EBS PMR Rev 01, CRWMS M&O is work in progress) indicate that waste-derived gamma radiolysis is not significant to corrosion of the drip shield or waste package. The Waste Form PMR (CRWMS M&O 2000an, Table 2.3-3) describes the basis for excluding radiolysis effects from TSPA. Effects of irregular wet and dry cycles are discussed in the Waste Package Degradation PMR, and results indicate that relative humidity has no significant effect on waste package and drip shield degradation (CRWMS M&O 2000ae, Section 5).	No additional work required beyond that already planned.
1-13. DOE demonstrates that the conditions and assumptions used to generate look-up tables or regression equations are consistent with all other conditions and assumptions in the total system performance assessment for abstracting the quantity and chemistry of water contacting waste packages.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED PENDING. Look-up tables are used for evaluating the quantity and quality of water. The independent variables in the look-up tables have been identified as those that are significant for corrosion and radionuclide	No additional work required

	transport (CRWMS M&O 2000ag).	
1-14. DOE uses important design features, including waste package design and material selection, backfill, drip shield, ground support, cladding, thermal-loading strategy, and degradation processes, to determine the initial and boundary conditions for calculations of the quantity and chemistry of water contacting waste packages and drip shield.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. 1.1.02.00.00-Excavation/construction: 1.1.02.01.00-Site flooding (during construction and operation): 1.1.02.03.00 Undesirable materials left: 1.1.03.01.00-Error in waste or backfill emplacement: 1.1.12.01.00-Accidents and unplanned events during operation DOE needs to provide a more robust technical basis for exclusion of these FEPs, perhaps by citing project documents where these assumptions and postulated actions (i.e., actions to correct mistakes) are codified. Also DOE needs to screen these FEPs so that the screening is consistent with actual post-closure performance assessment calculations. 2.1.06.06.00-Effects and degradation of drip shield. DOE must commit to a screening stance and provide an adequate technical basis to support their screening decision.	CLOSED PENDING. The FEPs database has undergone major revisions that provide sufficient technical basis for the exclusions and inclusions of FEPs. Important design features and quantities are taken into account in calculating the effect on the drip shield	No additional work required beyond that already planned.
1-15. DOE evaluates in-package criticality or external-to-package criticality within the emplacement drift and provides an adequate technical basis for screening these events. If either event is included in the total system performance assessment, DOE uses acceptable technical bases for selecting the design criteria that mitigate any potential impact of in-package criticality on the repository performance, identifies the FEPs that may increase the reactivity of the system inside the waste package, identifies the configuration classes and configurations that have potential for nuclear criticality, and includes changes in thermal condition's and degradation of engineered barriers in the abstraction of the quantity and chemistry of water contacting the waste packages and waste forms.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**

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OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED Criticality was addressed in a recent DOE-NRC technical exchange and, by mutual DOE-NRC agreement, will not be discussed during the ENFE Technical Exchange.	No additional work required
1-16. The abstraction of the quantity and chemistry of water contacting waste packages and drip shields is consistent with technical bases, data, and models in the flow in unsaturated zone abstraction, degradation of engineered barriers abstraction, mechanical disruption of engineered barriers abstraction, and radionuclide release rates and solubility limits abstraction.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED PENDING. Some items such as mechanical disruption of the waste packages have been excluded from TSPA based on FEPs screening The other items related to the quantity and chemistry of water contacting EBS components and the abstraction process are addressed mechanistically in models and abstractions. (See for example CRWMS M&O 2000ab, Sections 3.10.4.2, 3.10.5, and 3.10.11.) The EBS FEPs AMR (CRWMS M&O 2000af) is undergoing revision. The FEPs database has undergone major revisions that provide sufficient technical basis for the exclusions and inclusions of FEPs. The FEPs AMRs were revised with the intent of integrating the available source for justification for exclusion of FEPs	
1-17. DOE consistently addresses the effect of distribution of flow on the amount of water contacting the waste packages and drip shield in all relevant abstractions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN.	CLOSED PENDING.	

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Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	Current models conservatively depict average water flow rates and water diversion in the EBS (CRWMS M&O 2000ah). Gas generation or consumption by thermal evolution of waters, corrosion processes, waste decay, and microbial activity are addressed in current models (EBS Physical & Chemical Environment CRWMS M&O 2000 Rev. 01; **In-Drift Microbial Communities CRWMS M&O 2000 Rev. 01 is work in progress).** The EBS FEPs AMR (CRWMS M&O 2000af) is undergoing revision. FEPs concerned with waste form degradation are addressed in relation to Subissue 3. The FEPs database has undergone major revisions that provide sufficient technical basis for the exclusions and inclusions of FEPs.	
1-18. DOE consistently addresses the effect of waste package corrosion of the quantity and chemistry of water contacting waste packages in all relevant abstractions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.1)	CLOSED PENDING. The chemical effects of waste package corrosion are negligible because corrosion is a slow process and corrosion products are relatively inert in the environment outside the waste packages. The possible effects of corrosion products from steel, titanium, and Alloy-22 are discussed in the EBS	No further work required beyond that already planned.

	PMR (Rev. 01 is work in progress). Water flow through breaches in the waste package has been addressed; see criterion 1-11 above. The EBS FEPs AMR (CRWMS M&O 2000af) is undergoing revision. Precipitation/dissolution kinetics are addressed in item 1-9 above. Redox kinetics are addressed in current models by evaluating the potential magnitude of fluctuations in oxygen fugacity in the bulk environment (EBS Physical and Chemical Environment AMR Rev. 01) and by incorporating the physical separation between redox-sensitive steel and other materials in the ex-container environment. In-package redox effects are discussed in reference to Subissue 3. Electrochemical reactions are not addressed by models that describe the EBS environment, rather, they are incorporated in assessments of the performance of corrosion-resistant materials (Waste Package PMR Rev. 00 ICN 1).	
1-19. DOE consistently addresses the role of water chemistry parameters such as the pH and carbonate concentration and the effect of released radionuclides on the chemistry of water contacting the waste packages in all relevant abstractions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3, Sect. 5.4.2.2.1.1)	CLOSED PENDING. DOE has a mechanistic model for the composition of water in contact with the waste package. (pH and carbonate chemistry)This model is consistent with other process models and abstractions, but currently DOE has neglected effects of radionuclides on the chemistry of water contacting the waste package.	

	Justification for this is captured in the FEPs database. This approach is taken in part because waste package performance is relatively insensitive to the chemical environment. The integrated waste package model is described in Section 3.2 of the Waste Package Degradation PMR (CRWMS M&O 2000ae). The description includes descriptions of the abstractions of the various components of the integrated model (For example, see Sections 3.2.2, 3.2.3, and 3.2.7.) Further discussion of redox kinetics and electrochemical reactions is provided in item 1-18 above.	
1-20. DOE consistently addresses the size and distribution of penetrations of the drip shield and waste containers that affect the quantity and chemistry of water that contacts the waste package in all relevant abstractions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3, Sect. 5.4.2.2.1.1)	CLOSED PENDING. DOE's approach is consistent and the methods used represent the average flow of water that can pass through breaches. The various corrosion and cracking models that are used to represent waste package degradation are described in the integrated model section of the WP Degradation PMR (CRWMS M&O 2000ae, Sec. 3.2). Based on the discussion, TSPA includes stress corrosion cracks and patches that are formed by general corrosion. The movement of moisture through these types of breaches and the chemistry of this are addressed in the EBS PMR and supporting documentation.	No further work is required beyond that already planned.

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1-21. DOE peer reviews follow the guidance in NUREG-1297 and NUREG-1298 (Altman, Donnelly, and Kennedy, 1988a,b), or other acceptable approaches.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR, Rev. 3, Sect. 5.4.2.2.1.1)	CLOSED Peer reviews, expert elicitation, and qualification of data, when utilized, are conducted and documented in accordance with QARD requirements (DOE 2000a), which are consistent with guidance in NUREG-1297 and NUREG-1298, and NUREG-1563.	No additional work required

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Acceptance Criterion 2-Data and Model Justification for Evolution of the Near-Field Environment Subissue 2. Sufficient data on design features (including drip shield, backfill, waste packages, cladding, other engineered barrier components, and thermal loading), geology, hydrology, geochemistry, and geomechanics of the unsaturated zone and drift environment (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of the quantity and chemistry of water contacting waste packages and waste forms in the performance assessment. The data are also sufficient to assess the degree to which FEPs related to the quantity and chemistry of water contacting waste packages and waste forms and which affect compliance with postclosure performance objectives have been characterized and to determine whether the technical bases provided for exclusion of these FEPs are adequate. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the abstraction process. Specifically (see following items),

2-1. DOE demonstrates that sufficient data were collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions, including temporal and spatial variations in conditions, for conceptual models and simulations of THMC coupled processes that affect the waste package and drip shield chemical environment.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.2) There is little, if any, laboratory or field information available on the performance of the titanium drip shield, however, and at the current time, the status of the data sufficiency for this engineered barrier component is very uncertain. DOE will need to provide additional data on design features and the technical bases for the description of these features in DOE's total system performance assessment abstraction (ENFE IRSR, Rev. 3, Sect. 5.4.2.2.1.2)	CLOSED PENDING. DOE's natural system models are based on extensive site characterization data (CRWMS M&O 2000aa and CRWMS M&O 2000ad). The type, quantity, and reactivity of engineered materials has been evaluated CRWMS M&O 2000ab). Waste has looked at corrosion rates (reactivity) for Ti and Alloy-22 and were discussed in the CLST Technical Exchange. Potential interaction between steel and Ti has been evaluated. (ANL-EBS-MD-000006, Rev. 0, ICN 1)	No additional work beyond that already planned.

2-2. Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate other sources such as expert elicitation conducted in accordance with NUREG-1563 (Kotra, et al., 1996).

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OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.2)	CLOSED Expert elicitations regarding seepage and flow were conducted for both the UZ and NFE (CRWMS M&O 2000ad, S1PAC3). Expert elicitations associated with development of PMRs have been determined to be subject to the quality assurance program as described in the QARD (DOE 2000a) document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in NUREG-1563 (Kotra et al. 1996). Section 2.4.5 of the NFE PMR (CRWMS M&O 2000ad) addresses parts of the elicitation that relate to the NFE. For a more complete discussion refer to the UZ F&T PMR (CRWMS M&O 2000ab, Section 2.5.1).	No additional work required.
2-3. DOE provides sufficient data for sound bases for the exclusion of certain observed phenomena in its conceptual models.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.2)	CLOSED PENDING. DOE believes the FEPs screening process adequately addresses this criterion (e.g., CRWMS M&O 2000ai and CRWMS M&O 2000aj). The FEPs database has undergone major revisions that provide sufficient technical basis for the exclusions and inclusions of FEPs.	No additional work required beyond that already planned.
2-4. DOE collects sufficient information to formulate the conceptual approaches for analyzing water contact with the waste packages upon drip shield failure.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model	CLOSED The current model implemented in TSPA	No additional work required

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Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.2)	conservatively and accurately represents the average water diversion response of many waste packages subject to drip shield failure (CRWMS M&O 2000ah).	
2-5. DOE provides sufficient data to complete a nutrient and energy inventory calculation, if it has been used to justify the exclusion of the potential for microbial activity affecting the waste package and drip shield chemical environment, or has been used to abstract microbial effects.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.1.2) Staff notes the difficulty in placing reasonable bounds on the parameters needed to resolve topics related to microbial activity. However, the path to resolving these issues at a potential repository at Yucca Mountain is through bounding analysis of microbiological effects on chemistry coupled with the selection of materials resistant to microbiological activity.	CLOSED PENDING. This item has been addressed by information contained or cited in the In-Drift Microbial Communities model (CRWMS M&O 2000ak). This document bounds the nature and extent of microbial activity in the EBS. In its current version, results do not preclude the possibility of MIC of the waste package.	No additional work is required
2-6. If microbial activity could be sufficient to allow microbially induced corrosion of the waste package or drip shield, DOE provides sufficient data to determine the time-history of temperature, humidity, and dripping to constrain microbially induced corrosion and microbial effects such as production of organic by-products.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Sect. 5.4.2.2.1.2) The TSPA SR reference design calls for the drip	CLOSED PENDING. MIC of the waste package could occur and conditions that constrain MIC are incorporated in TSPA (e.g. CRWMS M&O 2000aa, Section 3.1.2.4). MIC is described in the AMR In-Drift Microbial Communities (CRWMS M&O 2000ak).	No additional work required

shield to be installed after waste emplacement is complete. DOE has provided a limited sensitivity analyses of the effects of a drip shield in the design selection report (CRWMS M&O, 1999b).		
1-7. DOE performs sensitivity, if needed, or uncertainty analyses (including consideration of alternative conceptual models) to test for the necessity of additional data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.2)	CLOSED Sensitivity and uncertainty analyses are performed as needed at the system level. Dose consequence is an appropriate basis for determining the need for additional testing and data collection. See for example CRWMS M&O 2000al and CRWMS M&O 2000am, Section 5).	No additional work required beyond that already planned.

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Acceptance Criterion 3-Data Uncertainty for Evolution of the Near-Field Environment Subissue 2. Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the abstraction of quantity and chemistry of water contacting waste packages and drip shields, such as the pH, chloride concentration, and amount of water flowing in and out of the breached waste package, are consistent with site characterization data, design data, laboratory experiments, field measurements, and natural analog data, are technically defensible and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the abstraction are provided. Specifically (see following items),		
3-1. Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the quantity and chemistry of water contacting waste packages and drip shields calculations in the performance assessment are technically defensible and reasonable, based on data from the Yucca Mountain region (e.g., results from large-block and drift-scale heater and niche tests) and a combination of techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.3) Two major assumptions DOE plans to implement in the TSPA-SR are relevant to both the ENFE Subissue 2 and the integrated subissue on quantity and chemistry of water contacting waste packages and waste forms. These assumptions are: (i) kinetics can be ignored because all reactions proceed to equilibrium, and (ii) coupled THC processes can be reasonably approximated by decoupling and then recoupling submodels. DOE must provide technical bases demonstrating that parameter values, assumed ranges, probability distributions, and bounding assumptions reasonably account for uncertainties.	CLOSED PENDING. The abstractions are based on integration of process models as documented in the UZ, NFE, and EBS PMRs (CRWMS M&O 2000ab, Section 5.2; CRWMS M&O 2000ad, Sections 3.4 and 5.1; CRWMS M&O 2000aa, Sections 3.1 and 3.2). The UZ model defines the seepage; the near-field environment model examines thermal effects, and the EBS model examines water diversion by the EBS. It is noted that for modeling water composition in the EBS, that mineral selections and suppressions are used to represent the major affects of kinetics, i.e. that precipitates will be limited to certain minerals and salts that have been observed as fracture minerals, or observed in laboratory tests, or are expected based on other paragenetic information. Further discussion is provided for Item 1-9.	No additional work beyond that already planned.

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	The assumptions regarding kinetics and coupled THC processes is addressed by the presentation "Chemical Equilibrium and treatment of Coupled Processes" (E. Hardin) presented at the ENFE KTI Technical Exchange.	
3-2. DOE demonstrates that parameters derived from process-level models used for the quantity and chemistry of water contacting waste packages and drip shields are consistent with site characterization data, laboratory experiments, field measurements, and natural analog information.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. **Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.** (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.3) Staff does not accept the claim in the preliminary draft Analysis and Model Report E0105 (Precipitates Salts Analyses) that model validation criteria are met in every case. The preliminary draft Analysis and Model Report reasonably notes major discrepancies between model results and data used to judge "validity." The validation criterion that the low relative humidity model should provide results that agree with the high relative humidity model where the two models are joined (p. 63) is risky if the high relative humidity model is imperfect (which it is).	CLOSED PENDING. **The PMRs document the abstractions (e.g.,** CRWMS M&O 2000ab, Section 5.2; CRWMS M&O 2000ad, Sections 3.4 and 5.1; CRWMS M&O 2000aa, Sections 3.1 and 3.2) and identify the information used as the bases for those abstractions. The PMRs generally differentiate between parameters developed from process models versus those that may be based on conservative estimates or assumptions. The Pitzer (PT4) model developed for the In-Drift Precipitates/Salts Analysis AMR (CRWMS M&O 2000) is tested against other published modeling approaches and data, for ambient temperature applications, in the EBS Physical & Chemical Environment AMR (CRWMS M&O 2000 Rev. 01). The PT4 database is currently being revised with the objective to improve agreement with constraint data (EBS Physical & Chemical Environment AMR, CRWMS M&O 2000, Rev. 02 is work in progress). Additional laboratory data on	

	the behavior of highly concentrated brines is being considered by DOE, which will provide additional constraint data below 85% relative humidity (low relative humidity salts model range). Environments on the Surfaces of the Drip Shield and Waste Package Outer Barriers, CRWMS M&O 2000, Rev. 01 is work in progress.	
3-3. DOE provides technical bases for parameter ranges, probability distributions or bounding values. DOE demonstrates that the parameter values are derived from site-specific data or provides an analysis to demonstrate that the assumed parameter values do not under-predict repository performance.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. DOE has not clearly documented the basis for the parameter probability distribution functions. This may be because data are not otherwise readily available. It thus appears as if informal expert elicitation is used to define the parameter ranges. Development of parameter distributions through elicitation is acceptable, but DOE should conduct and document these expert elicitations in accordance with the guidance in Kotra, et al. (1996) or other acceptable methods.	CLOSED PENDING. The PMRs document the abstractions (e.g., CRWMS M&O 2000ab, Section 5.2; CRWMS M&O 2000ad, Sections 3.4 and 5.1; CRWMS M&O 2000aa, Sections 3.1 and 3.2) and identify the information used as the bases for those abstractions. The PMRs differentiate between parameters developed from process models versus those that are based on conservative assumptions. The EBS PMR (CRWMS M&O 2000, Rev. 01 is work in progress) provides discussions relative to the items specified. Documentation of the current TSPA model, including the basis for parameter probability distributions, is provided in the TSPA Model AMR (CRWMS M&O 2000 Rev. 00) and supporting abstraction AMRs. AP 3.10 concerning technical work processes stipulates that all model inputs(data, assumptions,	

	etc) are identified. Where assumptions(such as assumed probability distributions) are not yet fully justified, the TBV tracking process is used to maintain these open items. (AP 3.15 Q)	
3-4. DOE demonstrates that input values used in the quantity and chemistry of water contacting engineered barriers (e.g., drip shield, waste package, and cladding) calculations and abstractions are consistent with the initial and boundary conditions and the assumptions of the conceptual models and design concepts for the Yucca Mountain site, such as waste package and engineered barrier system design (including backfill, drip shield, ground support, and cladding), waste package degradation (corrosion and mechanical disruption), cladding degradation, deep percolation flux, important THMC coupling effects, the thermal reflux model, the thermal-loading strategy (including effects of ventilation), natural system masses and fluxes, and other design features that may affect performance.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.3)	CLOSED PENDING. DOE has used numerical simulation to represent THC coupled processes that will control water composition in the host rock (CRWMS M&O 2000ab, Sections 3.9 and 3.10.5). Other models are used for evaporative evolution of waters in the EBS (e.g., CRWMS M&O 2000aa, Section 3.1.1). These models are consistent with the initial and boundary conditions and assumptions used for other important models that feed TSPA-SR. Details are provided in UZ, NFE, and EBS PMRs (CRWMS M&O 2000ab, CRWMS M&O 2000ad, CRWMS M&O 2000aa).	
3-5. DOE establishes that reasonable or conservative ranges of parameters or functional relations are used to determine effects of coupled THMC processes on the waste package and drip shield chemical environment.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.3)	CLOSED PENDING. For evaluation of bulk chemical conditions in the EBS, the processes of interest have been decoupled as described in the EBS PMR (e.g. CRWMS M&O	

	2000, Rev. 01 is work in progress) and the Waste Package PMR (CRWMS M&O 2000, Rev. 01 is work in progress). Decoupling is justified because intercoupling of chemical, hydrologic, and mechanical processes in the ex-container EBS will be limited, while smaller scale chemical heterogeneity and electrochemical reactions are evaluated in the corrosion test program. Descriptions and documentation of the response of the engineered barrier system to coupled processes are provided in the EBS and Waste Package PMRs as referenced above. Selected Cl, I and pH serve as measures of the chemical environment for the drip shield and waste package consistent with the corrosion behavior of the barrier materials.	
3-6. DOE shows that the parameters used to define initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THMC effects on the waste package and drip shield chemical environment are consistent with available data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.3)	CLOSED PENDING. DOE has used numerical simulation to represent the host rock and the EBS to develop water compositions for potential seepage (CRWMS M&O 2000aa, Sections 3.8, 3.10.2 and 3.10.5). Other models are used for evaporative evolution in the EBS CRWMS M&O 2000aa, Section 3.10.2). These models are consistent with the initial and boundary conditions and assumptions used for important models that feed TSPA-SR. Details are provided in UZ, NFE, and EBS PMRs (CRWMS	

	M&O 2000ab, CRWMS M&O 2000ad, CRWMS M&O 2000aa; some of these concerns are addressed by ongoing revisions of these reports, which are work in progress). The Pitzer (PT4) model developed for the In-Drift Precipitates/Salts Analysis AMR (CRWMS M&O 2000) is tested against other published modeling approaches and data, for ambient temperature applications, in the EBS Physical & Chemical Environment AMR (CRWMS M&O 2000 Rev. 01). **The PT4 data based is currently being revised with the objective to improve agreement with** constraint data (EBS Physical & Chemical Environment AMR, CRWMS M&O 2000, Rev. 02 is work in progress). Additional laboratory data on the behavior of highly concentrated brines is being considered by DOE, which will provide additional constraint data below 85% relative humidity (low relative humidity salts model range). (Environments on the Surfaces of the Drip Shield and Waste Package Outer Barriers, CRWMS M&O 2000, Rev. 01 is work in progress).	
3-7. DOE provides confirmation that the correlations between input values, if any exist, have been appropriately established in the total system performance assessment.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev. 3 Sect. 5.4.2.2.1.3)	CLOSED PENDING. Documentation of the current TSPA model is provided in the TSPA Model AMR (CRWMS M&O 2000 Rev. 00), In Drift Precipitates and Salts AMRs and supporting abstraction AMRs. LLNL	

	data are in the process of being qualified. Model validation depends on the intended use of the model (AP 3.10Q). DOE believes it is reasonable to use an approximate data set (with evident measurement errors) in the validation of this model.	
3-8. DOE demonstrates that parameter values, assumed ranges, probability distributions, and bounding assumptions reasonably account for uncertainties.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev. 3 Sect. 5.4.2.2.1.3)	CLOSED PENDING. Model inputs and assumptions are selected to reasonably account for uncertainties. Documentation is provided in Waste Form Degradation PMR (CRWMS M&O 2000an, Sections 3.1.2, 3.2.2, 3.3.2, 3.4.3, 3.5.2, 3.6.2, 3.7.2, 3.8.3), Waste Package Degradation PMR (CRWMS M&O 2000ae, Section 3.1.9), EBS Degradation PMR (CRWMS M&O 2000aa, Section, Near Field Environment PMR (e.g., CRWMS M&O 2000ad, Section 3.3.4, and UZ Flow and Transport PMR (e.g., CRWMS M&O 2000ab, Sections 3.6.5.2, 3.7.4.5, 3.8.5, and 3.10.6). It is noted that for modeling water composition in the EBS, that mineral selections and suppressions are used to represent the major affects of kinetics, i.e. that precipitates will be limited to certain minerals and salts that have been observed as fracture minerals, or observed in laboratory tests, or are expected based on other paragenetic information. Further discussion is provided for Item 1-9.	No further work required beyond that already planned.

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<table>
<tr><td colspan="3">3-9. DOE adequately considers the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THMC coupled processes that affect the waste package and drip shield chemical environment.</td></tr>
<tr><th>NRC Staff Analysis</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.</td><td>CLOSED PENDING.

Uncertainties are handled differently for different models. For example, uncertainty on UZ hydrology is handled differently from uncertainty associated with effects of coupled processes on corrosion. Uncertainty is represented in TSPA by probability distributions and use of conservative bounding assumptions. DOE improvement of model uncertainty analysis and sensitivity testing is ongoing (EBS PMR, Rev. 01 in progress)</td><td>No further work required beyond that already planned.</td></tr>
<tr><td colspan="3">3-10. DOE adequately represents uncertainty in parameter development for conceptual models, process-level models, and alternative conceptual models considered in developing the abstraction of quantity and chemistry of water contacting waste packages and drip shields, either through sensitivity analyses or conservative limits.</td></tr>
<tr><th>NRC Staff Analysis</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.</td><td>CLOSED PENDING.

Uncertainties are handled differently for different models. For example, uncertainty on UZ hydrology is handled differently from uncertainty associated effects of coupled processes on corrosion. Uncertainty is represented in TSPA by probability distributions, and use of conservative bounding assumptions. DOE improvement of model uncertainty analysis and sensitivity testing is ongoing (EBS PMR, Rev. 01 in progress)</td><td>No further work required than already planned.</td></tr>
<tr><td colspan="3">3-11. DOE demonstrates how parameters used to describe flow through the engineered barrier system bounds the effects of backfill and excavation-induced changes.</td></tr>
</table>

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NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.	CLOSED There is no backfill in the current design. Excavation effects are incorporated through the UZ seepage model (CRWMS M&O 2000ab, Section 3.9). Excavation effects on the rock have been measured in the ESF and DOE believes that these effects are adequately represented in the seepage model.	No additional work required.

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Acceptance Criterion 4-Model Uncertainty for Evolution of the Near-Field Environment Subissue 2. Alternative modeling approaches consistent with available data (e.g., design features, field, laboratory, and natural analog) and current scientific understanding are investigated, and results and limitations are appropriately factored into the abstraction of quantity and chemistry of water contacting waste packages and drip shields. DOE provided sufficient evidence that alternative conceptual models have been considered, that the models are consistent with available data and current scientific understanding, and that the effect of these alternative conceptual models on total system performance has been evaluated. Specifically (see following items),		
4-1. DOE investigates alternative modeling approaches consistent with available data and current scientific knowledge, and appropriately considers their results and limitations of these approaches in developing the abstraction of quantity and chemistry of water contacting waste packages and drip shields.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. **Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.** (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.4) The ability of DOE to adequately track the evolution in water composition between different in-drift submodels and RIP mixing cells is of functional importance to the resolution of ENFE Subissue 2. DOE should provide reasonable technical bases for the infiltrating water composition(s) used in each in-drift geochemical submodel. The Staff also supports DOE's plans to perform sensitivity studies to learn the effects of different infiltrating water compositions on the in-drift geochemical model output (CRWMS M&O, 1999a) and expect the results of these analyses to be placed in the context of the performance assessment. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.4)	CLOSED PENDING. **Alternative models are considered in the development of thermal seepage, water composition, and other submodels that describe the EBS.** See CRWMS M&O 2000ab, Sections 3.7, 3.8, 3.9, and 3.10, CRWMS M&O 2000ad, Section 5.1, and CRWMS M&O 2000aa, Section 5.3). Documentation of the current TSPA model, including model sensitivity, is provided in the TSPA Model AMR (*** CRWMS M&O 2000 Rev. 00) and supporting abstraction AMRs. This acceptance is addressed in presentation given at the ENFE KTI Technical Exchange in January, 2001. Our current models are better integrated than those used by the CNWRA. The effect of alternate water composition and release to biosphere is probably negligible as indicated by corresponding sensitivity in the TSPA (TSPA model AMR, Rev. 0)	

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4-2. DOE adequately considers the effects of THMC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products in their assessment of alternative conceptual models. DOE considers: (i) thermohydrologic effects on gas and water chemistry, (ii) hydrothermally driven geochemical reactions such as zeolitization of volcanic glass, which could affect water chemistry and waste package and drip shield environmental conditions, (iii) dehydration of hydrous phases liberating moisture that may affect the waste package and drip shield chemical environment, (iv) effects of microbial processes on the waste package and drip shield chemical environment, and (v) changes in water chemistry that may result from the release of corrosion products from the waste package and drip shield and interactions between engineered materials and groundwater, which, in turn, may affect the waste package and drip shield chemical environment, in their assessment of alternative conceptual models.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. **Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.** (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.4) DOE must adequately consider the effects of THMC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products in their assessment of alternative conceptual models. Hence, addressing the "major [DOE] assumption" that coupled processes can be reasonably approximated by decoupling and then recoupling the processes is a significant, but necessary, task associated with acceptance criterion 4. Technical bases should be provided demonstrating that parameter uncertainties associated with this assumption have been appropriately bounded and do not lead to an over-estimation of repository performance.	CLOSED PENDING. **DOE considers its approach to be valid and sufficient. The approach to coupled processes is** presentations given (E. Hardin and J. Nowak) at the ENFE KTI Technical Exchange (January 2001). TH and TC couplings are included in the models that support the current TSPA. THC couplings in the rock have been evaluated and work is ongoing to evaluate them in the drifts. The EBS PMR documents the consideration of thermal effects on gas and water chemistry (e.g., CRWMS M&O 2000 Rev. 01 is work in progress). Hydrothermally driven geochemical reactions are considered in the UZ PMR (CRWMS M&O 2000ab, Section 3.10.2.2, 3.10.4.1, and 3.10.4.2),and this work will continue. Dehydration of hydrous phases is addressed in the NFE PMR (e.g., CRWMS M&O 2000ad, Section 3.3.3.6). Microbial processes are addressed in the EBS and Waste Package PMRs (e.g., CRWMS M&O 2000 Rev. 01 is work in progress). Water chemistry in	

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	the EBS is addressed in the EBS PMR (CRWMS M&O Rev. 01 is work in progress), Waste Package PMR (CRWMS M&O 2000ae, Section 3.1.3) and Waste Form PMR (e.g., CRWMS M&O 2000an, Section 3.2). Models of released radionuclides and EBS materials are under development. The assumption that certain processes in the EBS can be decoupled, is justified because mass transport (liquid and solid) in the EBS is unidirectional, and small-scale processes are addressed through corrosion testing, as discussed above for Subissue 1, Item 1-9.	
4-3. If DOE uses an equivalent continuum models (ECMs), then DOE demonstrates that the models do not under-predict overall performance.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.4)	CLOSED PENDING. The Equivalent Continuum Model is not used in current modeling.	No additional work required.
4-4. DOE provides a description which includes a discussion of alternative modeling approaches not considered in its final analysis and the limitations and uncertainties of the chosen model.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.4) DOE should evaluate uncertainties associated with the PT4 database for modeling the behavior of electrolyte solutions and provide a more	CLOSED PENDING. The procedure AP-3.10Q requires discussion of alternative modeling approaches, and limitations and uncertainties. (See AP-3.10Q, Attachment 1.) The Pitzer (PT4) model developed for the In-Drift Precipitates/Salts Analysis AMR (*** CRWMS M&O 2000) is tested against other published	

representative list of FEPs associated with the Salts/Precipitates Analysis and Model Report. Therefore, staff recommends that the DOE salts/precipitates analysis include a rigorous analysis of model uncertainties, or bound the effects of the uncertainties on repository performance.	modeling approaches and data, for ambient temperature applications, in the EBS Physical & Chemical Environment AMR (*** CRWMS M&O 2000 Rev. 01). The PT4 data based is currently being revised with the objective to improve agreement with constraint data (EBS Physical & Chemical Environment AMR, CRWMS M&O 2000, Rev. 02 is work in progress). Additional laboratory testing is being considered by DOE to evaluate the behavior of highly concentrated brines will provide additional constraint data below 85% relative humidity (Environments on the Surfaces of the Drip Shield and Waste Package Outer Barriers, CRWMS M&O 2000, Rev. 01 is work in progress). Documentation of the current TSPA model, including sensitivity of the dose consequences to model components, is provided in the TSPA Model AMR (*** CRWMS M&O 2000 Rev. 00) and supporting abstraction AMRs. The analysis of model uncertainties for salts/precipitates is addressed in presentations "Chemical Equilibrium" and "Data Uncertainties and Sensitivities" by E. Hardin at the ENFE Technical Exchange, January, 2001.	

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Acceptance Criterion 5-Model Support for Evolution of the Near-Field Environment Subissue 2. Output from the abstraction of quantity and chemistry of water contacting waste packages and drip shields is justified through comparison with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, and natural analogs). Specifically (see following items),		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
5-1. DOE verifies that the outputs of the quantity and chemistry of water contacting the drip shield and waste package abstractions reasonably reproduce or bound the results of corresponding process-level models or empirical observations.		
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.	CLOSED PENDING. Thermal seepage abstraction, drift seepage abstraction, and the EBS radionuclide transport abstraction together provide a consistent and conservative representation of the quantity of water contacting the waste package and drip shield. Results from the In-Drift Precipitate/Salts process model are abstracted directly into the TSPA in the form of look-up tables that reasonably bound chloride concentration and ionic strength. Model results compare favorably with laboratory test data and tabulated data on soluble salts (CRWMS M&O 2000bm, Section 6.5). DOE is continuing to improve this model and its underlying database (EBS PMR Rev. 01 is work in progress).	No further work beyond that already planned.
5-2. OPEN. DOE demonstrates that abstracted models for coupled THMC effects on the waste package and drip shield chemical environment, are based on the same assumptions and approximations demonstrated to be appropriate for closely analogous natural or experimental systems.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.5)	CLOSED PENDING. To the extent possible, in the current PMRs the natural analogs have been and found to be consistent with the current approach taken.	

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The preliminary draft Analysis and Model Report U0135 (Natural Analogs for Unsaturated Zone) (CRINMS M&0, 2000g) recognizes the potential significance of natural analog studies and identifies several potentially important sites and studies, but presents limited direct applications to performance assessment model support for the Yucca Mountain repository.	Natural analogs and comparisons with laboratory test data are documented in the PMRs, as appropriate (e.g., CRWMS M&O 2000ab, Sections 3.10.9 and 3.11.12).	
5-3. DOE shows that abstracted model results were verified through comparison with outputs of detailed process-level models and empirical observations.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.5)	OPEN. Abstracted results for water composition in the EBS (Physical and Chemical Environment Abstraction, CRMWS M&O 2000) are developed directly from process model output (In-Drift Precipitates/Salts Analysis CRWMS M&O 2000bm). DOE is continuing to improve this process model and the underlying database. Other environmental conditions in the EBS (temperature, humidity, mass fluxes) are abstracted from results of the multiscale model, which is based on thermal-hydrologic models and properties that have been calibrated against field thermal test data (*** Thermal Testing AMR CRWMS M&O 2000; *** Multiscale Thermohydrologic Model AMR, CRWMS M&O; *** Near-Field Thermodynamic Environment Abstraction AMR, CRWMS M&O 2000))	No further work is required.
5-4. DOE evaluates the outputs of the abstraction against field and laboratory data and natural analogs information.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**

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OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.1.4) Staff supports continuation of DOE efforts to use natural analogs for model support, but note that natural analog data must be more directly related to specific performance assessment abstractions or process-level models in order to further resolution of ENFE subissues.	CLOSED PENDING. Natural analogs and comparisons with laboratory test data are documented in the PMRs, as appropriate. The abstractions are compared to laboratory and field test data, for example, In-Drift Precipitates/Salts Analysis. (CRWMS M&O 2000bm, Section 6.5)	
5-5. DOE appropriately adopts accepted and well-documented procedures to construct and test the numerical models used to simulate coupled THMC effects on the waste package and drip shield chemical environment.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.	CLOSED PENDING. Software management procedures are used as required by DOE's process validation and re-engineering initiative. Model validation practices are followed (e.g., CRWMS M&O 2000ab, Sections 3.5.6.3 and 3.7.4.4). Current models for the in-drift environment are decoupled, for mechanical and chemical effects. Analyses are under way to evaluate coupling.	
5-6. DOE compares abstracted model results with different mathematical models to judge robustness of results.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.	CLOSED PENDING. Abstraction models are consistent with their respective process models and are validated in accordance with procedure AP-3.10Q. This	No further work is required.

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	procedure also requires discussions of alternative modeling approaches, limitations, and uncertainties. DOE considers the abstractions used in the current TSPA are appropriate representations of the engineered barriers. Robustness is achieved using conservative model inputs or assumptions, and where necessary and appropriate by considering alternative mathematical models.	

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Integrated Subissue on Degradation of Engineered Barriers		
Acceptance Criterion 1-Integration for Evolution of the Near-Field Environment Subissue 2. Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of degradation of engineered barriers and other related abstractions in the total system performance assessment, and the technical bases are provided. The abstraction identifies and describes design features of the engineered barrier system and aspects of the degradation of engineered barriers that are important to waste isolation and includes the technical bases for these descriptions. Specifically (see following items),		
1-1 DOE identifies and considers likely corrosion and degradation modes for engineered barrier materials, including uniform corrosion, pitting corrosion, crevice corrosion, stress corrosion cracking, intergranular corrosion, microbially influenced corrosion, dry-air oxidation, and hydrogen embrittlement. DOE identifies the effects of material aging and phase stability of the engineered barrier materials and initial defects on the degradation modes for the engineered barriers.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.2.1) The NRC staff identified 32 FEPs (two additional FEPs, 2.1.09.02.00-Interaction with corrosion products, and 2.1.06.06.00-Effects and degradation of drip shield) compared with 30 FEPs identified by DOE that are related to the Integrated Subissue on Degradation of the Engineered Barriers (IRSR Rev 3, Table 5-4). Staff review of DOE's FEPs screening identified 15 FEPs that were excluded, partially excluded, or not assigned an exclude/include status by DOE. The description in Section 5.4.2.2.2.1 indicates that, of 15 FEPs were not included in DOE's screening, fourteen overlap with Quantity and Chemistry of Water Contacting the Waste Packages and are discussed under Subissue 3.	CLOSED PENDING. This item has been addressed under the CLST KTI Technical Exchange. Various corrosion models are discussed and documented in the Waste Package Degradation PMR (CRWMS M&O 2000ae, Sections 3.1.5, 3.1.6, 3.1.7, and 3.1.8). Parameters influencing microbial corrosion are discussed in the EBS PMR (CRWMS M&O 2000aa, Section 3.1.2.4) The EBS FEPs AMR (CRWMS M&O 2000af) is undergoing revision. DOE believes that the current FEPs screening is supported by available documentation (EBS PMR Rev. 01 is work in progress).	No further work is required beyond that already planned.

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1-2. DOE evaluates the possibility of gamma-radiolysis of the groundwater in contact with the engineered barriers and evaluated the effects of gamma-radiolysis products on the corrosion of the engineered barriers.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.2.1)	CLOSED PENDING. The effects of radiolysis inside the waste package (prior to first breach) have been shown to be limited (*** WP PMR CRWMS M&O 2000). The Waste Form PMR (CRWMS M&O 2000an, Table 2.3-3) describes the basis for excluding radiolysis effects on waste form degradation. The effects of ex-container radiolysis on the in-drift environment are addressed by the EBS PMR (Rev. 01 is work in progress).	No further work required beyond that already planned.
1-3. DOE considers whether the use of a drip shield could result in the extension of the humid-air corrosion regime, condensation formation and dripping from the under side of the drip shield, failure of the drip shield, hydrogen embrittlement and the possibility of crevice corrosion between the drip shield and the waste package.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.2.1)	CLOSED PENDING. This criterion is addressed in the EBS PMR (Rev. 01 is work in progress). The drip shield serves as a thermal barrier that increases the waste package temperature during the thermal period and therefore decreases relative humidity, however, this changes only the timing of conditions that could allow waste package corrosion, and only by a few hundred years at most. (EBS PMR Rev. 01 in progress) Drip shield failure is addressed in current models that support TSPA.(Water Distribution & Removal Model AMR, EBS Radionuclide Transport	

	Abstraction AMR) Drip shield corrosion and crevice corrosion between the drip shield and waste package are addressed in the Waste Package PMR (CRWMS M&O 2000ae, Sections 3.1.6, 3.1.7). Analysis of hydrogen embrittlement of the drip shield and steel in the EBS has been performed and documented (CRWMS M&O 2000ae, Section 3.1.8). The FEPs analysis is being updated in revised PMRs (e.g., CRWMS M&O 2000af).	

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Acceptance Criterion 2-Data and Model Justification for Evolution of the Near-Field Environment Subissue 2. Sufficient data from laboratory corrosion tests and in-service experience in pertinent industrial applications, as well as sufficient site-specific data, including data from drift-scale tests, are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of the degradation of engineered barriers in the performance assessment. The data are also sufficient to assess the degree to which FEPs related to the degradation of engineered barriers have been characterized and to determine whether the technical bases provided for exclusion of these FEPs are adequate. Specifically (see following items),		
2-1. DOE justifies data on the degradation of the engineered barriers, including general and localized corrosion, hydrogen embrittlement, and galvanic interactions are based on laboratory measurements and tests designed to replicate the range of conditions that may occur at the Yucca Mountain site.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.2.2)	CLOSED PENDING. Tests to investigate corrosion processes are designed to incorporate appropriate ranges of conditions. See Waste Package PMR (CRWMS M&O 2000af, Sections 3.1.1 through 3.1.11).	No further work required beyond that already planned.
2-2. DOE performs sensitivity and uncertainty analyses on the effects of coupled THC processes on the engineered barrier environment to determine the necessity for additional data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.2.2)	CLOSED PENDING. Current models show that waste package and drip shield corrosion are only slightly sensitive to the chemical environment (CRWMS M&O 2000af, Section 5) within the range of chemical conditions expected (EBS Physical & Chemical Environment AMR, CRWMS M&O 2000). Documentation of the current TSPA model, including sensitivity of the dose consequences to model components, is provided in the TSPA Model AMR (*** CRWMS M&O 2000 Rev. 00) and supporting abstraction AMRs.	

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2-3. DOE considers available data relevant to both temporal and spatial variations in conditions affecting coupled THC effects on the engineered barrier degradation.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed(ENFE IRSR, Rev. 3 Sect. 5.4.2.2.2.2)	CLOSED PENDING. Temporal changes and spatial variability in boundary conditions and uniform rock unit properties, are incorporated in TH models (Multiscale TH Model AMR, CRWMS M&O 2000, Rev. 00 ICN 1). Similar variability is incorporated in THC models (NFE PMR CRWMS M&O 2000, Rev. 00 ICN 03). DOE is considering further modeling that would evaluate the effects of random spatial heterogeneity of rock properties.	No further work beyond that already planned.
2-4. DOE provides sufficient data on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect degradation of engineered barriers.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. DOE has not provided sufficient data on the environmental conditions :that could lead to rapid drip shield degradation. While precipitates and aqueous complexes could sequester much of the available F-, DOE has not yet, but should, evaluate the extent of this sequestering. DOE should conduct further studies to identify and characterize the conditions of enhanced drip shield degradation, place reasonable constraints on the aqueous.	CLOSED PENDING. Characteristics of natural system materials are considered in reactive transport modeling of the host rock. Engineered materials are inventoried and evaluated in the EBS PMR and supporting AMRs. Matters regarding enhanced drip shield degradation were addresses as part of the CLST Technical Exchange "planned" activities to evaluate the behavior of F- and other species present, and the potential effects on the drip shield.	No further work beyond that already planned.

conditions at Yucca Mountain that might lead to drip shield degradation, and use this information to define appropriate conceptual models for developing the abstraction of the degradation of engineered barriers in the performance assessment. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.2.2)		
2-5. DOE considers a nutrient and energy inventory calculation that is sufficient to determine the potential for microbial activity that could impact degradation of engineered barriers. Should microbial activity be sufficient to allow microbially induced corrosion of the engineered barriers, DOE constrains the consequences of microbially induced corrosion.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev. 3 Sect. 5.4.2.2.2.2) DOE has not considered a nutrient and energy inventory calculation that is sufficient to determine the potential for microbial activity that could impact degradation of engineered barriers. The enhancement factor for microbially induced corrosion was calculated from the results of exposures to sterile and inoculated solutions (TRW Environmental Safety Systems, Inc., 2000a,d). However, no information is provided on the possible preferential dissolution of alloying elements as a result of microbial activity. The determination of enhancement factors for microbially induced corrosion are based on few data obtained in short-term exposures. The possibility for preferential dissolution of alloying	CLOSED PENDING. A nutrient-energy bounding calculation is done for microbial activity (Microbial Communities AMR CRWMS M&O 2000). MIC is possible on the waste package and experimental data have been used to quantify the estimate (*** Waste Package PMR CRWMS M&O 2000). Microbially induced corrosion of the waste package was addressed at the CLST Technical Exchange.	No further work beyond that already planned.

elements needs to be evaluated. In addition, the effect of temperature on the value of enhancement factor for microbially induced corrosion was not reported and should be considered. If specific conditions predicted by the in-drift geochemical model abstraction, such as water composition or temperature, favor microbially induced corrosion, these must also be considered in evaluations of the microbially induced corrosion enhancement factor. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.2.2)		

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Acceptance Criterion 3-Data Uncertainty for Evolution of the Near-Field Environment Subissue 2. Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the abstraction of degradation of engineered barriers are consistent with data available from laboratory corrosion tests and in-service experience in pertinent industrial applications, as well as with site-specific data, including data from drift-scale tests, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the abstraction are provided. Specifically (see following items),		
3-1. DOE identifies those engineered barrier degradation processes that are important to repository performance, and (i) adequately determines the broad range of environmental conditions in terms of temperature, applied stresses, redox conditions, and chemical composition of the water contacting engineered barriers that promote the various degradation processes, (ii) adequately bounds the likely range of environmental conditions within the waste package emplacement drifts, (iii) identifies reasonable or conservative ranges of parameters or functional relationships to define the chemical composition and the redox conditions of the engineered barrier environment and their evolution with time, and (iv) identifies uncertainty in data, due to both temporal and spatial variations affecting the engineered barrier physical and chemical environment.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.2.3)	CLOSED PENDING. The identified aspects of EBS models are addressed in the EBS PMR, (Rev. 01 in progress)including the FEPs analysis. The PMR and supporting AMRs describe the ranges of environ-mental conditions that will occur in the EBS. The descriptions address the potential for the existence of reducing conditions in the near-field environment, and uncertainties are identified. Also see Near Field and EBS PMRs.	No further work required beyond that already planned.
3-2. DOE justifies that input values used in the engineered barrier degradation calculations within total system performance assessment are reasonable based on data from the Yucca Mountain region, such as heater test results, and other applicable laboratory tests and natural analogs.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.2.3)	CLOSED PENDING. The multi-scale TH model calculations for the EBS environment are validated using results from field thermal tests, and by comparison with mountain-	No further work beyond that already planned.

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DOE expects infiltrating water compositions to evolve as a result of reactions with engineered barrier materials and variations in near-field temperature (see IRSR Section 5.4.2.1.2). Yet, water compositions used by DOE to evaluate general aqueous corrosion rates do not appear to be representative of either measured or modeled water compositions from Yucca Mountain. Although DOE may have used more corrosive conditions to determine the aqueous corrosion rate for the TSPA-SR, DOE's approach must also include an evaluation of corrosion rates that considers site-specific data. Site-specific data may include water compositions that were calculated in the corrosion products or precipitates/salts submodels or that were measured in the heater tests. If DOE can show that the current [non-site-specific] approach bounds predictions of dose, no further action would be required. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.2.3)	scale TH simulations (*** Multiscale TH Model AMR, CRWMS M&O 2000 Rev. 00 ICN 1). Other models rely on laboratory tests, natural and man-made analogs, and field data as appropriate, for validation. See EBS PMR. Issues regarding the water compositions were addressed in the CLST Technical Exchange.	
3-3. DOE justifies the initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THC effects on the degradation of engineered barriers and demonstrates that they are consistent with available data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.	CLOSED PENDING. The current fully coupled THC models are limited to the drift-scale model of the host rock response, which describes the evolution of water and gas composition that could enter the EBS. Sensitivity testing of this THC model is underway, and results will be evaluated for their effects on the EBS. In addition, fully coupled THC models that include	

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	the EBS are planned. See Near Field and EBS PMRs.	
3-4. DOE properly considers, in its evaluation of coupled THC processes, the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect degradation of the engineered barriers.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.2.3)	CLOSED PENDING. DOE considers the approach to coupled processes that is used for the current TSPA is valid and sufficient.(See ENFE KTI Technical Exchange, January, 2001 presentations by Nowak and Hardin) The current fully coupled THC models are limited to the drift-scale model of the host rock response, which describes the evolution of water and gas composition that could enter the EBS. Sensitivity testing of this THC model is underway, and results will be evaluated for their effects on the EBS. In addition, fully coupled THC models that include the EBS are planned. See Near Field and EBS PMRs.	No further work is required beyond that already planned.

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Acceptance Criterion 4-Model Uncertainty for Evolution of the Near-Field Environment Subissue 2. Alternative modeling approaches consistent with available data and current scientific understanding are investigated, and results and limitations are appropriately factored into the abstraction of the degradation of engineered barriers. DOE provides sufficient evidence that alternative conceptual models have been considered, that the models are consistent with available data (from laboratory corrosion tests and field measurements) and current scientific understanding, and that the effect of these alternative conceptual models on total system performance has been evaluated. Specifically (see following items),		
4-1. DOE considers plausible alternative models and justifies approaches used in the degradation of engineered barrier abstractions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. **Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.** Staff has no review comments relevant to this acceptance criterion as of May 15, 2000.	CLOSED PENDING. **Alternative models are addressed in the EBS PMR and supporting AMRs.** Alternative models are addressed in Analysis/Model Reports prepared under AP-3.10Q. In many cases plausible alternative models have not been identified. When appropriate, alternative models are discussed, and the selection of model approaches for TSPA is justified.	No further work is required beyond that already planned.
4-2. DOE incorporates appropriate models, tests, and analyses that are sensitive to the THC couplings under consideration for both natural and engineering systems as described in the following examples. The effects of THC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products include:(i) thermohydrologic effects on gas and water chemistry, (ii) hydrothermally driven geochemical reactions such as zeolitization of volcanic glass, which could affect water chemistry and engineered barrier environmental conditions, (iii) dehydration of hydrous phases liberating moisture that may affect the engineered barrier environment, (iv) effects of microbial processes on the engineered barrier environment, and (v) changes in water chemistry that may result from the release of corrosion products from the engineered barriers and interactions between cementitious materials and groundwater, which, in turn, may affect the degradation of engineered barriers.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.	CLOSED PENDING. The EBS PMR documents the consideration of thermal effects on gas and water chemistry. Hydrothermally driven geochemical reactions are	

Staff has no review comments relevant to this acceptance criterion as of May 15, 2000.	considered in the UZ PMR, and this work is continuing. (EBS Physical & Chemical Environment AMR Rev. 01) Dehydration of hydrous phases may be significant. Microbial processes are addressed in the EBS and Waste Package PMRs. (e.g. CRWMS M&O 2000aa, Section 3.1.2.4) MIC is included in TSPA, and microbial communities model AMR provides bounding analysis of microbial effects.. Water chemistry in the EBS is addressed in the EBS PMR (e.g. CRWMS M&O 2000aa, Section 3.1.2), Waste Package PMR (e.g. CRWMS M&O 2000ae, Section 3.1.3) and Waste Form PMR (e.g., CRWMS M&O 2000an, Section 3.2). Changes in water/gas chemistry are addressed in EBS Physical & Chemical Environment AMR,, Rev. 01) DOE is considering additional evaluation of the cementitious materials. THC coupled processes are simulated explicitly in the natural setting and addressed for the EBS by decoupling chemical effects on hydrologic properties (CRWMS M&O 2000aa, Section 3.1.1 – 3.1.4, and CRWMS M&O 2000ab, Section 3.3.12). DOE is considering additional analyses of mountain scale THC processes.	

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Acceptance Criterion 5-Model Support for Evolution of the Near-Field Environment Subissue 2. Output from the abstraction **of** the degradation of engineered barriers is justified through comparison with output **from** detailed process-level models and empirical observations arising from laboratory tests and field measurements. Specifically (see following items),		
5-1. DOE demonstrates that the mathematical models for degradation of engineered barriers are consistent with conceptual models based on inferences about the near-field environment, field data and natural alteration observed at the site, and expected engineered materials.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.2.5) Staff has no review comments relevant to this acceptance criterion as of May 15, 2000. (ENFE IRSR, Rev.3, Sect. 5.4.2.2.2.5)	CLOSED PENDING. DOE has concluded that its models are consistent with conceptual models for degradation of engineered barriers. Current models for degradation of engineered barriers are documented in the Waste Package PMR (CRWMS M&O 2000ae, Sections 3.1.5 – 3.1.8), Waste Form PMR CRWMS M&O 2000an, Section 3 and subsections) , and EBS PMR (CRWMSM&O 2000aa, Sections 3.1.1 – 3.1.4).	No further work required beyond that already planned.

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Importance to System Performance: The effects of coupled THC processes on the chemical environment for radionuclide releases from the engineered barrier system could be important to the performance of the potential repository and need to be considered in the abstraction of release of radionuclides. Interactions between cementious materials and the near-field system can be potentially beneficial for mitigating release of radionuclides. The persistent alkaline pH (>10) characteristic of pore fluids in contact with hydrated cement phases favors precipitation of a wide variety of radionuclides, including transuranics (Glasser, et al., 1985; Atkins, et al., 1990). On the other hand, alkaline conditions can be detrimental to the stability of nuclear waste glass. For instance, experiments by Heimann (1988) indicated that cement and glass interaction leads to accelerated dissolution and alteration of the nuclear waste glass compared to a system without cement present.

Acceptance Criterion (AC) 1—Integration for Evolution of the Near-Field Environment Subissue 3. Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of the quantity and chemistry of water contacting waste packages and waste forms in the performance assessment and other related abstractions in the total system performance assessment, and the technical bases are provided. The features, phenomena and couplings, and assumptions used to abstract the quantity and chemistry of waste contacting waste packages and waste forms have been provided. The abstraction is consistent with the identification and description of those aspects of the quantity and chemistry of waste contacting waste packages and waste forms that are important to waste isolation. The abstraction is also consistent with the technical bases for these descriptions of barriers important to waste isolation. Specifically (see following items),

1-1. DOE spatial and temporal abstractions appropriately address the physical couplings (THMC).

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.1)	CLOSED PENDING. As in the TSPA-VA analysis, effects of spatial and temporal variations in the exposure conditions over the repository were modeled by incorporating explicitly relevant exposure conditions histories into the waste package degradation analysis. Spatial and temporal abstractions are handled by examining drift-scale and mountain-scale variability (CRWMS M&O 2000ab, Sections 3.10 and 3.12). For TH couplings, DOE looks at the mountain-scale TH model (CRWMS M&O 2000bh, Section 3.12) and the Multi-Scale TH model (CRWMS M&O 2000bd, Section 3.14). Work is in progress to enhance the approach to	No additional work required beyond that currently planned.

	modeling THC coupling. This issue has been addressed in the TEF meeting. The chemical effects have been analyzed preliminarily. THC modeling is documented in the near-field PMR. THMC work is also in progress. The UZ PMR (CRWMS M&O 2000ab, Section 3.10) discusses drift-scale thermal-hydrological-chemical processes and models. Changes in hydrologic properties of fractures and the rock matrix are discussed in Section 3.10.2.4.Hydrologic property change relationships are discussed in Section 3.10.3.6, and the details of the THC seepage model are discussed in Section 3.10.5. The Drift-Scale Thermal-Hydrological-Chemical process model provides the chemical composition of the seepage and gas phase entering the drift during the post-closure period. This drift boundary condition input data along with the in-drift. TH conditions (ANL-EBS-HS-000003) are used by the Physical and Chemical Environment submodel Precipitates/Salts Analysis (ANL-EBS-MD-000045, REV 00) to calculate the chemical environment conditions on the drip shield/waste package and in the invert for radionuclide release.	

1-2. DOE provides adequate technical bases, including activities such as independent modeling, laboratory or field data, or sensitivity studies, for exclusion of any THMC couplings and FEPs.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. The NRC staff reviewed DOE's FEPs screening and identified 62 primary FEPs related to the integrated subissue on quantity and chemistry of	CLOSED The FEPs screening arguments reviewed by NRC were preliminary. The DOE has updated the screening arguments for waste form FEPs,	No additional work required.

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water contacting waste packages and ENFE Subissue 3. Review of 21 FEPs that were excluded in the DOE screening and 3 FEPs not associated with this Subissue by DOE, indicted that for 15 of the 24 FEPs, the staff does not agree with the DOE decision to exclude or the technical basis for exclusion is not adequate. The bases for the NRC staff determinations about the FEPs are discussed in pages 174-180 of the IRSR, Rev 3.(ENFE IRSR Rev 3, Section 5.4.3.2.1.1)	(CRWMS M&O 2000ao, Section 6.2). Other waste form-related FEPs have been updated in the clad degradation AMR (CRWMS M&O 2000p, Section 6) and in the waste form colloid AMR (CWMS M&O 2000aq, in attachments). Documentation includes justification for each excluded FEP, including the criterion on which it was excluded and the technical basis for the screening argument.	
1-3. The DOE abstraction is consistent with the detailed information on waste package design and other engineered features.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. DOE abstraction of in-package chemistry appears consistent with the detailed information on waste package design, but resolution of the subissue with respect to this acceptance criterion requires further review of DOE's Analysis and Model Reports and Process Model Reports. (ENFE IRSR Rev3, Section 5.4.3.2.1.1)	CLOSED The DOE abstraction of waste package chemistry is consistent with the detailed chemistry information on waste package design (CRWMS M&O 2000ar, Section 6 and in the waste form colloid AMR (CWMS M&O 2000aq, Section 6).	No additional work required.
1-4. DOE identifies and adequately considers the effects of the drip shield and backfill on the quantity and chemistry of water contacting waste packages and waste forms, including the potential for condensate formation and dripping from the underside of the shield.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. DOE has not considered the effects of the drip shield on the quantity and chemistry of water contacting the waste form. The potential effect of the drip shield has not been considered, and DOE will need to provide justification for neglecting the effect of condensate formation and dripping from the underside of the drip shield on the quantity and	CLOSED PENDING. This item was addressed during the CLST Technical Exchange in September 2000. CLST Delta Table, Subissue 6, AC4. The effects of the DS have been considered and evaluated in the analysis of WP performance. This aspect is discussed in WP PMR, (CRWMS M&O	No additional work required beyond that currently planned.

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chemistry of water contacting the waste form. (ENFE IRSR Rev3, Section 5.4.3.2.1.1)	2000ae, Section 3.1.3). The analysis conservatively assumes that the environment on the surface of the WP is not affected by the presence of the DS. The degradation model for the WP takes into account potential for crevice corrosion and degradation due to mechanical failure and assumes exposure to drift environment with no protection by DS against water dripping. Analyses in the Water Distribution and Removal Model (CRWMS M&O 2000as, Section 6.4) of condensation under the drip shield show that it is **unlikely unless seepage causes the liquid saturation in the invert ballast material to increase.** Condensation will be limited spatially and temporally, because it depends on infiltration flux (which varies), and heating rate (which decays). In accordance with current information used to predict corrosion rates for Total System Performance Assessment- Site Recommendation (TSPA-SR), if condensation occurs, the impact on corrosion rates for WP and DS materials would be negligible. The Water Distribution and Removal Model (CRWMS M&O 2000as, Sections 6.1.1.3 and 6.4) shows that condensation under the drip shield would be unlikely to contact the WP, but would tend to flow as droplets and films, on the underside of the drip shield. This is based on analogous behavior of condensation on solid surfaces. If condensation contacts the WP, the effect on dose rate at the biosphere would be limited to early failures, e.g., stress corrosion cracks in the WP outer barrier, which are predicted to be rare during the time	

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	period when thermally driven condensation is most likely to occur.	
The abstraction of in-package chemistry also ignores the potential interaction with grouted rock bolts, and interactions with other engineered materials on the chemistry of water inside waste packages. A justification used in the AMR is that the residence time of water in the waste package will be too short to allow reactions between the water and the waste package materials to occur. This justification is considered inadequate. (NRC/CNWRA Comment)	Grout surrounding the rock bolts will be carbonated and neutralized well before WP failure occurs and therefore will not affect chemistry of seepage entering the WP (Physical and Chemical Environment AMR (ANL-EBS-MD-000046 REV 01)(CRWMS M&O 2000ag). Other materials such as the ground support system will have a negligible impact on seepage chemistry especially at late WP failure times. [In Drift Corrosion Products. (ANL-EBS-MD-000041 REV 00)] (CRWMS M&O 1999)	No additional work required.
1-5. DOE identifies the range of environmental conditions to be expected inside of breached waste package, on the cladding, and contacting the waste forms		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The staff finds the approach taken by DOE in determining the range of in-package chemistry acceptable. The Staff agrees that, if corrosion is the only mechanism for degradation of waste packages, then breach of waste packages during the thermal period will not be significant and high-temperature phenomena need not be considered in determining the initial conditions for the in-package chemistry model. However, the potential for juvenile failure and for mechanical disruption of waste packages exists, and DOE will need to demonstrate the probability of these other mechanisms is not high enough to warrant evaluating the consequences of these other processes. (ENFE IRSR Rev3, Section 5.4.3.2.1.1)	CLOSED PENDING. The effects of the potential for juvenile failure are discussed in WP PMR, (CRWMS M&O 2000ae, Section 3.1.2). Mechanical disruption of waste packages has been considered and evaluated in the analysis of WP performance (CAL-EDS-ME-000001, Rev 00). The calculation indicates that no rockfall of sufficient size to damage the waste package is likely to occur during the postclosure period and that such damage does not need to be explicitly modeled for TSPA.	No additional work required beyond that currently planned.
The potential effects of some THC processes, as outlined in the preliminary draft Waste Form	High temperature phenomena effects on seepage entering the waste package are not considered	No additional work required beyond that currently planned.

Degradation Process Model Report (CRWMS M&0, 2000j), were neglected without sufficient technical basis. For example, there was no consideration of early stage, high temperature phenomena, such as evaporation and condensation on the composition of water entering the waste package. DOE will need to provide more adequate technical bases, for example, using sensitivity analyses, for neglecting these processes in their abstractions of the chemical environment for radionuclide release.(ENFE IRSR Rev3, Section 5.0.4)	because WP failure does not occur until after 10 K years regulatory period (WAPDEG Analysis of Waste Package and Drip Shield Degradation. ANL-EBS-PA-000001 REV 00 ICN 01)(CRWMS M&O 2000bq). Verification analyses are being considered to support the assumption that evaporative concentration effects are not important during the regulatory period. The topics of in-package chemistry and influences on that chemistry are described in the Waste Form Degradation PMR (CRWMS M&O 2000an, Section 3.2). **Analyses show that the in-package chemical environment is not sensitive to the** incoming seepage composition but is dominated by in-package degradation processes. (Waste Form Degradation PMR (CRWMS M&O 2000an) The Engineered Barrier System: Physical and Chemical Environment Model (CRWMS M&O 2000at, Section 7) gives the initial composition of waters that are likely to occur in the drifts during the thermal period. The effects of evaporation on such waters is predicted using a modeling approach that is closely tied to laboratory test data. The initial composition of waters is determined by evaluating many waters collected from the host rock, representing ambient conditions and thermally perturbed conditions. It has been found that these waters are categorized into two groups, based on the types of brines that form during evaporation. These analyses and assessments are well documented and are believed sufficiently robust for	

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	use in the LA.	
Abstraction of in-package chemistry ignores the potential effect of early-state high temperature phenomena. The chloride concentration used in the abstraction is equal to that of J-13 well water. This value ignores the potential increase in chloride concentration due to evaporation of water prior to its entry into the waste packages. The abstraction also ignored the potential increase in fluoride concentration, which could enhance cladding degradation. due to evaporation effects. (NRC/CNWRA Comment)	Regarding chloride concentration, high temperature phenomena are not considered for in-package chemistry because WP failure does not occur until after 10 K years. Evaporative concentration effects on seepage composition prior to entering the WP will therefore not be significant during the late times at which WP failure occurs. . Verification analyses are being considered to support the assumption that evaporative concentration effects are not important during the regulatory period. **Fluoride concentration: The cladding localized corrosion model is conservative and assumes that** all of the fluoride that enters the WP is utilized in zirconium corrosion. [Clad Degradation - Summary and Abstraction (ANL-WIS-MD-000007 REV 00 ICN 01)](CRWMS-M&O 2000aw). Therefore evaporative concentration of fluorides inside the WP will not have any effect on the model. Evaporative concentration of fluoride in the near field prior to seepage entering the WP will not be significant at later times when WPs fail.	No additional work required beyond that currently planned.
DOE predictions of in-package chemistry based on the EQ3/6 code have not been verified by empirical observations. The staff has concerns regarding the use of the EQ3/6 code because it does not incorporate electrochemical reactions. Experiments to simulate certain aspects of waste package geometry and materials may aid in gaining confidence in the EQ3/6 results. (ENFE IRSR Rev 3, Section 5.0.4)	The waste form PMR describes EQ3/6 reaction path modeling (CRWMS M&O 2000ae, Section 3.2.1.4. The AMR, Summary of In-Package Chemistry for Waste Forms (ANL-EBS-MD-000050) (CRWMS M&O 2000au) describes simulations of WP alteration by ambient groundwater that were done using the qualified reaction path code EQ3/6. Revision 1 of this AMR more fully discusses EQ3/6 model validation. Additional analyses are being considered before	No additional work required beyond that currently planned.

	experimental validation is started. Examples of analyses could include modeling of Argonne Drip Tests, and verifying acid production from corrosion of stainless steels.	
1-6. DOE uses important design features, including waste package design and material selection, backfill, drip shield, ground support, cladding, thermal-loading strategy, and degradation processes, to determine the initial and boundary conditions for calculations of the quantity and chemistry of water contacting the waste forms.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The Staff agrees that, if corrosion is the only mechanism for degradation of waste packages, then breach of waste packages during the thermal period will not be significant and high-temperature phenomena need not be considered in determining the initial conditions for the in-package chemistry model. However, the potential for juvenile failure and for mechanical disruption of waste packages exists, and DOE will need to demonstrate the probability of these other mechanisms is not high enough to warrant evaluating the consequences of these other processes. (ENFE IRSR Rev3, Section 5.4.3.2.1.1)	CLOSED DOE's current design does not contain backfill. The waste form PMR (CRWMS M&O 2000ae, Section 3.2) considers all of the parameters that are considered important design features needed to determine the initial and boundary conditions for calculations of the quantity and chemistry of water contacting the waste forms. See also DOE status for Acceptance Criterion 1-5, above.	No additional work required.
1-7. DOE identifies and considers likely modes of corrosion for container materials, including dry-air oxidation, humid -air corrosion, and aqueous corrosion processes, such as general corrosion, localized corrosion, microbial induced corrosion, stress corrosion cracking, and hydrogen embrittlement, as well as the effect of galvanic coupling, in determining the quantity and chemistry of water entering the waste packages.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The in-package chemistry model is based on assumed corrosion rates for waste package component materials. No technical justification was provided for the assumed rates, and the likely	CLOSED PENDING. Temperature and relative humidity are appropriate "master variables" for describing the in-drift chemical environment. Small amounts of salts that may form during the thermal period because of	No additional work required beyond that currently planned.

modes of corrosion that account for the rates were not identified. DOE needs to provide sufficient information on the likely modes of corrosion that could affect the quantity and chemistry of water entering waste packages and contacting waste forms. (ENFE IRSR Rev3, Section 5.4.3.2.1.1)	thermally perturbed seepage or dripping condensation, will initially be dry (therefore no aqueous corrosion). As the repository cools down these salts will interact with humidity in the drift environment, to form aqueous solutions with predictable composition. The maximum concentrations of anions are those which form in saturated solutions of mixed salts, at relatively low relative humidity in the range from approximately 50 to 85%. As relative humidity increases these solutions become progressively more dilute. If seepage occurs during the thermal period, these solutions will potentially be even more dilute. Thus the maximum concentrations of anions will occur early in the repository thermal evolution, as the relative humidity increases and salts deliquesce. As described in the Engineered Barrier System: Physical and Chemical Environment Model (CRWMS M&O 2000at) further cooling or seepage will tend to decrease the maximum concentrations. Wherever possible, the in-package chemistry model used the most conservative (i.e., fastest) corrosion rates in the calculation of WP chemistry evolution. These rates are listed in Section 4.1.1 of the updated In-Package Chemistry AMR (CRWMS M&O 2000ar). Use of relatively high rates bounds the largest potential impact that waste package component degradation might have on the in-package chemistry. Further technical justification of the specific modes of degradation was therefore not pursued.	
1-8. DOE identifies and considers likely modes of failure for cladding, including aqueous corrosion processes, such as localized corrosion, stress corrosion		

cracking, and hydrogen embrittlement, creep, delayed hydride cracking, unzipping from oxidation of fuel, and mechanical failure from rockfall, in determining the quantity and chemistry of water contacting waste forms.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. DOE will need to evaluate whether the results presented in the draft cladding degradation Analysis and Model Report are significantly different from the assumed clad damage and commercial spent nuclear fuel exposure to affect the results of the in-package chemistry abstraction. (ENFE IRSR Rev3, Section 5.4.3.2.1.1)	CLOSED PENDING. A sensitivity study to examine the effects of fuel exposure on in-package chemistry has been done (CRWMS M&O 2000au). The results generally indicate that higher fuel exposures lead to higher pH. Higher pH is generally considered favorable because it produces a less aggressive corrosion environment. Moreover, Section 6.1 of the updated in-package chemistry AMR (CRWMS M&O 2000ar) describes how the cases of 99%, 90%, and 0% clad coverage are considered in the calculation. This range covers all scenarios of concern.	No additional work required beyond that currently planned.
The effect of corrosion products on high-level waste glass degradation was not considered; radiolysis effects on waste form degradation was neglected; and enhancement of cladding corrosion in the presence of high chloride concentrations was excluded. DOE will need to provide more adequate technical bases, for example, using sensitivity analyses, for neglecting these processes in their abstractions of the chemical environment for radionuclide release. (ENFE IRSR Rev 3, Section 5.0.4)	The components of high-level waste degradation are described in the Waste Form PMR (CRWMS M&O 2000ae, Section 3.6). The DOE approach is considered conservative because it is based on intrinsic dissolution rate for the glass waste form. The Waste Form PMR (CRWMS M&O 2000an, Table 2.3-3) describes the basis for excluding radiolysis effects from TSPA. The basis for exclusion is low consequence since fluid is not expected to contact waste until gamma radiolysis has become negligible. Effects of chloride on cladding are described in the AMR, Clad Degradation—Local Corrosion of	No additional work required beyond that currently planned.

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	Zirconium and Its Alloys Under Repository Conditions (CRWMS M&O 2000av, Section 3.4). The report shows that zircaloy is not susceptible to stress corrosion cracking in NaCl, HCl, $MgCl_2$ and H_2S solutions. The environments known to cause stress corrosion cracking in zirconium include $FeCl_3$, $CuCl_2$, halogen or halide-containing methanol, concentrated HNO_3, liquid mercury or cesium and 64 to 69% H_2SO_4. The extreme oxidizing acidic conditions are not predicted for the bulk in-package chemistry but the possibility of such conditions occurring locally and transiently is included in the local corrosion model.	
The abstraction of CSNF degradation ignored the potential effects of several processes. The possible effect of radiolytic production of acid from moist air on the dissolution of uranium fuel is not adequately addressed. The effect of periodic wet and dry conditions on the dissolution rate is not considered.(NRC/CNWRA Comment)	The CSNF Waste Form Degradation AMR addresses radiolysis. This AMR uses rate laws for constantly saturated conditions, which is more conservative than the wetting/drying scenario. Therefore the latter has not been considered. (CSNF Waste Form Degradation: Summary Abstraction. ANL-EBS-MD-000015 REV 00)(CRWMS M&O 2000br)	No additional work required.
For the colloids abstraction, if irreversible attachment is excluded for SNF colloids, the DOE needs to provide a stronger technical basis for exclusion. Also the DOE needs to provide a stronger technical basis for the exclusion of geochemical, radiolytic, and coupled THC effects on colloids other than pH and ionic strength. (NRC/CNWRA Comment)	Spent fuel tests are being modified to allow better quantification of colloidal release. Initial results will be available later this year with additional results available to support the LA. Regarding exclusion of irreversible attachment, Argonne National Laboratory is examining existing drip-tests to provide stronger technical basis; findings will be reported in future revision of Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary Analysis/Model Report, ANL-WIS-MD-000012. (CRWMS-M&O 2000aq)	No additional work required beyond that currently planned.

	Regarding exclusion of geochemical, radiolytic, and coupled THC effects on colloids, pH and ionic strength are dominant processes. Two other potentially important factors were conservatively omitted: (a) presence of different mineral colloids with different surface charges, and (b) simultaneous consideration of different types of colloids. Other processes such as elevated temperatures and convection cells may stabilize colloids for awhile but do not exist a short distance from the waste package. (Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary Analysis/Model Report, ANL-WIS-MD-000012)(CRWMS-M&O 2000aq. To be revised) The primary effect of radiolysis is to lower the pH in localized environments. For colloid stability, bulk chemistry, as calculated by the In-Package Component, is appropriate to use since the colloids must travel through many micro-environments. The average of these microenvironments is best represented by the bulk chemistry. Production of small acidic environments by radiolysis does not dominate the bulk chemistry defined by waste form and waste package content degradation. Radiolysis effects on waste form and cladding degradation are addressed as feature event and process (FEP) and were discussed in the Technical Exchange on Container Life and Source Term. Future revision to Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary	

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	Analysis/Model Report (ANL-WIS-MD-00012) will more explicitly mention these arguments when excluding geochemical, radiolytic, and coupled THC processes. (CRWMS-M&O 2000aq)	
1-9 DOE consistently addresses the effect of corrosion products on the chemistry of water contacting the waste forms, and the effect on waste package corrosion of the quantity and chemistry of water contacting waste packages in all relevant abstractions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The effect of corrosion products on high-level waste glass degradation was not considered. (ENFE IRSR Rev 3, Section 5.0.4)	CLOSED The effects of corrosion products on chemistry of water contacting the waste forms were found not to be important and are described in ANL-EBS-MD-000050 (CRWMS M&O 2000ar). Abstraction of the quantity and chemistry of water contacting waste packages and waste forms is consistent with waste package design and EBS design. The EBS PMR (CRWMS M&O 2000aa, Executive Summary) identifies the following processes that relate to the chemistry of water contacting waste packages and eventually waste forms, especially: (1) seepage of water and its flow within the drift, (2) evaporation and condensation, (3) deposition of salts and precipitates within the drift, (4) chemical reactions between water, rock, and introduced materials, and (5) accumulation of corrosion products within the drifts and their effect on chemistry and flow. Section 5.3.2 of the EBS PMR summarizes the processes that control the physical and chemical environment of the EBS, and Section 5.3.3 summarizes the modeled processes that control radionuclide transport. The Executive Summary notes that the EBS report demonstrates	No additional work required.

	that EBS performance is sufficiently well understood to support reasonable predictions of the environmental conditions at drip shields and waste packages and of conditions that will affect radionuclide transport in the emplacement drifts.	
1-10. DOE consistently addresses the role of parameters such as pH and carbonate concentration of water and the effect of released radionuclides on the chemistry of water contacting the waste packages and waste forms in all relevant abstractions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Also at issue is the spatial variation in chemistry that is likely to occur in the waste package, which could result in local pH values more acidic than values calculated using a volume averaged mass. For example, pH in crevices and other tight spaces differ from bulk pH values due to dissolution reactions that become spatially separated from oxidation/reduction reactions. These locally more acidic pH solutions could enhance the dissolution rate of the waste form and the release of radionuclides. DOE will need to provide more adequate technical bases, for example, using sensitivity analyses, for neglecting these processes in their abstractions of the chemical environment for radionuclide release. (ENFE IRSR Rev 3, Section 5.0.4)	CLOSED PENDING. Analyses thus far focus on well-understood bulk-scale chemical processes that are likely to dominate the in-package chemical environment (Summary of In-Package Chemistry for Waste Forms. ANL-EBS-MD-000050 REV 01)(CRWMS M&O 2000ar). Local environments may be present but they are unlikely to have a significant effect on overall waste form dissolution and radionuclide release. Local variations in chemistry occur because transport of reactants and products is limited. If transport of reactants and products is limited, transport of radionuclides is also limited. Hence, the effects of local variations in chemistry would be expected to have negligible effects on radionuclide release.	No additional work required beyond that already planned.
To address our comments on colloid-assisted radionuclide release, DOE could either conduct additional analyses or incorporate critical assessments of the effects on colloidal radionuclide release that are beyond the scope of available experimental work. Parameters that may need to be addressed include (i) temperature, (ii) oxidation	Colloids and their role in radionuclide release are addressed in the UZ PMR (CRWMS M&O 2000ab, sections 3.11.2.7, 3.11.3.5, 3.11.7, 3.11.9.2, and 3.11.10.6). pH and ionic strength are the dominant chemical parameters controlling colloid stability and release	No additional work required beyond that already planned..

potential, (iii) major cation and anion concentrations, and (iv) in-package hydrologic conditions. (ENFE IRSR Rev 3, Section 5.0.4)	from the EBS. Two other potentially important factors were conservatively omitted: (1) presence of different mineral colloids with different surface charges, and simultaneous consideration of different types of colloids. Other processes such as elevated temperatures and convection cells may stabilize colloids for a while but do not exist at times the waste package fails (Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary, ANL-WIS-MD-000012 REV 00.) (CRWMS-M&O 2000aq)	
DOE should more explicitly evaluate whether the experimental results are adopted in a manner that is conservative with respect to ionic strength and pH effects (e.g., on colloidal plutonium concentration). Finally, DOE should extend the colloidal release abstraction to other radionuclides or provide a technical basis for exclusion of important radionuclides. (ENFE IRSR Rev 3, Section 5.0.4)	Colloids and their role in radionuclide release are addressed in the UZ PMR (CRWMS M&O 2000ab, sections 3.11.2.7, 3.11.3.5, 3.11.9.2, and 3.11.10.6). Specifically, transport of plutonium true colloids is described in the UZ PMR (CRWMS M&O 2000ab, Section 3.11.7). pH and ionic strength are the dominant chemical parameters controlling colloid stability and release from the EBS. Two other potentially important factors were conservatively omitted: (1) presence of different mineral colloids with different surface charges, and simultaneous consideration of different types of colloids. Other processes such as elevated temperatures and convection cells may stabilize colloids for a while but do not exist at times the waste package fails (Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary AMR, ANL-WIS-MD-000012 REV 00.) (CRWMS-M&O 2000aq) Even with conservative assumptions, colloids are	No additional work required beyond that already planned,.

	not major contributors to dose in the TSPA-SR. Pu and Am are the primary radionuclides; Pa and Th are also included because they are important daughters. Qualitative reasoning for selecting radionuclides are provided in Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary, ANL-WIS-MD-000012 REV 00. (CRWMS-M&O 2000aq).	
1-11. DOE demonstrates that the conditions and assumptions used to generate look-up tables or regression equations are consistent with all other conditions and assumptions in the total system performance assessment for abstracting the quantity and chemistry of water contacting waste packages and waste forms.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The assumptions and conditions used to generate regression equations for in-package chemistry presented in the draft Waste Form Degradation Process Model Report (CRWMS MAO, 2000j) and in the supporting draft Analysis and Model Reports (CRWMS M&O, 2000i) appears to be consistent. Consistency with other Analysis and Model Reports and Process Model Reports will be checked. (ENFE IRSR Rev 3, Section 5.4.3.2.1.1)	CLOSED This item is addressed in the AMR, Summary of In-Package Chemistry for Waste Forms (CRWMS M&O 2000ar). The report shows that assumptions are consistent in the total system performance assessment for abstracting the quantity and chemistry of water contacting waste packages and waste forms.	No additional work required.
1-12. DOE consistently addresses the effect of distribution of flow on the amount of water contacting the waste forms in all relevant abstractions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The Staff will review the relevant Process Model Reports and Analysis and Model Reports to determine if the quantity of water contacting waste packages and waste forms has been addressed consistently in all relevant abstractions. (ENFE IRSR Rev 3, Section 5.4.3.2.1.1)	CLOSED PENDING. This issue is scheduled to be addressed in the next revision of the PMRs.	No additional work required beyond that already planned..
1-13. DOE consistently addresses the size and distribution of penetrations of waste containers that affect the quantity and chemistry of water that contracts the		

waste form in all relevant abstractions.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The Staff will review the relevant Process Model Reports and Analysis and Model Reports to determine if the quantity of water contacting waste packages and waste forms has been addressed consistently in all relevant abstractions. (ENFE IRSR Rev 3, Section 5.4.3.2.1.1)	CLOSED PENDING. This item is addressed in the following PMR and AMRs: Engineered Barrier System Degradation, Flow and Transport Process Model Report. [TDR-EBS-MD-000006 REV 00 ICN 01 (CRWMS-M&O 2000aa)], Summary of In-Package Chemistry for Waste Forms. [ANL-EBS-MD-000012 REV 01 (CRWMS M&O 2000ar)], and EBS Radionuclide Transport Abstraction [ANL-WIS-PA-000001 REV 00 ICN 01.(CRWMS-M&O 2000ah)].	No additional work required beyond that already planned.

Analysis of the Resolution Status for the Key Technical Issue on the Evolution of the Near Field Environment

Subissue 3:Effects of Coupled Thermal-Hydrologic-Chemical Processes on the Chemical Environment for Radionuclide Release

Acceptance Criterion (AC) 2—Data and Model Justification for Evolution of the Near-Field Environment Subissue 3. Sufficient data on design features (including drip shield, backfill, waste packages, cladding, other engineered barrier components, and thermal loading), geology, hydrology, geochemistry, and geomechanics of the unsaturated zone and drift environment (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of the quantity and chemistry of water contacting waste packages and waste forms in the performance assessment. The data are also sufficient to assess the degree to which FEPs related to the quantity and chemistry of water contacting waste packages and waste forms and which affect compliance with postclosure performance objectives have been characterized and to determine whether the technical bases provided for exclusion of these FEPs are adequate. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the abstraction process. Specifically (see following items):

2-1 DOE demonstrates that sufficient data were collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions, including temporal and spatial variations in conditions, for conceptual models and simulations of THMC coupled processes that affect the chemical environment for radionuclide release.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. A preliminary review of the preliminary draft DOE Analysis and Model Reports and Process Model Reports indicates that there is sufficient data to establish initial and boundary conditions for conceptual models and simulations of coupled THC processes that affect the chemical environment for radionuclide release. However, resolution of the subissue with respect to this acceptance criterion requires further review of the pertinent DOE Analysis and Model Reports and Process Model Reports. (ENFE IRSR Rev 3, Section 5.4.3.2.1.2)	CLOSED DOE's natural system models are based on extensive site characterization data (CRWMS M&O 2000aa and CRWMS M&O 2000ad). The type, quantity, and reactivity of engineered materials has been evaluated CRWMS M&O 2000ab).	No additional work required.

2-2. Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate other sources such as expert elicitation conducted in accordance with NUREG-1563 (Kotra, et al., 1996).

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.	CLOSED Expert elicitations regarding seepage and flow were conducted in both the UZ and NFE aspects. Expert	No additional work required.

	elicitations associated with development of the NFE and UZ PMRs were determined to be subject to the quality assurance program as described in the QARD (DOE 2000a) document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in NUREG-1563 (Kotra, et al. 1996). Section 2.4.5 of the near field PMR (CRWMS M&O 2000ad) addresses expert elicitation regarding parts of the elicitation that relate to the NFE. Refer to that section for a description of how expert elicitation was used. For a complete discussion, refer to the UZ F&T PMR (CRWMS M&O 2000ab).	
2-3. DOE collects sufficient information to formulate the conceptual approach(es) for analyzing water contact with the cladding and waste forms upon waste package failure.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. A preliminary review of the preliminary draft DOE Analysis and Model Reports and Process Model Reports indicates there are sufficient data available to adequately define relevant parameters and conceptual models necessary to develop the abstraction of the quantity and chemistry of water contacting waste forms in the .performance assessment. However, resolution of the subissue with respect to this acceptance criterion requires further review of the pertinent DOE Analysis and Model Reports and Process Model Reports. (ENFE IRSR Rev 3, Section 5.4.3.2.1.2)	CLOSED As documented in the waste form PMR and associated AMRs (Summary of In-Package Chemistry for Waste Forms (ANL-EBS-MD-000050 REV 01) (CRWMS M&O 2000au), In-Package Chemistry Abstraction. (ANL-EBS-MD-00037 REV 00, ICN 01) (CRWMS-M&O 2000bp), and calculations, DOE has collected sufficient information to formulate the conceptual approach for analyzing water contact with the cladding and waste forms upon waste package failure. Details with respect to cladding are documented in the Clad Degradation – Summary and Abstraction (CRWMS M&O 2000aw).	No additional work required.
2-4 DOE provides sufficient data or sound bases for the inclusion or exclusion of certain observed phenomena in its conceptual models.		

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NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. The DOE needs to state which radionuclides are to be included in colloid attachment modeling (both reversible and irreversible), provide a technical basis for that list, and provide relevant model parameters for each radionuclide and each waste form. (NRC/CNWRA Comment)	CLOSED Even with conservative assumptions colloids are not major contributors to the dose. Pu and Am are the primary radionuclides; Pa and Th also included because they are important daughters. Qualitative reasoning for selecting radionuclides is provided in Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary Analysis/Model Report (ANL-WIS-MD-00012). (CRWMS M&O 2000aq). Documentation of the data and technical bases for the inclusion or exclusion of certain observed phenomena in conceptual models is also provided in the following AMRs: Engineered Barrier System Degradation Modes & Features, Events, and Processes Abstraction (CRWMS M&O 2000af), Miscellaneous Waste-Form FEPs (CRWMS M&O 2000ao), Clad Degradation – FEPs Screening Arguments (CRWMS M&O 2000ap)	No additional work required.
2-5 DOE provides sufficient data to complete a nutrient and energy inventory calculation, if it has been used to justify the exclusion of the potential for microbial activity affecting the chemical environment for radionuclide release.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
CLOSED.	CLOSED. DOE agrees with the NRC status.	No additional work required.
2-6 If microbial activity could be sufficient to affect repository performance, DOE provides sufficient data to assess microbial effects such as production of organic by-products and microbially enhanced dissolution of the high-level waste glass form.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
CLOSED.	CLOSED.	No additional work required.

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NRC staff considers the technical basis for exclusion of microbial activity from the DOE evaluation of coupled THC effects on the chemical environment for radionuclide release as acceptable. (ENFE IRSR Rev 3, Section 5.4.3.2.1.1)	DOE agrees with the NRC status.	
2-7 DOE performs sensitivity, if needed, or uncertainty analyses (including consideration of alternative conceptual models) to test for the necessity of additional data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Large uncertainties are recognized in the thermodynamic and kinetic data and in the simplified approach used for the abstraction of in-package chemistry. Some attempts have been made to account for uncertainties in the model parameters. For example, uncertainty in the dissolution rates of waste package materials is dealt with using high and low values. Drip rates onto the waste package ranged from 1.5 to 150 liters per year. The composition of water entering the waste package was assumed to be that of J-13 well water and was not varied. The simulation temperature was set at 25 °C, on the basis that many of the thermodynamic parameters are not strongly sensitive to temperature over the range 25 to 100 °C. The effect of using other initial water compositions or higher temperatures on the calculated in-package chemistry is unknown. DOE should conduct additional process-level modeling to ascertain the chemistry of in-package water has been bounded by the approach presented in the preliminary draft Waste Form Degradation Process Model Report and supporting Analysis and Model	CLOSED PENDING. Sensitivity and uncertainty analyses are performed as needed at the system level. Dose consequence is an appropriate basis for determining the need for additional testing and data collection. See for example CRWMS M&O 2000al and CRWMS M&O 2000am, Section 5) Alternative conceptual models that are relevant to waste form degradation components are discussed in the waste form PMR (CRWMS M&O 2000an, Sections 3.2.3, 3.3.3, 3.4.4, 3.5.3, 3.6.3, 3.7.3, and 3.8.4). Additional analysis and discussion concerning temperature effects, the use of thermodynamic data at 25C, and whether chemistry of in-package water has been bounded will be included in the next revision of the Summary of In-Package Chemistry for Waste Forms AMR (ANL-EBS-MD-000050 REV 01)(CRWMS-M&O 2000au). J-13 water was used as an initial water composition. However, a range of initial water compositions	No additional work required beyond that already planned..

Reports. (ENFE IRSR Rev 3, Section 5.4.3.2.1.1) The DOE should provide a technical basis for limiting in-drift water chemistry for purposes of colloid modeling to either waste package water or a mixture of waste package water and J-13. (NRC/CNWRA Comment)	were evaluated in the revised Summary of In-Package Chemistry for Waste Forms AMR ANL-EBS-MD-000050. REV01 (CRWMS-M&O 2000au) and the effect of initial water composition on in-package chemistry was found to be insignificant compared to the effects of WP contents.	
The AMR on in-package chemistry abstraction does not provide enough information on the corrosion rate used in the abstractions. It is not clear if the high rate is related to localized corrosion or the highest rate for uniform corrosion. It is not clear if the corrosion rate used in this AMR is consistent with WAPDEG predictions. What references were used for the degradation rates of the waste package components? Are the rates taken from the references relevant to the specific in-package environment being simulated? (NRC/CNWRA Comment)	An improved description and selection of corrosion rates have been provided in the revised In-Package Chemistry AMR (CRWMS-M&O 2000bp). New corrosion rates are consistent with data obtained from long-term corrosion test facility experiments done under conditions relevant to YMP. High rates were chosen in order to remain conservative.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on the Evolution of the Near Field Environment

Subissue 3: Effects of Coupled Thermal-Hydrologic-Chemical Processes on the Chemical Environment for Radionuclide Release

<table>
<tr><td colspan="3">Acceptance Criterion 3-Data Uncertainty for Evolution of the Near-Field Environment Subissue 3. Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the abstraction of quantity and chemistry of water contacting waste packages and waste forms, such as the pH, chloride concentration, and amount of water flowing in and out of the breached waste package, are consistent with site characterization data, design data, laboratory experiments, field measurements, and natural analog data, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the total system performance assessment abstraction are provided. Specifically (see following items),</td></tr>
<tr><td colspan="3">3-1. Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the quantity and chemistry of water contacting waste forms calculations in the performance assessment are technically defensible and reasonable, based on data from the Yucca Mountain region (e.g., results from large-block and drift-scale heater and niche tests) and a combination of techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies.</td></tr>
<tr><td>NRC Staff Analysis</td><td>DOE Status</td><td>DOE-Proposed Path Forward</td></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.3)</td><td>CLOSED PENDING.

Existing project procedures ensure that when work is completed this acceptance criterion will be met.</td><td>No additional work required beyond that currently planned.</td></tr>
<tr><td colspan="3">3-2. DOE demonstrates that parameters derived from process-level models used for the quantity and chemistry of water contacting waste forms are consistent with site characterization data, laboratory experiments, field measurements, and natural analog information.</td></tr>
<tr><td>NRC Staff Analysis</td><td>DOE Status</td><td>DOE-Proposed Path Forward</td></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.3)</td><td>CLOSED PENDING.

The results of the large-block and drift-scale heater and niche tests are used in the modeling of water chemistries and are documented in the AMR Summary of In-Package Chemistry (CRWMS M&O 2000au, Section 6.2). This AMR is currently undergoing revision.</td><td>No additional work required beyond that currently planned</td></tr>
<tr><td colspan="3">3-3. DOE provides technical bases for parameter ranges, probability distributions or bounding values. DOE demonstrates that the parameter values are derived from site-specific data or provides an analysis to demonstrate that the assumed parameter values do not under-predict repository performance.</td></tr>
<tr><td>NRC Staff Analysis</td><td>DOE Status</td><td>DOE-Proposed Path Forward</td></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model</td><td>CLOSED

The results of the large-block and drift-scale heater</td><td>No additional work required.</td></tr>
</table>

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Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.3)	and niche tests are used in the modeling of water chemistries and are documented in the AMR Summary of In-Package Chemistry (CRWMS M&O 2000au, Section 6.2). Specifically, a sensitivity study of the impact of different fluid inputs on the WP effluent chemistry has been performed, and the effects were found to be minor. Conclusions from the physical and chemical environment abstraction models are valid for the coupled system, and appropriate water compositions have been used. (In-Drift Precipitates/Salts Analysis. ANL-EBS-MD-000045 REV 00 ICN 02)(CRWMS M&O 2000bs) The current Total System Performance Assessment model for invert water chemistry for the purpose of colloid modeling is adequate and conservative. (Engineered Barrier System: Physical and Chemical Environment Model. ANL-EBS-MD-000033 REV 01)(CRWMS M&O 2000bt) Exclusion of credible alternative models for in-drift colloid transport is also adequate and conservative. (In-Drift Colloids and Concentration. ANL-EBS-MD-000042, REV 00) (CRWMS-M&O 2000bl).	
3-4 DOE demonstrates that input values used in the quantity and chemistry of water contacting engineered barriers (e.g., drip shield, waste package, and cladding) calculations in the total system performance assessment are consistent with the initial and boundary conditions and the assumptions of the conceptual models and design concepts for the Yucca Mountain site, such as waste package and engineered barrier system design (including backfill, drip shield, ground support, and cladding), waste package degradation (corrosion and mechanical disruption), cladding degradation, deep percolation flux, important THMC coupling effects, the thermal reflux model, the thermal loading strategy (including effects of ventilation), natural system-masses and fluxes, and other design features that may affect performance.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**

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OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.3)	CLOSED Input values used are consistent with initial and boundary conditions and model assumptions and design concepts. Water chemistry effects on cladding degradation are discussed in the AMR, Cladding Degradation—Local Corrosion of Zirconium and Its Alloys under Repository Conditions (CRWMS M&O 2000ar)	No additional work required.
3-5 DOE establishes that reasonable or conservative ranges of parameters or functional relations are used to determine effects of coupled THMC processes on the chemical environment for radionuclide release.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. In the AMR on in-package chemistry abstraction, the abstraction of ionic strength for times greater than 1,000 years, the average value of ionic strengths calculated from the process level modeling was used. The DOE needs to provide a better technical justification for not using the more conservative approach of minimum ionic strength. (NRC/CNWRA Comment)	CLOSED PENDING. The In-Package Chemistry Abstraction AMR (currently undergoing revision) has improved the resolution and treatment of ionic strength calculations by considering an additional time period and defining ionic strength distributions for each time period that will be sampled in TSPA calculations (CRWMS-M&O 2000bp). The approach of using minimum ionic strength would be overly conservative. A probabilistic approach is being considered that samples the range of ionic strengths. The probabilistic approach is more reasonable and meets the acceptance criteria.	No additional work required beyond that currently planned.
The evolution of the in-package chemistry depends on the rate of dissolution of waste package components assumed in the calculations. The dissolution rates of stainless steels assumed for the analysis are particularly important because degradation of stainless steels lead to lower pH. If the dissolution rate assumed in the calculation is	An improved description and selection of corrosion rates have been provided in the revised In-Package Chemistry AMR. New corrosion rates are consistent with data obtained from long-term corrosion test facility experiments done under conditions relevant to YMP. High rates were chosen in order to remain conservative. (CRWMS-	No additional work required.

improperly low, the effect of low pH on calculated dose may not be observed from the results. The dissolution rate assumed for Type 316 stainless steel and borated stainless steel is one order of magnitude lower than the rate measured experimentally for alloy 22, which is counter-intuitive to the known higher corrosion resistance of alloy 22 compared to stainless steels. The DOE needs to provide a technical bases for the corrosion rates used in their calculations. (NRC/CNWRA Comment)	M&O 2000bp).	
3-6 DOE shows that the parameters used to define initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THMC effects on the chemical environment for radionuclide release, are consistent with available data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.3)	CLOSED PENDING. DOE has used numerical simulation to represent the host rock and the EBS to develop water compositions for potential seepage (CRWMS M&O 2000aa, Sections 3.8, 3.10.2 and 3.10.5). Other models are used for evaporative evolution in the EBS CRWMS M&O 2000aa, Section 3.10.2). These models are generally consistent with the initial and boundary conditions and assumptions used for important models that feed TSPA-SR. Details are provided in UZ, NFE, and EBS PMRs (CRWMS M&O 2000ab, CRWMS M&O 2000ad, CRWMS M&O 2000aa; some of these concerns are addressed by ongoing revisions of these reports, which are work in progress).	No additional work required beyond that currently planned.
3-7 DOE provides confirmation that the correlations between input values, if any exist, have been appropriately established in the DOE total system performance assessment.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**

OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.3)	CLOSED Cladding degradation values that are inputs to TSPA have been adequately addressed and described and documented in the AMR, Clad Degradation – Summary and Abstraction (CRWMS M&O 2000aw).	No additional work required.
3-8 DOE demonstrates that parameter values, assumed ranges, probability distributions and bounding assumptions reflect the range of environmental conditions to be expected inside breached waste packages.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. **Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.** (ENFE IRSR Rev 3, Section 5.4.3.2.1.3)	CLOSED **The parameter values, assumed ranges, and assumptions and their justification along with** expected in-package chemistry have been adequately addressed and are described and documented in the AMR, Summary of In-Package Chemistry for Waste Forms (CRWMS M&O 2000au).	No additional work required.
3-9 DOE demonstrates that parameter values, assumed ranges, probability distributions, and bounding assumptions reasonably account for uncertainties.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The DOE needs to provide reasonable assurance that the adopted maximum concentration of irreversibly-attached plutonium is bounding. (NRC/CNWRA Comment)	CLOSED PENDING. The input data used in the treatment of colloids is reasonably bounding and accounts for key uncertainties. Regarding the data uncertainty of colloids, the maximum concentration was re-evaluated recently (only slight adjustment made on maximum) and was determined to be reasonably bounding; also, lower range now provided; DOE will provide updated information in future revision to Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary Analysis/Model	No additional work required beyond that currently planned.

	Report (ANL-WIS-MD-00012) (CRWMS-M&O 2000aq). The uncertainties in expected in-package chemistry are described and documented in the Waste Form PMR (CRWMS M&O 2000ae, Section 3.2.2)	
3-10 DOE adequately considers the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THMC coupled processes that affect the chemical environment for radionuclide release.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. **Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.** (ENFE IRSR Rev 3, Section 5.4.3.2.1.3)	CLOSED PENDING. **Uncertainties are handled differently for different models. For example uncertainty on UZ hydrology** is handled differently from uncertainty associated with effects of coupled processes on the chemical environment for radionuclide release. Uncertainty is represented in TSPA by probability distributions and use of conservative bounding assumptions. There is an ongoing effort to quantify uncertainties in the TSPA.	No additional work required beyond that currently planned.
3-11 DOE adequately represents uncertainty in parameter development for conceptual models, process-level models, and alternative conceptual models considered in developing the abstraction of quantity and chemistry of water contacting waste forms, either through sensitivity analyses or conservative limits.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN The AMR on in-package chemistry summary states that the input surface areas, waste package component dissolution rates, and thermodynamic database have yet to be verified. The DOE needs to provide the status of this verification work. (NRC/CNWRA Comment)	CLOSED PENDING. The thermodynamic database has been verified. Verification work is in progress. The sensitivity of chemistry to surface areas and corrosion rates are being considered for the quantification of uncertainty effort. If these parameters are found to be important, their values will be sufficiently verified and completed prior to	No additional work required beyond that already planned..

	the License Application.	
There is no attempt in the AMR on in-package chemistry abstraction to explain how good a fit the response surfaces are to the values computed using EQ/6. (NRC/CNWRA Comment)	The current revision (rev 01) of the In-Package Chemistry Abstraction provides fit information (R-squared values) for the response surfaces. (CRWMS-M&O 2000bq).	No additional work required.
It is claimed that waste form degradation can be adequately modeled with 25 °C thermodynamic database. It is claimed that many of the thermodynamic parameters are not strongly sensitive to temperature over the range 25 to 100 °C, hence the broad scale features of the calculated fluid compositions are considered independent of temperature. However, no evidence of the insensitivity of calculated results was provided. The DOE needs to conduct sensitivity analyses to determine if temperature effects is important. (NRC/CNWRA Comment)	Sensitivity analyses are being considered to determine if temperature effects are important and to verify the reasonable claim. The uncertainties in expected in-package chemistry are described and documented in the Waste Form PMR (CRWMS M&O 2000ae, Section 3.2.2). Additional analysis and discussion addressing temperature sensitivities of thermodynamic data will be included in the next revision of the Summary of In-Package Chemistry for Waste Forms (ANL-EBS-MD-000050 REV 01)(CRWMS-M&O 2000au).	No additional work required beyond that currently planned.

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Acceptance Criterion 4--Model Uncertainty for Evolution of the Near-Field Environment Subissue 3. Alternative modeling approaches consistent with available data (e.g., design features, field, laboratory, and natural analog) and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of quantity and chemistry of water contacting waste packages and waste forms. DOE provided sufficient evidence that alternative conceptual models have been considered, that the models are consistent with available data and current scientific understanding, and that the effect of these alternative conceptual models on total system performance has been evaluated. Specifically (see following items),		
4-1. DOE investigates alternative modeling approaches consistent with available data and current scientific knowledge, and appropriately considers their results and limitations of these approaches in developing the abstraction of quantity and chemistry of water contacting waste forms.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The DOE should evaluate the effect on performance of the alternative colloid release model. Though the AMR on Waste Form Colloid Release Abstraction includes a detailed description of an alternative model, its effect on repository performance has not been evaluated. (NRC/CNWRA Comment) No alternative models for in-drift colloid transport are discussed. The alternative model presented in the Waste Form Colloid Release Abstraction is not appropriate for in-drift transport. (NRC/CNWRA Comment)	CLOSED PENDING. Although an alternative colloid model was described, the data necessary to develop parameters were not available. A more conservative model for which parameters could be developed was selected. Re-examination of tests to develop parameters on CSNF irreversible colloids (NRC comment on Criterion 1) is being considered to provide basis for conservatism of model chosen. Documents available for NRC review include the Waste Form Degradation Process Model Report, TDR-WIS-MD-000001, REV 00 ICN 01 (CRWMS-M&O 2000an) and Waste-Form Colloid-Associated Concentration Limits Analysis/Model Report, ANL-WIS-MD-000012, REV 00 ICN 01 (CRWMS-M&O 2000aq). The expected in-package chemistry is described and documented in the AMR, Summary of In-Package Chemistry for Waste Forms (CRWMS M&O 2000au).	No additional work required beyond that currently planned.

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	Alternative model components include filtration and lateral diffusion/dispersion of colloids. Exclusion of these alternative model components for in-drift colloid transport is conservative (EBS Radionuclide Transport Abstraction. ANL-WIS-PA-00000, REV 00, ICN 02)(CRWMS-M&O 2000bk).	
The analysis assumes water may circulate freely enough in the partially degraded waste package so that all degraded solid products may react with each other through the fluid. Also, an assumption is made that circulation and mixing of water occurs inside the package that allows complete exposure of waste package components to incoming fluids. The analyses lumped all components into a single mass for purposes of calculating the chemistry of water that interacts with waste package components. It was claimed that this assumption maximizes the amount of waste package degradation. However, the assumption ignores the development of local environments that are more corrosive than calculated based on a volume-averaged basis. (NRC/CNWRA Comment)	Analyses thus far focus on well-understood bulk-scale chemical processes that are likely to dominate the in-package chemical environment. Local environments may be present but they are unlikely to have a significant effect on overall waste form dissolution and radionuclide release. Future analyses are being considered to verify this assumption.	No additional work required beyond that currently planned.
4-2. DOE adequately considers the effects of THMC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products in their assessment of alternative conceptual models. DOE considers: (i) thermohydrologic effects on gas and water chemistry, (ii) hydrothermally driven geochemical reactions such as zeolitization of volcanic glass, which could affect flow pathways, water chemistry and waste package environmental conditions, (iii) dehydration of hydrous phases liberating moisture that may affect the chemical environment for radionuclide release, (iv) effects of microbial processes on the chemical environment for radionuclide release, (v) changes in water chemistry that may result from the release of corrosion products from the waste package and interactions between engineered materials and groundwater, which, in turn, may affect the chemical environment for radionuclide release, and (vi) changes in boundary conditions (e.g., drift shape and size) and hydrologic properties relating to the response of the geomechanical system to thermal loading, in their assessment of alternative conceptual models.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN	CLOSED PENDING.	No additional work required beyond that currently

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.4)	The EBS PMR documents the consideration of thermal effects on gas and water chemistry (e.g., CRWMS M&O 2000 Rev. 01 is work in progress). Hydrothermally driven geochemical reactions are considered in the UZ PMR (CRWMS M&O 2000ab, Section 3.10.2.2, 3.10.4.1, and 3.10.4.2), and this work will continue. Dehydration of hydrous phases is addressed in the NFE PMR (e.g., CRWMS M&O 2000ad, Section 3.3.3.6). Microbial processes are addressed in the EBS and Waste Package PMRs (e.g., CRWMS M&O 2000 Rev. 01 is work in progress). Water chemistry in the EBS is addressed in the EBS PMR (CRWMS M&O Rev. 01 is work in progress), Waste Package PMR (CRWMS M&O 2000ae, Section 3.1.3) and Waste Form PMR (e.g., CRWMS M&O 2000an, Section 3.2). Models of released radionuclides and EBS materials are under development.	planned.
4-3. DOE provides a description which includes a discussion of alternative modeling approaches not considered in its final analysis and the limitations and uncertainties of the chosen model.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.4)	CLOSED Exclusion of credible alternative model components for in-drift colloid transport is conservative. Processes that are neglected include filtration in the invert and lateral diffusion in the invert. (EBS Radionuclide Transport Abstraction. ANL-WIS-PA-00000, REV 00, ICN 02) (CRWMS-M&O 2000bk) The alternative modeling approaches considered are described and documented in the Waste Form PMR	No additional work required.

	(CRWMS M&O 2000an, various subsections of Section 3, e.g., 3.2.3).	

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<table>
<tr><td colspan="3">Acceptance Criterion 5--Model Support for Evolution of the Near-Field Environment Subissue 3. Output from the abstraction of quantity and chemistry of water contacting waste forms is justified through comparison with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, natural analogs).</td></tr>
<tr><td colspan="3">5-1. DOE verifies that the outputs of the quantity and chemistry of water contacting waste forms abstraction reasonably reproduce or bound the results of corresponding process-level models or empirical observations.</td></tr>
<tr><th>NRC Staff Analysis</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.5)</td><td>CLOSED PENDING.

The In-Package Chemistry Abstraction AMR (currently undergoing revision will improve the resolution and treatment of ionic strength calculations by considering an additional time period and defining ionic strength distributions for each time period that will be sampled in TSPA calculations (In-Package Chemistry Abstraction. ANL-EBS-MD-37. REV01.) (CRWMS-M&O 2000bp).

The expected in-package chemistry is described and documented in the AMR, Summary of In-Package Chemistry for Waste Forms (CRWMS M&O 2000au).</td><td>No additional work required beyond that currently planned.</td></tr>
<tr><td colspan="3">5-2. DOE demonstrates that abstracted models for coupled THMC effects on the chemical environment for radionuclide release, are based on the same assumptions and approximations demonstrated to be appropriate for closely analogous natural or experimental systems.</td></tr>
<tr><th>NRC Staff Analysis</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.5)</td><td>CLOSED

Natural analogs and comparisons with laboratory test data are documented in the PMRs, as appropriate (e.g., CRWMS M&O 2000ab, Sections 3.10.9 and 3.11.12)</td><td>No additional work required.</td></tr>
<tr><td colspan="3">5-3. DOE shows that abstracted model results were verified through comparison with outputs of detailed process-level models and empirical observations.</td></tr>
</table>

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NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. It is stated in the AMR on in-waste package summary that it is not possible to fully validate the model at this time or to assign absolute confidence limits to in-package chemistry outputs. The DOE should identify confirmatory steps that will be conducted to validate the models. (NRC/CNWRA Comment)	CLOSED PENDING. Confirmatory steps are being identified and sufficient progress towards model validation will be completed prior to the License Application. Model validation is discussed in detail in the Waste Form PMR (CRWMS M&O 2000an, various subsections of Section 3, e.g., 3.2.2).	No additional work required beyond that currently planned.
5-4. DOE evaluates the outputs of the abstraction against field and laboratory data and natural analogs information.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. DOE predictions of in-package chemistry based on the EQ3/6 code have not been verified by empirical observations. In particular, staff has concerns regarding the use of the EQ3/6 code because it does not incorporate electrochemical reactions. Experiments to simulate certain aspects of waste package geometry and materials may aid in gaining confidence in the EQ3/6 results. (NRC/CNWRA Comment)	CLOSED PENDING. Short-term validation experiments for key in-package processes being considered and will be completed prior to the license application. Comparisons of waste form abstraction to appropriate field and laboratory data and natural analog information are documented in the Waste Form PMR, (CRWMSM&O 2000an, Sections 3.3.2, 3.6.3, and 3.8.2) (currently undergoing revision)..	No additional work required beyond that currently planned.
5-5. DOE Appropriately adopts accepted and well-documented procedures to construct and test the numerical models used to simulate coupled THMC effects on the chemical environment for radionuclide release.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.5)	CLOSED PENDING. Software management procedures are used as required by DOE's process validation and re-engineering initiative. Model validation practices are followed (e.g., CRWMS M&O 2000ab,	No additional work required beyond that currently planned.

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	Sections 3.5.6.3 and 3.7.4.4). Current models for the in-drift environment are decoupled, for mechanical and chemical effects. Analyses are under way to evaluate coupling.	
5-6. DOE compares abstracted model results with different mathematical models to judge robustness of results.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.1.5)	CLOSED Abstraction models are consistent with their respective process models and are validated in accordance with procedure AP-3.10Q. This procedure also requires discussions of alternative modeling approaches, limitations, and uncertainties.	No additional work required.

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Integrated Subissue on Radionuclide Release Rates and Solubility Limits. Detailed analyses of DOE abstractions, models, and analyses of radionuclide release rates and solubility limits are provided in the Container Life and Source Term IRSR Revision 2 (U.S. Nuclear Regulatory Commission, 1999d). Of relevance to the ENFE IRSR is the effect of coupled THC processes on the chemical environment affecting radionuclide release rates and solubility limits. Staff analysis of DOE's approach to abstraction of coupled THC effects on the chemical environment affecting radionuclide release and solubility limits is presented in the following sections.

Acceptance Criterion 1-Integration for Evolution of the Near-Field Environment Subissue 3. Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of radionuclide release rates and solubility limits in the total system performance assessment, and the technical bases are provided. The features, phenomena and couplings, and assumptions used to abstract release of radionuclides from waste forms inside the waste package and the transport and release of radionuclides from the engineered barrier system have been provided. The abstraction is consistent with the identification and description of those aspects of radionuclide release rates and solubility limits that are important to waste isolation. The abstraction is also consistent with the technical bases for these descriptions of barriers important to waste isolation. Specifically (see following items),

1-1. As part of its FEPs analysis in developing the abstraction, DOE identifies and considers processes for cladding performance, spent nuclear fuel degradation, high-level waste glass dissolution, degradation of other radioactive wastes, the compatibility of spent nuclear fuel and high-level waste glass and other radioactive waste forms with internal components of the waste package, and the release of radionuclides from the engineered barrier system and provides adequate technical bases for the exclusion of any of these processes.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (NEFE IRSR Rev 3, Section 5.4.3.2.2.1)	CLOSED Documentation of the supporting data and technical bases for the inclusion or exclusion of processes for cladding performance, spent nuclear fuel degradation, high-level waste glass dissolution, degradation of other radioactive wastes, the compatibility of spent nuclear fuel and high-level waste glass and other radioactive waste forms with internal components of the waste package, and the release of radionuclides from the engineered barrier system in conceptual models is provided in the following AMRs: Engineered Barrier System Degradation Modes &	No additional work required.

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	Features, Events, and Processes Abstraction. ANL-WIS-PA-000002 Miscellaneous Waste-Form FEPs (CRWMS M&O 2000aw) Waste-Form Colloid-Associated Concentrations Limits (CRWMS M&O 2000aq) Clad Degradation – FEPs Screening Arguments (CRWMS M&O 2000ap)	
1-2. DOE provides adequate technical bases for exclusion of any potentially important couplings and FEPs.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. **NRC staff review of DOE's FEPs screening identified 57 primary FEPS as relevant to both the integrated subissue on radionuclide release rates and solubility limits and to ENFE Subissue 3. Of these 57, twenty-two were excluded by the DOE screening process, of which 15 overlap with the excluded FEPs identified as relevant to the integrated subissue on quantity and chemistry of water contacting the waste packages and waste forms (See previous discussion of FEPs under Subissue 3).** Review of nine excluded FEPs (not including the 15 that are discussed previously under Subissue 3) indicates that the staff does not agree with the exclusion decision or concluded that the technical basis for exclusion is not adequate for five of the 9 FEPs. Discussions of the NRC staffs conclusions about the 5 FEPs are presented in the IRSR Rev 3 (pages 191-193). (ENFE IRSR Rev 3, Section 5.4.3.2.2.1)	CLOSED **FEPs analyses have been revised. Adequate documentation of the supporting data and technical bases for the inclusion or exclusion of certain observed phenomena in conceptual models is provided in the following AMRs:** Engineered Barrier System Features, Events, and Processes (FEPS) / Degradation Modes Abstraction. ANL-WIS-PA-000002 Rev 01.(CRWMS-M&O 2000af). Miscellaneous Waste-Form FEPs (CRWMS M&O 2000ao) Waste-Form Colloid-Associated Concentrations Limits (CRWMS M&O 2000aq) Clad Degradation – FEPs Screening Arguments(CRWMS M&O 2000ap)	No additional work required.

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1-3 DOE's abstraction is consistent with the detailed information on waste package and other engineered features.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The in-package chemistry calculations should be supported by empirical observations and more detailed process-level models. For example, the abstractions do not explicitly consider some interactions between various waste package internal components and spent nuclear fuel. Spent fuel, because of its hyperstoichiometry, is a p-type semiconductor and, hence, capable of sustaining electrochemical reactions. Thus, galvanic interactions between cladding and fuel, basket materials and fuel, and other components need to be evaluated. DOE's analysis ignores the presence of corrosion products, such as FeOOH, $FeCl_2$, and $FeCl_3$, resulting from dissolution of waste package internal components that could influence glass corrosion processes and the pH dependence of the dissolution rate. The colloid abstraction does not explicitly address a sufficient range of possible coupled and uncoupled effects on colloid stability and radionuclide attachment to ensure that the abstraction is adequate for the range of possible repository conditions. (ENFE IRSR Rev 3, Section 5.4.3.2.2.1)	CLOSED The DOE abstraction of waste package chemistry is consistent with the detailed chemistry information on waste package design (CRWMS M&O 2000au, Section 6 and CRWMS M&O 2000av, Section 6).	No additional work required.
1-4 DOE reasonably accounts for the range of environmental conditions, including water composition and water and vapor movement, expected inside breached waste packages and in the engineered barrier environment surrounding the waste package (e.g., temporal and spatial variations in conditions affecting coupled THC effects on the chemical environment for radionuclide release rates and solubility limits).		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN.	CLOSED	No additional work required.

The effect of chloride anions is not considered in DOE's analysis of localized corrosion and stress corrosion cracking of cladding. Instead, the role of fluoride as a species promoting accelerated corrosion in local areas is emphasized. the analysis of the flow and volume of water contacting the fuel rods to evaluate local attack of the cladding by fluoride is limited and requires additional justification. Inconsistencies occur regarding the evaluation of the in-package pH because a low pH is assumed for the attack by fluoride, whereas it is not taken into account in the concentration in solution of Fe^{3+} ions that may promote oxidizing conditions conducive for pitting in chloride solutions. (ENFE IRSR Rev 3, Section 5.4.3.2.2.1)	The current approach for representing the EBS in TSPA uses several GoldSim cells. The current design limits the number of materials that are present in the EBS (CRWMS M&O 2000aa, Section 1.6). Current models for the EBS capture the important aspects or water composition for performance (e.g., CRWMS M&O 2000aa, Executive Summary). Section 5.3.2 of the EBS PMR (CRWMS M&O 2000aa) summarizes the conceptual models of processes that control the physical and chemical environment of the EBS. Effects of TH processes (boiling, condensation, and drainage) on water and gas chemistry and mineral evolution are discussed in the UZ PMR (CRWMS M&O 2000ab, Section 3.10.2.2). Section 3.10.5 discusses the THC seepage model, and section 3.10.11 discusses the abstraction of the model for TSPA-SR. Effects of coupled THC processes on seepage and flow are discussed in Section 4.2.1.1. The current TSPA approach uses consistent set of water compositions, except for the waste form degradation model, which used a J-13 water composition. DOE believes this approach is adequate because the degradation products inside breached waste packages will dominate the water composition (CRWMS M&O 2000aa, Section 3.1.2) and much of the mobilized radionuclide inventory will be colloidal (CRWMS M&O 2000ae, Section 3.8).	
1-5. The abstraction is consistent with technical bases, data and models in the spatial and temporal distribution of flow abstraction, the quantity and chemistry of		

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water contacting waste package and waste forms abstraction, the degradation of engineered barriers abstraction, and the mechanical disruption of engineered barriers abstraction.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.1)	CLOSED The DOE models for waste package chemistry and its abstraction are consistent with the range of seepage fluxes provided by the seepage abstraction (Abstraction of Drift Seepage. ANL-NBS-MD-000005 REV 00)(CRWMS-M&O 2000bf) and the EBS flow abstraction (EBS Radionuclide Transport Abstraction ANL-WIS-PA-00000, REV 00, ICN 02)(CRWMS-M&O 2000ah) and the detailed chemistry information on waste package design (Summary of In-Package Chemistry for Waste Forms, Section 6. ANL-EBS-MD-000050 REV 01)(CRWMS M&O 2000au), and (Clad Degradation-Local Corrosion of Zirconium and Its Alloys Under Repository Conditions, Section 6. ANL-EBS-MD-000012 REV 00)(CRWMS M&O 2000av). DOE believes that the other topics identified in the criterion are beyond the scope of topics that are relevant to the degradation of the waste form (except as how they may impact seepage flux and seepage chemistry entering the packages) as documented in the Waste Form Degradation Process Model Report (CRWMS M&O 2000an). The degradation and mechanical disruption of engineered barriers abstractions are addressed in the EBS Radionuclide Transport Abstraction ANL-WIS-PA-00000, REV 00, ICN 02)(CRWMS-M&O 2000ah)	No additional work required.

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Subissue 3:Effects of Coupled Thermal-Hydrologic-Chemical Processes on the Chemical Environment for Radionuclide Release

Acceptance Criterion 2--Data and Model Justification for Evolution of the Near-Field Environment Subissue 3. Sufficient data on design features (including drip shield, backfill, waste packages, waste forms, other engineered barrier components, and thermal loading), geology, hydrology, and geochemistry of the unsaturated zone and drift environment (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of radionuclide release rates and solubility limits used in the performance assessment. The data are also sufficient to assess the degree to which FEPs related to radionuclide release rates and solubility limits and which affect compliance with the postclosure performance objectives have been characterized and to determine whether the technical bases provided for exclusion of these FEPs are adequate. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated. Specifically (see following items),

2-1 DOE demonstrates that sufficient data have been collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions, including temporal and spatial variation, for conceptual models and simulations of THC coupled processes, including the potential for microbial processes that may affect radionuclide release for this abstraction.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Additional data are needed for DOE to demonstrate that, with the chloride concentrations expected inside waste packages, cladding degradation and consequent radionuclide release will not be enhanced. Insufficient information has been provided on the potential effect of corrosion products on high-level waste glass degradation. The initial and boundary conditions used in calculating high-level waste glass degradation should account for the potential effect of corrosion products resulting from dissolution of waste package components. (ENFE IRSR Rev 3, Section 5.4.3.2.2.2)	CLOSED DOE's natural system models are based on extensive site characterization data (CRWMS M&O 2000aa and CRWMS M&O 2000ad). The type, quantity, and reactivity of engineered materials has been evaluated CRWMS M&O 2000ab)	No additional work required.

2-2 Where DOE uses data supplemented by models to support abstraction of solubility limits, the anticipated range of proportions and compositions of phases under the various physiochemical conditions expected are supported by experimental data (U.S. Nuclear Regulatory Commission, 1984). DOE adequately evaluates run product compositions for liquids and solids and determines radionuclide solubilities from undersaturation and over-saturation. If DOE does not use experimental reversal to determine the solubility limit, an approach from over-saturation is used.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN.	CLOSED	No additional work required.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.2)	Physiochemical conditions related to waste form degradation were bounded for the present analyses by the use of very soluble controlling solids. The predicted solubilities are above the experimental observed repository type tests and are based on under and over-saturation experiments on bounding phases. (CRWMS M&O 2000ax)	
2-3 DOE justifies the use of test results not specifically collected from the Yucca Mountain site for cladding performance, spent nuclear fuel, high-level waste glass, other radioactive waste forms intended for disposal, and other engineered barrier system components such as drip shield and backfill, for the environmental conditions expected to prevail.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.2)	CLOSED DOE evaluates data related to cladding performance, spent nuclear fuel, and high-level waste glass according to a process specified in the procedure to develop analysis and model reports (AP-3.10Q). The procedure specifies the method to be used to justify test results and assumptions.	No additional work required.
2-4 Where sufficient data do not exist, the definition of parameters values and conceptual models is based on appropriate other sources such as expert elicitation conducted in accordance with NUREG-1563 (Kotra, et al., 1996).		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.2)	CLOSED Expert elicitations regarding seepage and flow were conducted in both the UZ and NF aspects. Expert elicitations associated with development of this PMR were determined to be subject to the quality assurance program as described in the QARD (DOE 2000a) document. Appendix C of the QARD and implementing procedures for expert elicitation were developed using the guidance provided in	No additional work required.

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	NUREG-1563 (Kotra, et al. 1996). Section 2.4.5 of the near field PMR (CRWMS M&O 2000ad) addresses expert elicitation regarding parts of the elicitation that relate to the NFE. Refer to that section for a description of how expert elicitation was used. For a complete discussion, refer to the UZ F&T PMR (CRWMS M&O 2000ab)	
2-5 Sensitivity or uncertainty analyses are adequate to determine the possible need for additional data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.2)	CLOSED PENDING. The SRCR sensitivity studies document the importance of the waste form models for radionuclide release (CRWMS M&O 2000am, Chapter 5). However, since the waste form models are conservatively bounding the sensitivity analyses does not include many unquantified uncertainties and may overstate the importance of waste form model parameters. Work to more realistically quantify (rather than simply bound) uncertainty has started in 4 waste form models: in-package chemistry, cladding, solubility limits and colloids. Results are expected near the end of the second quarter of FY01. If parameters are found to be important their values will be sufficiently verified prior to the License Application.	No additional work required beyond that currently planned.

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Subissue 3: Effects of Coupled Thermal-Hydrologic-Chemical Processes on the Chemical Environment for Radionuclide Release

Acceptance Criterion 3-Data Uncertainty for Evolution of the Near-Field Environment Subissue 3. Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the abstraction of radionuclide release rates and solubility limits are consistent with site characterization, design data, laboratory experiments, field measurements, and natural analog data. Specifically (see following items),		
3-1. Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the abstractions of radionuclide release rates and solubility limits in the TSPA are technically defensible and reasonable based on data from the Yucca Mountain region, laboratory tests, and natural analogs.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.3)	CLOSED Documentation and technical bases of parameter values, assumed ranges, probability distributions, and bounding assumptions used in the abstractions of radionuclide release rates and solubility limits in the TSPA are consistent with available data and are adequately described and documented in the Waste Form Degradation PMR (CRWMS M&O 2000an sections 3.3, 3.6 and 3.7).	No additional work required.
3-2. DOE demonstrates the use of reasonable or conservative ranges of parameters or functional relations to determine effects of coupled THC processes such as secondary mineral formation and localized corrosion products on radionuclide release. These values are consistent with the initial and boundary conditions and the assumptions for the conceptual models and design concepts at the Yucca Mountain site. For example, estimations used in each abstraction are based on the thermal-loading strategy, including effects of ventilation; engineered barrier system design; and natural system masses and fluxes.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.3)	CLOSED PENDING. As conceptual models and designs are updated, the abstractions will be updated.	No additional work required beyond that currently planned.
3-3. DOE includes experimental and conceptual uncertainty in determining the range in solubility limits.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.	CLOSED PENDING. A bounding conceptual model and parameters were used as documented in the AMR Summary of	No additional work required beyond that currently planned.

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Subissue 3: Effects of Coupled Thermal-Hydrologic-Chemical Processes on the Chemical Environment for Radionuclide Release

(ENFE IRSR Rev 3, Section 5.4.3.2.2.3)	Dissolved Concentration Limits (CRWMS M&O 2000ax) and the Waste Form Degradation PMR (CRWMS M&O 2000an, Section 3.7). The uncertainty work currently being considered will replace bounds with uncertainties.	
3-4. Uncertainty is adequately represented in parameter development for conceptual models, process models, and alternative conceptual models considered in developing the abstraction of radionuclide release rates and solubility limits, either through sensitivity analyses or use of conservative limits.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.3)	CLOSED PENDING. Uncertainty is addressed in the waste form AMRs and PMR, usually with a conservative bounding strategy (CRWMS M&O 2000an). Work to more realistically quantify (rather than simply bound) uncertainty has started in 4 waste form models: in-package chemistry, cladding, solubility limits and colloids.. Results are expected near the end of the second quarter of FY01.	No additional work required beyond that currently planned.
3-5. DOE adequately considers the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THC coupled processes that affect radionuclide release.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.3)	CLOSED PENDING. Uncertainties are handled differently for different models. For example uncertainty on UZ hydrology is handled differently from uncertainty associated with effects of coupled processes on radionuclide release. Uncertainty is represented in TSPA by probability distributions and use of conservative bounding assumptions. There is an ongoing effort to quantify uncertainties in the TSPA.	No additional work required beyond that currently planned.
The results of the in-package chemistry calculations	DOE's models do not consider the effects of high-	No additional work required beyond that currently

were not fully utilized in evaluating the solubility limits and the evaluation of dissolved concentration limits did not fully account for the variation in-package chemistry. The effect of chloride anions was not considered in the DOE analysis of localized corrosion and stress corrosion cracking of the commercial spent nuclear fuel cladding. The effect of corrosion products on high-level waste glass dissolution was not considered. (ENFE IRSR Rev 3, Section 5.4.3.2.2.3)	level waste glass corrosion products, and the components of high-level waste degradation are described in the Waste Form PMR (CRWMS M&O 2000an, Section 3.6). The DOE approach is considered conservative because it is based on intrinsic dissolution rate for the glass waste form. Some of the effects of chloride on cladding are described in the AMR, Clad Degradation—Local Corrosion of Zirconium and Its Alloys Under Repository Conditions (CRWMS M&O 2000av, Section 3.4). The descriptions in the report indicate that zircaloy is not susceptible to stress corrosion cracking in NaCl, HCl, $MgCl_2$ and H_2S solutions. The environments known to cause stress corrosion cracking in zirconium include $FeCl_3$, $CuCl_2$, halogen or halide-containing methanol, concentrated HNO3, liquid mercury or cesium and 64 to 69% H_2SO_4. The extreme oxidizing acidic conditions are not predicted for the bulk in-package chemistry but the possibility of such conditions occurring locally and transiently is included in the local corrosion model.	planned.
3-6. DOE addresses and provides adequate technical bases for the exclusion of colloids in the abstraction.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. No technical basis was provided for the inclusion of colloidal effects only on plutonium and americium release and for the exclusion of americium from irreversible attachment modeling. The exclusion of a colloidal release component for other radionuclides needs to be supported. (ENFE IRSR	CLOSED Am is not excluded from irreversible attachment modeling. Am is assumed to behave as does Pu in terms of mobilization from waste degradation and formation of irreversible association with smectite colloids and clay layers on HLW. This is a reasonable assumption based on chemical	No additional work required.

Rev 3, Section 5.4.3.2.2.3)	characteristics of Pu and Am. Pu, Am, Th, Pa, Cs, and Sr are assumed to be the most significant radionuclides available for colloid association; data indicate that smectite colloids may contain Pu, Am, Th, U, Cm, Np, and rare earth elements (REEs), and that Pu generally behaves similarly to Th, Am and REEs. Desorption of Pu and Am from pseudocolloids is assumed to be slow relative to transport rates within the waste package, i.e., pseudocolloid sorptive attachment is effectively irreversible within the waste package. (Waste Form Colloid-Associated Concentration Limits:Abstraction and Summary AMR, ANL-WIS-MD-000012 Rev 00) (CRWMS-M&O 2000aq)	
3-7. DOE uses an appropriate range of time-history of temperature, humidity, and dripping to constrain the probability for microbial effects, such as production of organic by-products that act as complexing ligands for actinides and microbial-enhanced dissolution of the high-level waste glass form.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
CLOSED. The staff considers the technical basis for exclusion of microbial activity from DOE's evaluation of coupled THC effects on chemical environment for radionuclide release sufficient. (ENFE IRSR Rev 3, Section 5.4.3.2.2.3)	CLOSED. DOE agrees with the staff assessment.	No additional work required.

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Subissue 3:Effects of Coupled Thermal-Hydrologic-Chemical Processes on the Chemical Environment for Radionuclide Release

Acceptance Criterion 4-Model Uncertainty for Evolution of the Near-Field Environment Subissue 3. Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of radionuclide release rates and solubility limits. In its technical basis, the DOE has provided sufficient evidence that alternative conceptual models have been considered, that the models are consistent with available data (e.g., design features, field, laboratory, and natural analog) and current scientific understanding, and that the effect of these alternative conceptual models on total system performance has been evaluated. Specifically (see following items),		
4-1. Conceptual model uncertainties are adequately defined and documented and effects on conclusions regarding performance are properly assessed.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.4)	CLOSED Uncertainties in conceptual models, especially in terms of confidence, limitations, and validation are adequately documented in the Waste Form Degradation PMR (CRWMS M&O 2000an; see for example Section 3.2.2).	No additional work required.
4-2. DOE investigates alternative modeling approaches consistent with available data and current scientific knowledge, and appropriately considers their results and limitations in developing the total system performance assessment abstraction.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.4)	CLOSED The modeling approaches selected are bounding approaches and are consistent with available data and current scientific knowledge. Alternative modeling approaches are adequately described and documented in the Waste Form Degradation PMR (CRWMS M&O 2000an; see for example Section 3.2.3).	No additional work required.
4-3. In considering alternative conceptual models for radionuclide release rates and solubility limits, DOE uses appropriate models, tests, and analyses that are sensitive to the processes modeled for both natural and engineering systems.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model	CLOSED The conceptual waste form models selected are	No additional work required.

Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.4)	bounding models that include the processes important to their performance. These conceptual models are discussed in the Waste Form Degradation PMR (CRWMS M&O 2000an, for example in sections 3.2.1 and 3.3.1). Alternative modeling approaches are documented in the Waste Form Degradation PMR (CRWMS M&O 2000an; see for example Section 3.2.3).	
4-4. DOE appropriately considers the effects of THC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products on radionuclide release.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. The evaluation of dissolved concentration limits did not fully account for . the variation of in-package chemistry. The effect of chloride anions was not considered in DOE's analysis of localized corrosion and stress corrosion cracking of the commercial spent nuclear fuel cladding. The effect of corrosion products on high-level waste glass dissolution was not considered. (ENFE IRSR Rev 3, Section 5.4.3.2.2.4)	CLOSED PENDING. Section 5.3.2 of the EBS PMR (CRWMS M&O 2000aa) summarizes the conceptual models of coupled processes that control the physical and chemical environment of the EBS. Effects of TH processes (boiling, condensation, and drainage) on water and gas chemistry and mineral evolution are discussed in the UZ PMR (CRWMS M&O 2000ab, Section 3.10.2.2). Section 3.10.5 discusses the THC seepage model, and section 3.10.11 discusses the abstraction of the model for TSPA-SR. Effects of coupled THC processes on seepage and flow are discussed in Section 4.2.1.1. Gas generation or consumption by thermal evolution of waters, corrosion processes, waste decay, and microbial activity are addressed in current models [EBS Physical & Chemical Environment Model (CRWMS M&O 2000at), In-Drift Microbial Communities (CRWMS M&O 2000ak)(Revision 01 is work in progress)].	No additional work required beyond that currently planned.

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Subissue 3: Effects of Coupled Thermal-Hydrologic-Chemical Processes on the Chemical Environment for Radionuclide Release

Acceptance Criterion 5--Model Support for Evolution of the Near-Field Environment Subissue 3. Output from the abstraction of radionuclide release rates and solubility limits is justified through comparison with output from detailed process-level models and empirical observations (e.g., laboratory testing, field measurements, natural analogs).		
5-1. DOE verifies that the outputs of radionuclide release rates and solubility-limits abstractions reasonably reproduce or bound the results of corresponding process-level models, empirical observations, or both.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.5)	CLOSED Validation of conceptual models used in the analysis of waste form degradation is discussed and documented in the Waste Form Degradation PMR (CRWMS M&O 2000an, especially for example in sections 3.7.2 and 3.8.3).	No additional work required.
5-2. DOE bases abstracted models for coupled THC effects on radionuclide release on the same assumptions and approximations shown to be appropriate for closely analogous natural or experimental systems.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.5)	CLOSED PENDING. The current fully coupled THC models are limited to the drift-scale model of the host rock response, which describes the evolution of water and gas composition that could enter the EBS. Sensitivity testing of this THC model is underway, and results will be evaluated for their effects on the EBS. In addition, fully coupled THC models that include the EBS and effects on radionuclide release are being considered. See Near Field and EBS PMRs	No additional work required beyond that currently planned.
5-3. DOE adopts well-documented procedures that have been accepted by the scientific community to construct and test the numerical models used to simulate coupled THC effects on radionuclide release.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN.	CLOSED	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on the Evolution of the Near Field Environment

Subissue 3:Effects of Coupled Thermal-Hydrologic-Chemical Processes on the Chemical Environment for Radionuclide Release

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.3.2.2.5)	DOE recently revised the procedures that are used to construct and test numerical models used to simulate the natural processes at Yucca Mountain. The Process Validation and Reengineering initiative includes a comprehensive set of procedures that are based on accepted scientific standards for the constructing and testing of numerical models that are used to simulate coupled THC effects on radionuclide release. Models are validated in accordance with procedure AP-3.10Q. This procedure also requires discussions of alternative modeling approaches, limitations, and uncertainties	

Analysis of the Resolution Status for the Key Technical Issue on the Evolution of the Near Field Environment

Subissue 4: Effects of Coupled Thermal-Hydrologic-Chemical Processes on Radionuclide Transport.

Importance to Performance: DOE's approach to assess the effects of coupled THC processes on the chemical environment for radionuclide release must meet the following generic criteria for each relevant integrated subissue: (i) integration, (ii) data and model justification, (iii) data uncertainty, (iv) model uncertainty, and (v) model support. Quality assurance is handled in a separate section of the Yucca Mountain Review Plan.

Two integrated subissues require input from the ENFE KTI within the scope of the ENFE subissue on radionuclide transport through engineered and natural barriers. The abstractions are (i) Radionuclide Release Rates and Solubility Limits and (ii) Radionuclide Transport in the Unsaturated Zone.

The effects coupled thermal-hydrological-chemical processes on system performance are considered in the nominal case (CRWMS M&O 2000al). Preliminary analyses indicate that none of these processes is a primary factor influencing repository performance.

Integrated Subissue on Radionuclide Release Rates and Solubility Limits

Acceptance Criterion 1-Integration for Evolution of the Near-Field Environment Subissue 4. Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of radionuclide release rates and solubility limits in the total system performance assessment, and the technical bases are provided. The features, phenomena and couplings, and assumptions used to abstract release of radionuclides from waste forms inside the waste package and the transport and release of radionuclides from the engineered barrier system have been provided. The abstraction is consistent with the identification and description of those aspects of radionuclide release rates and solubility limits that are important to waste isolation. The abstraction is also consistent with the technical bases for these descriptions of barriers important to waste isolation. Specifically (see following items):

1-1. DOE reasonably accounts for the range of environmental conditions, including water composition and water and vapor movement, expected inside breached waste packages and in the engineered barrier environment surrounding the waste package (e.g., temporal and spatial variations in conditions affecting coupled THC effects on the chemical environment for radionuclide release rates and solubility limits).

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR, Section 5.4.4.2.1.1).	CLOSED PENDING. The in-package chemical environment is described in detail in the in-package chemistry abstraction AMR (CRWMS M&O 2000ar). Environmental characteristics of the environment external to the waste package are described in a series of AMRs: In drift colloids and concentration (CRWMS M&O 2000bk), In drift gas flux and composition (CRWMS M&O 2000bl),	No additional work required beyond that already planned.

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Subissue 4: Effects of Coupled Thermal-Hydrologic-Chemical Processes on Radionuclide Transport.

	In drift precipitates/salts analysis (CRWMS M&O 2000bm), In drift corrosion products (CRWMS M&O 1999), and In drift microbial communities (CRWMS M&O 2000ak) Drift-Scale Coupled Processes (DST and THC Seepage Models) (CRWMS M&O 2000ba) The water composition and other environmental conditions are summarized in the EBS PMR (CRWMS M&O 2000aa, especially sections 3.1 and 3.2), the NFE PMR (CRWMS M&O 2000ad, sections 3.1, 3.2, 3.3, 3.4, and associated subsections), and the UZ PMR (CRWMS M&O 2000ab, especially sections 3.10 and 3.11). Abstraction models for in-package and ex-package environments are consistent with and based on their respective process models (CRWMS M&O 2000ag, CRWMS M&O 2000bm, CRWMS M&O 2000bo). For TSPA-SR, EBS performance is sufficiently well understood to support reasonable predictions of the environmental conditions that affect radionuclide transport. (Engineered Barrier System Degradation, Flow, and Transport Process Model Report. TDR-EBS-MD-000006 REV 00 ICN 01)(CRWMS M&O 2000aa.) The scientific approach, technical bases, and assumptions used to develop the abstractions are documented in each AMR in accordance with AP-3.10Q.	

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Subissue 4: Effects of Coupled Thermal-Hydrologic-Chemical Processes on Radionuclide Transport.

	Studies of axial-dependent processes, including ventilation and cold-trapping, are underway in FY01.	
1-2. DOE provides adequate technical bases for exclusion of any potentially important couplings and FEP.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN NRC staff review of DOE's FEPs screening identified 48 Primary FEPS as relevant to both the integrated subissue of radionuclide release rates and Subissue 4. The staff determined that the technical bases supporting exclusion of 5 FEPs are adequate. However, the staff believe that the remaining 21 FEPs either should not be excluded or the technical bases supporting DOE's exclude decisions are not adequate. The following FEPs require additional technical bases: 2.2.09.01.00-Microbial activity in the geosphere. 2.2.10.07.00-Thermal-chemical alteration of Calico Hills unit. 2.2.10.09.00-thermal-chemical alteration of Topopah Spring Basal vitrophyre. (ENFE IRSR , Rev. 3 Section 5.4.4.2.1.1)	CLOSED PENDING. DOE has comprehensively evaluated FEPs, and the documentation of bases for exclusion have been improved. See ENFE Subissue 1, Acceptance Criteria 1-2, and 4-1 **FEPs information will be updated in Rev. 01 EBS AMRs (CRWMS M&O 2000af). This is preliminary information, and will be revised again before LA.** The EBS FEPs AMR (CRWMS M&O 2000af) Rev. 01 will integrate previous work (eliminating conflicting information and focusing on the no-backfill design.) The NFE FEPs/Degradation Modes Abstraction (CRWMS M&O 2000ai) and the UZ FEPs AMR (CRWMS M&O 2000aj) are also being updated. Extended discussions of FEPs are planned for the TSPA&I technical exchange.	
1-3. The abstraction is consistent with technical bases, data and models in the spatial and temporal distribution of flow abstraction, the quantity and chemistry of water contacting waste package and waste forms abstraction, the degradation of engineered barriers abstraction, and the mechanical disruption of engineered barriers abstraction.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN	CLOSED PENDING.	

Analysis of the Resolution Status for the Key Technical Issue on the Evolution of the Near Field Environment

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Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR , Rev. 3 Section 5.4.4.2.1.1)	Abstraction models for in-package and ex-package environments are consistent with and based on their respective process models (CRWMS M&O 2000ag, CRWMS M&O 2000bm, CRWMS M&O 2000bo). For TSPA-SR, EBS performance is sufficiently well understood to support reasonable predictions of the environmental conditions that affect radionuclide transport.	
DOE will either need to provide additional analyses to evaluate the effects of no-backfill on the engineered barrier system or provide a technical basis for the applicability of the earlier calculations. Possible effects include temperature, flow rates, and water chemistry. (ENFE IRSR R3, 5.0.4.)	The no-backfill case, including temperature, flow rate, and water chemistry effects, is described in Revision 01 of the EBS, NFE, WPD, and WFD PMRs (CRWMS M&O 2000aa, CRWMS M&O 2000ad, CRWMS M&O 2000ae, and CRWMS M&O 2000an) and revisions and ICNs of supporting AMRs.	No additional work required.
In several cases, DOE used bounding analyses. A good example is the assumption of no retardation for transport through the invert. Given the short flow path through the invert (< 1 meter) relative to the flow path to the critical group (~20 kilometers), this assumption is not likely to underestimate dose to the critical group and is acceptable. However, the analysis in DOE's Repository Safety Strategy, Revision 3 (CRW MS M&O, 2000a) suggests that diffusive transport through the invert may have a significant effect on dose, and additional bounding analyses may be necessary. (ENFE IRSR R3, 5.0.5)	Current models show that diffusion is overwhelmed by advection in the invert under most conditions (i.e. after tens of thousands of years) when releases are likely to occur (CRWMS M&O 2000ab, e.g. Section 5.2.4). Work being considered addresses invert diffusion characteristics to determine if the current model is too conservative (EBS). Slower diffusion may result from a revised model, i.e. better performance for breached waste packages under intact drip shields, or where there is zero seepage.	No additional work required

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Subissue 4: Effects of Coupled Thermal-Hydrologic-Chemical Processes on Radionuclide Transport.

Acceptance Criterion 2—Data and Model Justification for Evolution of the Near-Field Environment Subissue 4. Sufficient data on design features (including drip shield, backfill, waste packages, waste forms, other engineered barrier components, and thermal loading), geology, hydrology, and geochemistry of the unsaturated zone and drift environment (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction- of radionuclide release rates and solubility limits used in the performance assessment. The data are also sufficient to assess the degree to which FEPs related to radionuclide release rates and solubility limits and which affect compliance with the postclosure performance objectives have been characterized and to determine whether the technical bases provided for exclusion of these FEPs are adequate. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated. Specifically (see following items),		
2-1. DOE demonstrates that sufficient data have been collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions, including temporal and spatial variation, for conceptual models and simulations of THC coupled processes, including the potential for microbial processes that may affect radionuclide release for this abstraction.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN There is little, if any, laboratory or field information available on the performance of the titanium drip shield. Also at the current time the status of the data sufficiency for this engineered barrier component is uncertain. DOE will need to provide additional data on design features and the technical bases for the description and implementation of these features in the total system performance assessment abstraction. Some inconsistency occurs in the DOE model for the formation of iron pseudocolloids. DOE notes data that indicate the irreversibility of plutonium sorption on iron colloids and corrosion products. The treatment of colloids in the abstraction, however, calls for only reversible sorption onto corrosion products and natural groundwater colloids. Because there is a likely to be a significant amount of corrosion products, and because	CLOSED PENDING. Performance of titanium drip shields was addressed in the Container Life and Source Term technical exchange, and concerns about data sufficiency, design features, and technical bases for the description and implementation of these features in TSPA abstractions are being addressed through the agreements from that technical exchange. The UZ PMR (CRWMS M&O 2000ab) and the NFE PMR (CRWMS M&O 2000ad) document natural system characteristics under ambient and thermally perturbed conditions. Changes in the EBS are described in the EBS PMR (CRWMS M&O 2000aa), the Waste Package Degradation PMR (CRWMS M&O 2000ae) and the Waste Form Degradation PMR (CRWMS M&O 2000an). Effects of coupled processes on radionuclide transport are described in the UZ PMR (CRWMS M&O 2000ab, Section 3.11) and the potential for	No additional work required beyond that already planned.

irreversible sorption on colloids potentially will have a stronger impact on performance, DOE will need to provide additional support on colloid formation. (ENFE IRSR Rev 3, Section 5.4.4.2.1.2).	microbial processes that could affect radionuclide release is described in the microbial communities AMR (CRWMS M&O 2000ak) and summarized in the EBS PMR (CRWMS M&O 2000aa, e.g., Executive Summary). Water chemistry parameters are addressed in the EBS PMR (CRWMS M&O Sections 3.1.2, and 5.3.2, and drift-scale THC processes are addressed in the UZ PMR (CRWMS M&O 2000ab, Section 3.10). The characterization of colloids is summarized in the EBS PMR. The affinity of ferric colloids for radionuclides has been tested in the laboratory, and is probably most important for radioelements such as plutonium and americium. These elements have limited solubilities, but high affinities, so sorption to colloids could product a relatively large increase in mobility. Under certain conditions, sorption of plutonium to hematite colloids is apparently irreversible; that is, significant desorption has not been observed in laboratory tests CRWMS M&O 2000aa, Section 5.3.2.6). Engineered materials in the EBS are identified in the EBS PMR (CRWMS M&O 2000aa, Section 1.6) and are addressed using bounding analysis, which limits the need for new data or confirmatory testing for LA. EBS performance is sufficiently well understood to support reasonable predictions of the environmental conditions at the drip shields and waste packages, and of conditions that will affect radionuclide	

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	transport in the emplacement drifts (CRWMS M&O 2000aa, Section 5.4). The models will continue to be refined prior to the license application.	
2-2. Sensitivity or uncertainty analyses are adequate to determine the possible need for additional data.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR , Rev. 3 Section 5.4.4.2.1.2)	CLOSED PENDING. The UZ PMR (CRWMS M&O 2000ab, Section 3.11.10) provides a discussion and documentation of uncertainties and limitations associated with various UZ transport processes. Section 3.13 provides an overview of uncertainty in UZ flow and transport models, and section 5.2.5 summarizes the treatment of uncertainty in UZ flow and transport modeling. The NFE PMR (CRWMS M&O 2000ad) discusses uncertainties and limitations associated with the THC process model (Section 3.3.4) and summarizes the validation and confidence building exercises associated with the model in Sections 3.6.4, 5.4 and 5.5. The EBS PMR (CRWMS M&O 2000aa) discusses uncertainties and limitations associated with the water distribution and removal model in Section 3.1.1.3. Uncertainties in the thermal hydrology model are discussed in Section 3.1.2.1.2. Uncertainties in the Gas Flux and Fugacity model are discussed in Section 3.1.2.2.2. Validation of the introduced materials model is discussed in Section	

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	3.1.2.3.6. Uncertainties in the microbial effects model are discussed in Section 3.1.2.4.2.2. Uncertainties in the Precipitates and Salts model are discussed in Section 3.1.2.5.2.3 and 3.1.2.5.3.3. Uncertainties in the chemical reference model are discussed in Section 3.1.2.7.2. Uncertainties in the multiscale thermohydrologic model are discussed in Section 3.1.4.1. The completed uncertainty analyses indicate that parameters are sufficiently well understood to develop process models and abstractions for TSPA-SR. (Total System Performance Assessment for the Site Recommendation. TDR-WIS-PA-000001 REV 00 ICN 01)(CRWMS M&O 2000am) All three PMRs use field and laboratory testing results (ESF seepage, drift-scale thermal test, and EBS tests at the Atlas facility) to validate conceptual models.	

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<table>
<tr><td colspan="3">Acceptance Criterion 3-Data Uncertainty for Evolution of the Near-Field Environment Subissue 4. Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the abstraction of radionuclide release rates and solubility limits are consistent with site characterization, design data, laboratory experiments, field measurements, and natural analog data. Specifically (see following items):</td></tr>
<tr><th>NRC Staff Analysis</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td colspan="3">3-1. Parameter values, assumed ranges, probability distribution, and bounding assumptions used in the abstractions of radionuclide release rates and solubility limits in the total system performance assessment are technically defensible and reasonable based on data from the Yucca Mountain region, laboratory tests, and natural analogs.</td></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR , Rev. 3 Section 5.4.4.2.1.3)</td><td>CLOSED

Assumptions, constraints, bounds, limits, values of input parameters, and model validation requirements are identified and justified in the appropriate AMRs in accordance with the QARD (DOE 2000a) and AP-3.10Q. Further, any assumed parameters or input values are identified and justified. All available data have been used in the selection of input parameters and formulation of the bases for assumptions.</td><td>No additional work is required.</td></tr>
<tr><td colspan="3">3-2. DOE demonstrates the use of reasonable or conservative ranges of parameters or functional relations to determine effects of coupled THC processes such as secondary mineral formation and localized corrosion products on radionuclide release. These values are consistent with the initial and boundary conditions and the assumptions for the conceptual models and design concepts at the Yucca Mountain site. For example, estimations used in each abstraction are based on the thermal-loading strategy, including effects of ventilation; engineered barriers design, including drift liner, backfill, and drip-shield; and natural system masses and fluxes.</td></tr>
<tr><th>NRC Staff Analysis</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR , Rev. 3 Section 5.4.4.2.1.3)</td><td>CLOSED PENDING.

Effects of coupled THC processes on key features of the repository thermal loading strategy, such as repository layout, EBS design, and operating mode, are included in TSPA abstraction models. No performance credit is taken for radionuclide sorption onto corrosion products (ANL-WIS-PA-</td><td></td></tr>
</table>

	000001 REV00/ICN02). DOE is examining the potential benefits of secondary mineral formation on radionuclide release (ANL-EBS-MD-000019 REV00/ICN01). Performance credit may be taken for this process in the future. Drainage capacity of the host rock appears to be orders of magnitude greater than needed to ensure free drainage from the repository (CRWMS M&O 2000ay, Section 6.6). Effects of ventilation are being considered in ongoing work, prior to license application. **Assumptions, constraints, bounds, limits, values of input parameters and model validation requirements are identified and justified in the appropriate** abstraction AMRs in accordance with the QARD (DOE 2000a) and AP-3.10Q. Further, any assumed parameters or input values are identified and justified.	
3-3. Uncertainty is adequately represented in parameter development for conceptual models, process models, and alternative conceptual models considered in developing the abstraction of radionuclide release rates and solubility limits, either through sensitivity analyses or use of conservative limits.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. In the TSPA-VA, DOE did not consider uncertainty in data due to both temporal and spatial variations in conditions affecting coupled THC effects on radionuclide transport. This is not acceptable for this acceptance criterion. DOE should consider contributions to data uncertainty from both temporal and spatial variability, especially given the recent changes to exclude backfill from the TSPA-SR reference design. For example, most of the analyses presented in preliminary draft of the	CLOSED Uncertainties are identified in supporting AMRs and PMRs, and are acknowledged in the abstraction of process models for TSPA. Bounding parameter values are used in place of uncertain parameters when processes are too complex or there is insufficient data to reasonably quantify parameter uncertainty. The implications of uncertainties are evaluated within each AMR in accordance with AP-3.10Q and in the TSPA-SR documentation (CRWMS M&O 2000am). Uncertainties are	No additional work is required.

EBS PMR seem to be based on the presence of backfill. These new design features and their contributions to uncertainty should be implemented in DOE's abstractions of the effects of coupled THC processes on radionuclide transport. The TSPA-SR methods and assumptions report indicates that spatial and temporal variations in results from the drift-scale heater test are now considered in the process-level modeling studies, which may move towards meeting this acceptance criterion.(ENFE IRSR Rev 3, Section 5.4.4.2.1.3)	adequately represented for TSPA-SR. Both backfill and no-backfill designs are addressed in SR models.	
3-4. The parameters used to describe flow through and out of the engineered barrier system sufficiently bound the effects of backfill, if used, excavation-induced changes, and thermally induced mechanical changes that affect flow.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed (ENFE IRSR , Rev. 3 Section 5.4.4.2.1.3)	CLOSED Water distribution and removal from the EBS (seepage of water and its flow within the drift) are summarized in the EBS PMR (CRWMS M&O 2000aa, Section 5.3.1). For the backfill design, no combination of model parameters led to a prediction of condensation beneath the drip shield. Drainage capacity of the host rock appears to be orders of magnitude greater than needed to ensure free drainage from the repository (CRWMS M&O 2000ay, Section 6.6), based on information obtained from the as-built exploratory tunnels at YM. Both backfilled and no-backfill designs are considered in SR models.	No additional work required

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	The abstraction model for flow through the EBS bounds flow response to thermal effects (CRWMS M&O 2000aa, Section 3.2.1). Thermally induced mechanical changes to EBS structures and their impact on performance are discussed in the EBS FEPs screening analyses (CRWMS M&O 2000af). Thermal expansion induced failure (separation) of the drip shields has been screened out because the anticipated change in length is much less than the overlap between adjacent drip shields. Thermal expansion of other components, such as the waste package and emplacement pallet, will not be a problem because the separation between adjacent waste packages is adequate to accommodate this small amount of expansion. Overall, thermal effects on flow are not expected to have a significant effect on system performance. (Engineered Barrier System Degradation, Flow, and Transport Process Model Report. TDR-EBS-MD-000006 REV 00 ICN 01) (CRWMS M&O 2000aa)	

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Acceptance Criterion 4--Model Uncertainty for Evolution of the Near-Field Environment Subissue 4. Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of radionuclide release rates and solubility limits. In its technical basis, DOE has provided sufficient evidence that alternative conceptual models have been considered, that the models are consistent with available data (e.g., design features, field, laboratory, and natural analog) and current scientific understanding, and that the effect of these alternative conceptual models on the total system performance has been evaluated. Specifically (see following items):

4-1. In considering alternative conceptual models for radionuclide release rates and solubility limits, DOE uses appropriate models, tests, and analyses that are sensitive to the processes modeled for both natural and engineering systems.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. The proposed approach to modeling radionuclide transport through the engineered barrier system is consistent with models used to simulate transport through the natural barrier system. The conceptual model will need to be modified further to reflect the TSPA-SR reference design and refined to demonstrate the effects of changing chemical conditions on transport. As necessary, updated calculations will need to be provided to reflect the removal of backfill from the reference design. (ENFE IRSR Rev 3, Section 5.4.4.2.1.4)	CLOSED The consideration of alternative models for radionuclide transport is described in the UZ PMR (CRWMS M&O 2000ab, Section 3.11.9) and the EBS PMR (CRWMS M&O 2000aa). The source term model includes the effects of changing chemical conditions. Alternatives associated with various components of the waste form degradation and related to radionuclide release rates are described in the waste form degradation PMR (CRWMS M&O 2000an, Sections 3.1.3, 3.2.3, 3.3.3, 3.4.4, 3.5.3, and 3.6.3). Alternative models of dissolved radionuclide components and colloidal components are discussed in the waste form degradation PMR (CRWMS M&O 200an) in sections 3.7.3, and 3.8.4. Both backfilled and no-backfill designs are addressed in SR models. DOE has considered credible alternative models and documented that the choice of models for TSPA-SR is appropriate.	No additional work is required.

4-2. DOE appropriately considers the effects of THC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products on radionuclide release.

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NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. The major limitation recognized by NRC staff is that although conceptually the complexity of coupled THC processes is recognized, many aspects of these processes are greatly simplified or omitted in the TSPA-VA analyses. Effects of the coupled THC processes on radionuclide transport were omitted. Neglect of these processes contributes to model uncertainty without proper support and justification is not acceptable. DOE should use appropriate models, tests, and analyses sensitive to the THC couplings being considered for both natural and engineering systems. Information provided in the TSPA-SR methods and assumptions report and in the preliminary draft Engineered Barrier System Degradation, Flow, and Transport Process Model Report indicate that DOE is attempting to address this acceptance criterion for Site Recommendation, but that many of the THC processes will continue to be uncoupled. (ENFE IRSR Rev. 3, Section 5.4.4.2.1.4)	CLOSED PENDING. DOE's models for TSPA-SR are based on additional data not available at the time of the VA. The Physical & Chemical Environment AMR (CRWMS M&O 2000at) considers changes in porosity of the invert ballast material from evaporating waters. The changes are relatively small, localized to portions of the invert where most evaporation occurs, and could affect intra-particle processes more than inter-particle transport. The consequences of THC coupled processes in the invert are expected to be minor because drainage capacity of the host rock exceeds that needed to ensure free drainage of the EBS by orders of magnitude (CRWMS M&O 2000ay, Section 6.6). The Drift-Scale Coupled Processes (DST and THC Seepage Models) AMR (CRWMS M&O 2000ba) considers changes in porosity of the near-field rock due to dissolution and precipitation for the current design and one percent fracture porosity used in the simulation. The changes were negligible. The EBS PMR (CRWMS M&O 2000aa, Section 5.4) notes that EBS performance is sufficiently well understood to support reasonable predictions of the environmental condition at drip shields and waste packages, and of conditions that will affect radionuclide transport in emplacement drifts. Work being considered will address invert ballast	No additional work is required beyond that already planned

	material transport properties (especially diffusion characteristics) and will include the potential for hydrologic and chemical transport property changes.	

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Acceptance Criterion 5--Model Support for Evolution of the Near-Field Environment Subissue 4. Output from the abstraction of radionuclide release rates and solubility limits is justified through comparison with output from detailed process-level models and empirical observations (e.g., laboratory testing, field measurements, natural analogs). Specifically (see following items),		
5-1. DOE verifies that the outputs of radionuclide release rates and solubility limits abstractions reasonably reproduce or bound the results of corresponding process-level models, empirical observations, or both.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. DOE should conduct additional exercises using experimental, site, and natural analog data to support their models. DOE should use the results from both their laboratory and field heater test program to test their abstracted models for consistency with observations. Models used should produce results reasonably representative of the systems modeled. (ENFE IRSR Rev 3, Section 5.4.4.2.1.5)	CLOSED DOE has conducted exercises using experimental, site, and natural analog data to support models (Waste Form Degradation Process Model Report. TDR-WIS-MD-000001 REV 00 ICN 01) (CRWMS M&O 2000an) In addition, the model validation process includes steps to ensure that model outputs, including outputs of abstraction models, reasonably reproduce or bound results of corresponding process level models and/or observational data as required by AP 3.10 Q. Model validation work for each component of the waste form degradation model is described and documented in the waste form degradation PMR (CRWMS M&O 2000an, Sections 3.1.2, 3.2.2, 3.3.2, 3.4.3, 3.5.2, 3.6.2, 3.7.2, and 3.8.3). No performance credit is taken for transport on the inner or outer surfaces of the waste package.	No additional work is required.
5-2. DOE bases abstracted models for coupled THC effects on radionuclide release on the same assumptions and approximations shown to be appropriate for closely analogous natural or experimental systems.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. There was a general lack of data to support and test	CLOSED. The abstracted model for EBS Radionuclide	No additional work is needed.

critical assumptions in mathematical models used by DOE in TSPA-VA. Additional exercises using experimental, site, and natural analog data are necessary to support DOE abstractions. (ENFE IRSR Rev 3, Section 5.4.4.2.1.5)	Transport (CRWMS M&O 2000aa, Sections 3.1.3 and 5.3.3) is similar to models used to interpret laboratory column tests. This model is based on more data than were available at the time of the VA. Testing and validation of the model are sufficient, and the model results are reasonably representative.	
5-3. DOE adopts well-documented procedures that have been accepted by the scientific community to construct and test the numerical models used to simulate coupled THC effects on radionuclide release.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. **DOE should use well-documented procedures to construct and test the numerical models.** DOE should also use the results from their laboratory experiments, field heater test program, and natural analog program to test the abstracted models for consistency with observations: DOE should conduct exercises using experimental, site, and natural analog data to aid verification of their models. Models used should produce results reasonably representative of the systems modeled. (ENFE IRSR Rev 3, Section 5.4.4.2.1.5)	CLOSED PENDING. **DOE has documented the construction and testing of numerical models. Radionuclide transport** through the invert (CRWMS M&O 2000aa, Section 3.1.3) is based on simple bounding models of a type that is well known in the scientific literature. DOE's models and abstractions for waste form degradation are described and documented in the waste form PMR (CRWMS M&O 2000an, Section 3). DOE's models are based on experimental, site, and natural analog data. Validation work is described and documented (e.g., CRWMS M&O 2000aa, Section 3.1.4). A summary of models and abstractions for TSPA-SR for drift-scale thermal-hydrological-chemical processes is presented in the Near Field PMR (CRWMS M&O 2000ad, Section 3.3), the UZ PMR (CRWMS M&O 2000ab, Section 5.2.3) and for UZ transport in Section 5.2.4.	

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<table>
<tr><th colspan="3">Integrated Subissue on Radionuclide Transport Through the Unsaturated Zone</th></tr>
<tr><td colspan="3">Acceptance Criterion 1-Integration for Evolution of the Near-Field Environment Subissue 4. Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of radionuclide transport in the unsaturated zone and other related abstractions in the total system performance assessment, and the technical bases are provided. The abstraction identifies and describes aspects of radionuclide transport in the unsaturated zone that are important to waste isolation and includes the technical bases for these descriptions. Specifically (see following items):</td></tr>
<tr><td colspan="3">1-1. The DOE description is adequate and the conditions and assumptions in the abstraction of radionuclide transport in the unsaturated zone are readily identified and consistent with the body of data presented in the description.</td></tr>
<tr><th>NRC Staff Analysis</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.(ENFE IRSR Rev 3, Section 5.4.4.2.2.1)</td><td>CLOSED PENDING.

Abstraction of the UZ transport model is described and documented in the UZ PMR (CRWMS M&O 2000ab, Section 3.11.13). Results indicate that the particle tracking method for 1-D transport agrees well with well-established diffusion and sorption analytical solutions (CRWMS M&O 2000ab, Section 3.11.13.4). The abstraction identifies and describes aspects of radionuclide transport in the unsaturated zone that are important to waste isolation and includes the technical bases for these descriptions. However, the PA abstraction used in early SR calculations conservatively underestimated retardation due to matrix diffusion. The PA abstraction is being revised to remove the conservatism.</td><td>No additional work beyond that already planned.</td></tr>
<tr><td colspan="3">1-2. DOE provides adequate technical bases for exclusion of any potentially important couplings and FEPs.</td></tr>
<tr><th>NRC Staff Analysis</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td>OPEN.

[DOE identified] 24 primary FEPs as being related to both the radionuclide transport through the</td><td>CLOSED

The UZ FEPs AMR (CRWMS M&O 2000aj) and the thermal hydrology FEPs AMR (CRWMS M&O</td><td>No additional work is required.</td></tr>
</table>

unsaturated zone integrated subissue and this ENFE subissue. Of these 24, six are excluded by the preliminary DOE screening process. Of the six excluded FEPs, two overlap with the radionuclide release rates and solubility limits integrated subissue and were discussed previously in Section 5.4.4.1.1 [of the IRSR]. Review and evaluation of the technical bases for excluding the remaining four FEPs will focus on the relevant Analysis and Model Reports (ENFE IRSR Rev 3, Section 5.4.4.2.2.1)	2000ai) document the technical bases for consideration of couplings and disposition of the associated FEPs. Models have been developed to address FEPs identified as potentially important to performance. These models are described in the AMRs associated with the UZ PMR (CRWMS M&O 2000aa), the EBS PMR (CRWMS M&O 2000aa) and the NFE PMR (CRWMS M&O 2000ad). The models provide the technical bases for exclusion of FEPs from TSPA or for abstractions of the processes that are the means to include FEPs in TSPA. Work continues to improve the technical bases for FEPs disposition decisions (e.g., drift-scale TH model (MDL-NBS-HS-000001) is being revised to include enhanced technical bases for consideration of TH couplings).	

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Acceptance Criterion 2-Data and Model Justification for Evolution of the Near-Field Environment Subissue 4. Sufficient data on the geology, hydrology, and geochemistry of the unsaturated zone (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of radionuclide transport in the unsaturated zone in the total system performance assessment. The data are also sufficient to assess the degree to which FEPs related to radionuclide transport in the unsaturated zone have been characterized and to determine whether the technical bases provided for exclusion of these FEPS are adequate. Specifically (see following items),		
2-1. DOE demonstrates that sufficient data have been collected on the characteristics of the natural system and engineered system, as it affects the natural system, to establish initial and boundary conditions, and temporal and spatial variations, for the abstraction of radionuclide transport, including the potential effects from coupled THC processes in the unsaturated zone.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. **NRC has several issues regarding alteration of the Calico Hills unit and impacts on radionuclide transport discussed in IRSR 5.4.4.2.2.2. (NRC/CNWRA Comment)** Some cementitious materials such as grouted rock bolts and concrete-lined ventilation shafts and tunnels are likely to be used in constructing the repository. The quantity of materials and effects of these materials on radionuclide transport in the TSPA-SR reference design will need to be addressed by DOE.(ENFE IRSR Rev 3, Section 5.4.4.2.2.2)	CLOSED PENDING. **The WF, EBS, NFE, and UZ PMRs describe the initial and boundary conditions and temporal and spatial variations used in the abstraction of radionuclide transport. Mineral changes in the UZ (NFE) are discussed in the THC AMR (Drift-Scale Coupled Processes (DST and THC Seepage) Models. MDL-NBS-HS-000001 REV 00) (CRWMS M&O 2000ba).** Based on information in the EBS PMR (CRWMS M&O 2000aa), limiting the use of cement to grouting rockbolts will preclude a significant impact of cement leachate on the pH of water within the drift. The treatment of transport in the NFE and overall UZ is further discussed below: As described in the UZ PMR (CRWMS M&O 2000ab, Section 3.11.13.1), the transport model abstraction is a 3-D, dual-permeability, particle-tracking method. Flow fields	No additional work is required beyond that already planned.

	derived using the 3-D site-scale flow model are input directly to the particle-tracking method and are used to compute transport velocities. The method explicitly accounts for transport in both the fracture and matrix continua, with exchange between continua resulting from advective or diffusive processes. The velocity fields from the flow model are also used for advective transport exchange between fracture and matrix continua. The various aspects of the transport processes-advection, diffusion, dispersion, sorption, radionuclide decay, and colloid-facilitated transport—are all explicitly modeled. (Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab) Results of the exercise of the abstraction are discussed in the UZ PMR (CRWMS M&O 2000ab, Section 3.11.14): Two-dimensional simulations show that transport in the CHn is strongly dependent on the distribution of the vitric and zeolitic tuffs at the different locations. Occurrence of the zeolitic CHn leads to fast transport; on the other hand, the vitric CHn acts as an effective barrier to radionuclide transport, and its effectiveness increases with the sorptive tendencies of the radionuclides. (Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab)	

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	Three-dimensional site-scale simulations indicate that radionuclide transport is both dominated and controlled by the faults (especially at early times). Faults provide fast pathways to downward migration to the water table, but also limit lateral transport across them. (Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab) Fractures are also the main pathway of transport. Diffusion from the fractures into the matrix is the main retardation mechanism in radionuclide transport. By sorbing onto the matrix into which they diffuse, the migration of radionuclides is retarded. Three-dimensional site-scale simulations show that radionuclide breakthrough at the water table occurs relatively early after release from a waste package and over a large area in the southern part of the potential repository block. The maximum water flow within the footprint of the potential repository in the southern part in the Perched water model #1 contributes to this transport pattern. Also the low-permeability zones at the TSw-CHn inter-face in the northern part of the potential repository are barriers to water drainage and lead to low water velocities and formation of perched water bodies. The presence of the highly conductive Solitario Canyon fault Splay G and Ghost Dance fault splay also contributes to the dominance of the southern part as the main pathway. (Unsaturated Zone Flow and Transport Model Process Model Report. TDR-	

	NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab) The members of the decay chain (^{239}Pu, ^{131}U, and ^{231}Pa) must be considered in the transport Of 239Pu. ^{235}U will become the main contributor in the release at the water table after 10,000 years (at most) because of its weaker sorption onto the matrix and longer half-life. The contributions of ^{231}Pa are not important. **(Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab)** Colloidal transport is very sensitive to filtration parameters, and for the given parameters, the colloid size has a significant effect on transport. [Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02 (CRWMS M&O 2000ab), Engineered Barrier System Degradation, Flow, and Transport Process Model Report. TDR-EBS-MD-000006 REV 00 ICN 01 (CRWMS M&O 2000aa)] More than 40 tracer transport simulations indicate a wide range of time for mass breakthrough depending on infiltration rates, type of tracers/radionuclides, and perched water conceptual models. The most important of these factors for transport times are (1) surface infiltration rates and (2) adsorption effects in the CHn. Compared with the effects of infiltration and adsorption, perched water conceptual models	

	are of secondary importance to the overall impact on transport, but have primary impact on determining breakthrough areas of tracers/radionuclides at the water table. (Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab) The modeling results of tracer (^{36}Cl) transport from the land surface to the repository level indicate the existence of possible fast flow pathways with transport times of 50 years. However, the **cumulative mass breakthrough carried by the fast flow is relative small (about 1%) for the early times of 50 to 100 years. The 50% mass breakthrough** times to the repository level since release from the surface is estimated between 5,000 to 20,000 years under the present-day, mean infiltration scenario. The fast flow breakthrough at the earlier time occurs mainly along faults. (Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab) Available tracer transport results of the ESF Alcove I and Busted Butte tests are analyzed for model validation as a confidence-building process. The Alcove I analyses indicate that the continuum approach is valid for modeling flow and transport in unsaturated fractured rock, an active fracture model can capture the major features of fingering flow and transport in fractures, and matrix diffusion has a significant effect on the overall transport behavior. Busted Butte tracer tests and simulations of the vitric	

	CHn show that the unit behaves as a porous medium, which is consistent with the expected behavior. (Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab) Known analog sites for UZ transport are reviewed as additional corroborative analyses with respect to radionuclide transport at Yucca Mountain. Analyses of the Nopal I uranium deposit in Mexico and the trace metal migration study in Greece indicate that unsaturated systems in and environments may provide favorable sites for geologic disposal of radioactive waste. (Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab) An efficient particle-tracking model abstraction for 3-D site-scale simulations of radionuclide transport in the UZ has been developed for TSPA analysis. This model abstraction utilizes simplified mathematical representations of advection, dispersion, sorption, matrix diffusion, colloid transport, and radionuclide chain decay in a dual-permeability system. Comparisons show that the TSPA particle tracker will yield conservative transport calculations. (Unsaturated Zone Flow and Transport Model Process Model Report. TDR-NBS-HS-000002 REV 00 ICN 02)(CRWMS M&O 2000ab)	
DOE should also provide the qualified version of TOUGHREACT code. (NRC/CNWRA Comment)	A qualified version TOUGHREACT Code will be available to the NRC.	

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DOE should provide consistent explanations that THC processes from the repository will not adversely affect the properties of the natural system using the 70 degree C values obtained by LANL. (NRC/CNWRA Comment)	This comment is addressed in presentations at the ENFE KTI Technical Exchange, January, 2001 (E. Sonnenthal).	
2-2. The data on the geology, hydrology, microbial ecology, and geochemistry of the unsaturated zone, including the influence of structural features and stratigraphy, used in the abstraction are based on techniques that may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.4.2.2.2)	CLOSED The methods used to develop data on the geology, hydrology, microbial ecology, and geochemistry of the unsaturated zone, including the influence of structural features and stratigraphy, used in the abstraction are based on techniques that include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. These techniques are described in the following references: 1. In-Drift Microbial Communities. ANL-EBS-MD-000038 REV 00. (CRWMS M&O 2000ak). 2. UZ Flows Models and Submodels. MDL-NBS-HS-000006 REV 00. (CRWMS M&O 2000bu). 3. Unsaturated Zone Flow and Transport Model Process Model Report, TDR-NBS-HS-000002, REV 00 ICN 02. (CRWMS-M&O 2000ab). 4. Geologic Framework Model (GFM3.1). MDL-NBS-GS-000002. REV 00 ICN 01. (CRWMS	No additional work is required.

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	M&O 2000bv). 5. Development of Numerical Grids for UZ Flow and Transport Modeling. ANL-NBS-HS-000015 REV 00. (CRWMS M&Obw). These models will be refined prior to license application as additional waste form and site data become available.	
2-3. Sensitivity or uncertainty analyses used to support DOE's abstraction are adequate to determine the possible need for additional data. If additional data are needed, DOE has identified specific plans to acquire necessary information.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.4.2.2.2)	CLOSED PENDING. Sensitivity and uncertainty analyses relevant to the unsaturated zone are documented in the UZ PMR (e.g. CRWMS M&O 2000ab, Section 3.13). Cementitious materials are addressed in the EBS PMR (CRWMS M&O 2000aa, e.g., Section 5.3.2.7). The sensitivity analyses are sufficient to identify those features and processes that are significant to repository performance. However, work is planned to examine the mountain-scale THC model and the effects of the alkaline plume from concrete in the perimeter drift.	No additional work required beyond that already planned.

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Acceptance Criterion 3-Data Uncertainty for Evolution of the Near-Field Environment Subissue 4. Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the abstraction of radionuclide transport in the unsaturated zone are consistent with site characterization data, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the abstraction are provided. Specifically (see following items):

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
3-1. For those radionuclides whose transport in the unsaturated zone is important to performance, DOE has adequately assessed the effects of coupled THC processes on the fraction of flow traveling through both fractures and matrix in the unsaturated zone, and the flow velocities through both fractures and matrix in the unsaturated zone.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.4.2.2.3)	CLOSED PENDING. Mountain-scale THC coupled processes have been analyzed. The results of the near field THC modeling suggest that any feedback of THC processes to flow or transport at the mountain-scale THC model would be small. Sensitivity studies that include local variations and THC effects are ongoing.	No additional work is required beyond that already planned.
3-2. If the DOE safety case relies on matrix diffusion in the unsaturated zone, rock fracture matrix and solute diffusion parameters include both temporal and spatial variations associated with coupled THC processes that may affect performance.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.4.2.2.3)	CLOSED Issues regarding matrix diffusion and the fracture-matrix boundary are discussed under Subissue 1, Acceptance Criterion 4, Item 4-1.	No additional work is required.
3-3. Uncertainty is adequately represented, including both temporal and spatial variations in parameter development for conceptual models, process-level models, and ACMs considered in developing the abstraction of radionuclide transport including the potential effects from coupled THC processes in the unsaturated zone, either through sensitivity analyses or conservative limits.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN.	CLOSED	

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DOE should consider contributions to data uncertainty from both temporal and spatial variability. (ENFE IRSR Rev 3, Section 5.4.4.2.2.3)	Uncertainties in parameters related to radionuclide transport are described and documented in the UZ PMR (CRWMS M&O 2000ab, Section 3.11.10 and 3.13). Uncertainties in THC coupled processes abstractions are addressed in the UZ PMR (CRWMS M&O 2000ab, Section 5.2.5). Representations of uncertainty are sufficient to describe spatial and temporal variations in parameters for conceptual models, process-level models considered in developing abstractions of radionuclide transport. Temporal variations have been shown to be small.	

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<table>
<tr><td colspan="3">Acceptance Criterion (AC) 4-Model Uncertainty for Evolution of the Near-Field Environment Subissue 4. Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of radionuclide transport in the unsaturated zone. DOE has provided sufficient evidence that alternative conceptual models have been considered, that the models are consistent with available data (e.g., field, laboratory, and natural analog) and current scientific understanding, and that the effect of these alternative conceptual models on the total system performance has been evaluated. Specifically,</td></tr>
<tr><td colspan="3">4-1. DOE investigates alternative modeling approaches that are consistent with available data and current scientific knowledge, and appropriately considers their results and limitations in developing the abstraction of radionuclide transport, including the potential effects from coupled THC processes in the unsaturated zone.</td></tr>
<tr><th>NRC Staff Analysis</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td>OPEN.

Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.4.2.2.4)</td><td>CLOSED PENDING.

DOE has considered alternative modeling approaches as required by this criterion. Alternative models considered in the description of UZ transport are documented in the UZ PMR (CRWMS M&O 2000ab, Sec. 3.11.9). The approach for developing the UZ transport model is described in the UZ PMR (CRWMS M&O 2000ab, Sec. 3.11.1.2). The physical processes are identified and described in section 3.11.2 (and subsections). Transport properties are identified and described in Sec. 3.11.3, and the geological layers below the repository are described in Sec. 3.11.4. DOE's approach to identification of viable alternatives and selection of appropriate process models for radionuclide transport abstraction is explained in the UZ PMR (CRWMS M&O 2000ab, Sec. 5.2).</td><td></td></tr>
<tr><td colspan="3">4-2. In considering alternative conceptual models for radionuclide transport in the unsaturated zone, DOE uses appropriate models, tests, and analyses that are sensitive to the processes, including coupled THC processes, modeled. For example, for radionuclide transport through fractures, DOE adequately considers alternative modeling approaches to develop its understanding of fracture distributions and ranges of fracture properties in the unsaturated zone so that the limitations of understanding of fracture distributions and properties are appropriately abstracted and propagated through the process-level and performance assessment models.</td></tr>
</table>

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NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.4.2.2.4)	CLOSED PENDING. DOE has considered alternative conceptual models as required by this criterion. Alternative models considered in the description of UZ transport are documented in the UZ PMR (CRWMS M&O 2000ab, Section 3.11.9). As discussed in Section 3.11.91 of the UZ PMR (CRWMS M&O 2000ab), the main mechanism of radionuclide retardation in the UZ is diffusion from fractures into the matrix. An alternative conceptual model that does not allow diffusion (but still allows advection) into the matrix was investigated. Results indicate that for the no-diffusion alternative model using present-day infiltration, non-sorbing ^{99}Tc and moderately sorbing ^{237}Np move unhindered in the fractures. Limited sorption on fracture walls is, however, sufficiently important to retard transport of strongly sorbing ^{239}Pu in fractures. For simulations of colloid transport, results discussed in the UZ PMR (CRWMS M&O 200ab, Section 3.11.9.2) indicate that diffusion is less significant in colloid transport than in solute transport because (a) colloid diffusion is smaller than solute molecular diffusion because of the larger colloid size, and (b) size-exclusion effects at the interfaces of different geologic units further limit entry through diffusion into the matrix, and the effect becomes more important as colloid size decreases.	

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	As discussed above, DOE has examined viable alternative models of processes that could affect radionuclide transport in the UZ. The consideration is adequate for TSPA-SR, and no additional analyses are needed for TSPA-SR.	

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Acceptance Criterion 5--Model Support for Evolution of the Near-Field Environment Subissue 4. Output from the abstraction of radionuclide transport in the unsaturated zone is justified through comparison with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, natural analogs). Specifically (see following items),		
5-1. DOE-verifies that the outputs of radionuclide transport, including the potential effects from coupled THC processes, in the unsaturated zone abstractions reasonably produce or bound the results of corresponding process-level models, empirical observations, or both.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.4.2.2.5) **DOE should provide data supporting its current conceptual approach for colloid transport in the unsaturated zone to support detailed process models. These models should consider not only J-13 water, but also evolved water and gas phases that are the output of coupled THC calculations. The DOE needs to provide a stronger technical basis for the exclusion of geochemical, radiolytic, and coupled THC effects other than pH and ionic strength. The DOE should provide a technical basis for limiting in-drift water chemistry (for purposes of colloid modeling) to either waste package water or a mixture of waste package water and J-13. (NRC/CNWRA Comment)**	CLOSED PENDING. DOE has compared the particle tracking models using PA with process models for radioactive transport. This comparison shows that the process model is bounded by the abstraction model. See Analysis of Base-Case Particle Tracking Results of the Base-Case Flow Fields. ANL-NBS-HS-000024 REV 00. (CRWMS-M&O 2000bx) NRC comments regarding colloidal transport in the unsaturated zone are addressed in the presentation "NRC Comments on Colloidal Transport in the Unsaturated Zone" (J. Houseworth) at the ENFE KTI Technical Exchange, January, 2001.	No additional work is required beyond that already planned.
5-2. DOE bases abstracted models for radionuclide transport in the unsaturated zone on the same assumptions and approximations shown to be appropriate for closely analogous natural, including natural alteration observed at the site, or experimental systems.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed.	CLOSED PENDING. Abstraction of the UZ transport model is documented in the UZ PMR (CRWMS M&O	No additional work is required beyond that already planned.

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(ENFE IRSR Rev 3, Section 5.4.4.2.2.5)	2000ab) Section 3.11.13 and Section 5.2. Assumptions and approximations used in the abstraction model for radionuclide transport are shown to give conservative results compared to the process models. The process models have been compared with experimental data from the site. The results to date match field observations. Additional field tests are ongoing.	
5-3. DOE adopts well-documented procedures that have been accepted by the scientific community to construct and test the mathematical and numerical models used to simulate radionuclide transport through the unsaturated zone.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. To the extent that models are generally regarded as preliminary, model verification for the effects of coupled THC processes on the transport of radionuclides is premature. As part of the continuing DOE effort to support their abstracted model of the effects of coupled THC effects on radionuclide transport in the unsaturated zone, DOE should use well-documented procedures to construct and test the numerical models. (ENFE IRSR Rev 3, Section 5.4.4.2.2.5)	CLOSED Models and analyses are developed in accordance with procedure AP 3.10 Q. Software development is in accordance with AP SI1 Q. All phases of construction and testing of models are extensively documented in the UZ PMR (CRWMS M&O 2000ab) in Sections 3.7, 3.8, 3.9, 3.10, 3.11 and 3.12 and associated subsections. The scientific bases for construction and testing of the numerical TH model are discussed in the UZ PMR (CRWMS M&O 2000ab, Section 3.12.4) as part of the discussion of model validation. The TH model is considered valid for the intended use because of the good agreement with the heater test models, the validity of the geothermal analog models, and the documented theoretical and physical validity of similar unsaturated flow studies with and without heat (CRWMS M&O 2000ab, Section 3.12.4).	No further work is required.

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5-4. DOE provides sensitivity analyses or bounding analyses to support the abstraction of radionuclide transport in the unsaturated zone that cover ranges consistent with site data, field or laboratory experiments and tests, and natural analog research.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
OPEN. Further review of DOE's Analysis and Model Reports and Process Model Reports is needed. (ENFE IRSR Rev 3, Section 5.4.4.2.2.5)	CLOSED PENDING. DOE believes that the radionuclide transport analyses are consistent with site and analog data. For a discussion of this issue, see Acceptance Criterion 2, Item 2-1.	

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