U.S. Department of Energy
Office of Civilian Radioactive Waste Management

Subissue 3, Thermal-Mechanical Effects on Underground Facility Design and Performance - Component 3, Thermal Effects on Flow into Emplacement Drifts

Presented to:
DOE-NRC Technical Exchange on the Key Technical Issue and Subissues Related to Repository Design and Thermal-Mechanical Effects

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YUCCA MOUNTAIN PROJECT

Outline

- **Presentation Objectives**
- **Current Subissue Status**
- **For Subissue 3, Component 3 identified in the Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3, this presentation will:**
  - Identify applicable acceptance criterion
  - Identify action or information needs
  - Summarize technical basis for resolution of criterion and information needs
  - Identify basis documents (References)
  - Summarize technical adequacy of basis
- **Conclusions**

Presentation Objectives

- **Describe the basis for resolving Component 3 of Subissue 3, Repository Design and Thermal-Mechanical Effects Issue Resolution Status Report, Rev. 3**
- **Component 3 - Thermal-Mechanical Effects on Flow into Emplacement Drifts**
  - *Degradation of Engineered Barriers*
    - Acceptance Criterion 1 - *Evaluation and Abstraction of Design Features and Processes*: DOE has evaluated the significant design features and processes for abstraction into performance assessment analyses. DOE considers this criterion Closed-Pending resolution of the need for additional rockfall verification
  - *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms*
    - Acceptance Criterion 1 - *Evaluation and Abstraction of Design Features and Processes* : DOE has evaluated the significant design features and processes for abstraction into performance assessment analyses. DOE considers this criterion Closed-Pending completion of ongoing work in progress

Presentation Objectives
(Continued)

– *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- Acceptance Criterion 2 - *Sufficiency of Data*: DOE considers that sufficient data have been obtained and evaluated for abstraction into performance assessment analysis. DOE considers this criterion Closed-Pending documentation of thermal-hydrologic-mechanical effects in future process model report revisions
- Acceptance Criterion 3 - *Data Uncertainty*: DOE considers the approach to coupled processes that is used for the Total System Performance Assessment to be valid and sufficient. DOE considers this criterion Closed-Pending accomplishment of the agreements from the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001
- Acceptance Criterion 4 - *Alternative Conceptual Models*: DOE has considered a range of credible alternative models and documented that the choice of models for the current Total System Performance Assessment is appropriate. DOE considers this criterion Closed-Pending accomplishment of the agreements from the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001

Presentation Objectives
(Continued)

– *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- Acceptance Criterion 5 - *Model Abstractions*: DOE considers the approach used for the current Total System Performance Assessment to be valid and sufficient. DOE considers this criterion Closed-Pending accomplishment of the agreements from the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001

Presentation Objectives
(Continued)

– *Spatial and Temporal Distribution of Flow*

- Acceptance Criterion 1 - *Evaluation and Abstraction of Design Features and Processes*: DOE has evaluated the significant design features and processes for abstraction into performance assessment analyses. DOE considers this criterion Closed-Pending accomplishment of the agreements from the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001
- Acceptance Criterion 3 - *Data Uncertainty*: DOE considers the approach used for the current Total System Performance Assessment to be valid and sufficient. DOE considers this criterion Closed-Pending accomplishment of the agreements from the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001

Current Subissue Status

- **Repository Design and Thermal- Mechanical Effects Issue Resolution Status Report, Rev. 3 indicates that Component 3 of Subissue 3 is Open**

Acceptance Criterion 1: *Degradation* of *Engineered Barriers*

- 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 Total System Performance Assessment abstraction in the DOE license application 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

Acceptance Criterion 1
(Continued)

- **Action or Information Needs**
  - Adequacy of Treatment of Seismic and Thermal Loading in Drift Degradation Analysis
  - Assumption of Thermal Load Initial Conditions for Thermal-Hydrological Effects on the Engineered Barrier Environment
- **Basis for closure**
  - DOE has considered the effects of thermal-mechanical processes and thermal-hydrologic processes on the engineered barrier environment
    - Thermal-mechanical processes on the engineered barrier environment
      - Assessment of drift geometry is a component of the rockfall analyses, which includes seismic, thermal, and time-dependent processes
      - The rockfall analyses explicitly account for variability in the joint geometry data as determined from tunnel mapping in the Exploratory Studies Facility
    - DOE has considered thermal-mechanical effects on fracture permeability
    - Thermal-hydrological models and effects were discussed at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001

Acceptance Criterion 1
(Continued)

- **Basis for closure** (Continued)
  - DOE has bounded the range of thermally driven flux
    - A conservative model abstraction of drift seepage has been developed *(Abstraction of Drift Seepage Model Analysis and Model Report)*
    - Mountain-scale thermal-hydrologic model is used to evaluate the effects of heat on two-dimensional and three-dimensional flow fields
    - In the Total System Performance Assessment, thermal perturbations to seepage are accounted for by using percolation flux from the multi-scale thermal hydrology model as input to the seepage abstraction model
  - DOE is considering the possibility of water reflux during cool-down
    - Current thermal-hydrologic models that support performance assessment are capable of modeling water reflux during cooldown
    - Spatial heterogeneity of fracture characteristics has been identified as a potentially important factor for seepage during the thermal period (as well as for post-thermal ambient seepage)
    - DOE is considering additional modeling to evaluate spatial heterogeneity effects, which will include major faults/permeable features

Acceptance Criterion 1
(Continued)

- **Basis for closure** (Continued)
  - DOE has considered the effects of thermal-mechanical processes on ground movement, including rockfall, rock deformation, and alterations to porosity and existing fractures. DOE has also considered changes to the drift geometry that may affect the engineered barrier chemical environment
    - The change in drift geometry on emplacement drift seepage is included in the Abstraction of Drift Seepage Model. The In-Drift Chemistry Model for Total System Performance Assessment uses seepage as an input
    - The effect of floor heave on engineered barrier system performance has been screened out
      - » Floor heave estimates are based on thermal-mechanical closure analysis separate from the rockfall analysis (ANL-WIS-PA-000001 Rev. 00 ICN 02)
      - » Calculations have demonstrated that the vertical displacement of the floor due to in situ stress and thermal response will be on the order of 10 mm and will have minor effect on drip shields and waste packages
    - The effect of rockfall on thermal hydrology and chemical environment is negligible

Acceptance Criterion 1
(Continued)

- **References**
  - *Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux*, ANL-EBS-HS-000003, Rev 00 ICN 1
  - *Abstraction of Drift Seepage Model,* ANL-NBS-MD-000005 Rev 00
  - *Multi-scale Thermohydrologic Model*, ANL-EBS-MD-000049 Rev 00 ICN 1
  - *Drift Degradation Analysis,* ANL-EBS-MD-000027 Rev 01
  - *Drift Scale Couple Processes (DST and THC Seepage) Models*, MDL-NBS-HS-000001, Rev 00
  - *Thermal Tests Thermal-Hydrological Analysis/Model Report*, ANL-NBS-TH-000001, Rev 00 ICN 1

Acceptance Criterion 1
(Continued)

- DOE has evaluated the significant design features and processes for abstraction into performance assessment analyses
- The drift degradation analysis presents an adequate technical basis and approach for analyzing time-dependent, thermal, and seismic effects on rockfall in support of Site Recommendation. Confirmatory rockfall verification analyses are being considered to increase confidence
- DOE considers this acceptance criterion Closed-Pending resolution of the need for additional rockfall verification

Adequacy of Treatment of Seismic and Thermal Loading in Drift Degradation Analysis

- **Basis for Resolution**
  - The technical basis for drift degradation and changes in emplacement drift geometry is provided in the *Drift Degradation Analysis* and was discussed in the presentation for Subissue 3, Component 2

Thermal Load Initial Conditions for Thermal-Hydrological Effects on the Engineered Barrier Environment

- **Basis for Resolution**
  - Current thermal-hydrologic models used directly for Total System Performance Assessment explicitly account for heat removal by forced ventilation in the preclosure period
- **References**
  - *Multiscale Thermohydrologic Model*, ANL-EBS-MD-000049 Rev 00 ICN 1
- **The initial conditions used in the analysis are appropriate for postclosure considerations. No additional work is required**

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms*

- 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

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Action or Information Need**
  - Evaluation of changes in drift geometry on water chemistry and quantity
  - Technical basis for parameters used to assess thermal-mechanical effects on hydrological properties
  - Technical basis for temperature distributions used in ventilation design
- **Basis for closure**
  - DOE has evaluated the potential for focusing of water flow into drifts caused by coupled processes
    - The thermal-hydrologic-chemical seepage model shows limited changes in hydrological parameters due to thermal-hydrologic-chemical processes, and therefore insignificant effects on seepage and flow focusing
    - Thermal-hydrologic-mechanical models suggest changes in permeability may increase or decrease by one or two orders of magnitude
    - The coupling among thermal-hydrologic-mechanical-chemical processes is of secondary importance as indicated by laboratory testing by others and thermal testing at Yucca Mountain

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Basis for closure (Continued)**
  - DOE abstractions appropriately account for the various design features, site characteristics, and alternative conceptual approaches
    - Thermal-mechanical effects are screened out of the Total System Performance Assessment with the exception of the effect of changing drift geometry on drift seepage (to be verified)
    - The Multiscale Thermohydrologic Model captures the repository-scale variability, details of the emplacement drifts and engineered components, and variability of heat output from the waste package inventory
    - The Drift-Scale Coupled Processes (DST and THC Seepage) Model provides the temporal variations in chemical composition of the seepage and gas phase entering the drift during the postclosure period
    - Thermal-hydrologic conditions and incoming gas and seepage compositions are abstracted (Abstraction of Drift Seepage) from the Multiscale and Drift-Scale models and used as input in the In-Drift Chemistry Model Abstraction

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Basis for closure** (Continued)
  - DOE has developed the bases and justification for modeling assumptions and approximations where simplifications for modeling coupled effects on seepage and flow and the waste package chemical environment are used for performance assessment
    - Thermal-hydrological-mechanical coupling is screened out of the Total System Performance Assessment (*Unsaturated Zone and Near-Field Environment Features, Events, and Processes Analysis and Model Reports*, to be verified)
    - The bases and justification for modeling coupled thermal-hydrological-chemical processes in the Total System Performance Assessment were presented at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Basis for closure** **(Continued)**
  - DOE has elicited expert opinions on coupled process effects on the repository host rock
    - The objective of the elicitation was to evaluate the temporal and spatial distribution of thermal, hydrologic, mechanical, and chemical effects associated with heating of the host rock
    - The Near-Field/Altered Zone Coupled Effects Expert Elicitation Project (1997/1998) was conducted in a manner consistent with NRC guidance on expert elicitation:
      - » NUREG-1563, Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program
      - » NUREG/CR-6372 and LLNL UCRL-ID-122160, Senior Seismic Hazard Analysis Committee (SSHAC), 1995, Recommendations for Probabilistic Seismic Hazard Analysis-Guidance on Uncertainty and Use of Experts
      - » Principles and Guidelines for Formal Use of Expert Judgment by the Yucca Mountain Site Characterization Project, DOE

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Basis for closure (Continued)**
  - Expert opinions on coupled process effects on the repository host rock are summarized as follows:
    - Thermal-hydrologic-mechanical and thermal-hydrologic-chemical effects will be expressed in the host rock
    - Thermal-hydrologic-chemical effects on permeabilities will mainly affect fracture-matrix coupling and not fracture permeability
    - Thermal-hydrologic-mechanical effects on fracture permeabilities will vary for
      - Horizontal and vertical fractures
      - Proximity to drift openings
      - Location in the repository layout

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Basis for closure (Continued)**
  - Vertical fracture permeability near the drifts will be reduced by 1 to 3 orders of magnitude
    - Fractures with the smallest initial apertures will experience the greatest relative changes but the smallest absolute closures
    - Effect may be expressed as far as 2 to 5 diameters away from drift openings (relative to the Viability Assessment design)
  - Horizontal permeability was estimated to increase, ranging from 2x to 100x from the center of the repository layout outward
  - Although thermal-hydrologic-mechanical permeability changes will be important at a local scale, changes in bulk rock permeabilities are expected to be comparable to or less than the ambient spatial variability

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Basis for closure** (Continued)
  - DOE considers important design features, including waste package design and material selection, drip shield, ground support, cladding, thermal loading strategy, and degradation processes, to determine initial and boundary conditions for calculations of the quantity and chemistry of water contacting waste packages and waste forms
    - Existing models that support the Total System Performance Assessment directly, and through the features, events, and processes screening include important design features
      - » Waste package, drip shield, invert, and thermal loading strategy are considered in thermal-hydrologic modeling (Multiscale Model)
      - » Chemical effects from ground support and other introduced materials are considered in the Engineered Barrier System Physical and Chemical Environment Model
      - » Cladding performance and effects from materials used within the waste packages are considered in the Waste Form Degradation Model
    - The approaches used for these calculations were described in further detail at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **References**
  - *Abstraction of Drift-Scale Coupled Processes,* ANL-NBS-HS-000029 Rev 00
  - *Drift-Scale Coupled Processes (DST and THC Seepage) Models,* MDL-NBS-HS-000001 Rev 00
  - *Abstraction of Drift Seepage,* ANL-NBS-MD-000005 Rev 00
  - *UZ Flow and Transport FEPs*, ANL-NBS-MD-000001 Rev 00 ICN 01
  - *Near-Field Environment FEPs*, ANL-NBS-MD-000004 Rev 00 ICN 01
  - *Multiscale Thermohydrologic Model,* ANL-EBS-MD-000049 Rev 00 ICN 1
  - *Near-Field/Altered Zone Coupled Effects Expert Elicitation Project,* ACC: MOL.19980729.0638

Acceptance Criterion 1: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **DOE has evaluated the significant design features and processes for abstraction into performance assessment analyses. DOE considers this criterion Closed-Pending completion of ongoing work in progress as described in following slides**

Evaluation of Changes in Drift Geometry on Water Chemistry and Quantity

- **Basis for Resolution**
  - The Drift Degradation analysis and model report addresses changes in drift geometry resulting from rockfall
  - The effects of drift degradation on seepage are included in the Drift Seepage Model and therefore in the Total System Performance Assessment
    - The Drift Seepage Model uses input from the Drift Degradation Analysis
    - Other thermal-mechanical effects are screened out
  - Additional analyses are under consideration to extend the validation of the rockfall model presented in the *Drift Degradation Analysis* and model report using an approach that can explicitly apply thermal and seismic loads
    - Refer to presentations in for Subissue 3, Component 2
- **References**
  - *Abstraction of Drift Seepage AMR*, ANL-NBS-MD-000005 Rev 00
  - *Drift Degradation Analysis*, ANL-EBS-MD-000027 Rev 01

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties

- **Basis for Resolution**
  - Thermal-mechanical effects on hydrological properties are screened out of the abstraction (to be verified)
  - Preliminary estimates shows that the permanent thermal-mechanical effects on the fracture system increase the permeability approximately an order of magnitude in the regions above and below the drift and a factor of three higher in the regions to the side of the drift
  - The Coupled Thermal-Hydrologic-Mechanical Effects on Permeability Analysis and Models Report that is now underway will revisit the estimate in fracture permeability over time resulting from thermal mechanical effects, and will include normal and shear deformation of discrete fractures
    - This is a three-dimensional study, which incorporates fracture sets used in the Drift Degradation Analysis
    - Additional analyses are under consideration to extend the validation of the Drift Scale Thermal-Hydrologic-Mechanical Model that is presented in this analysis and model report

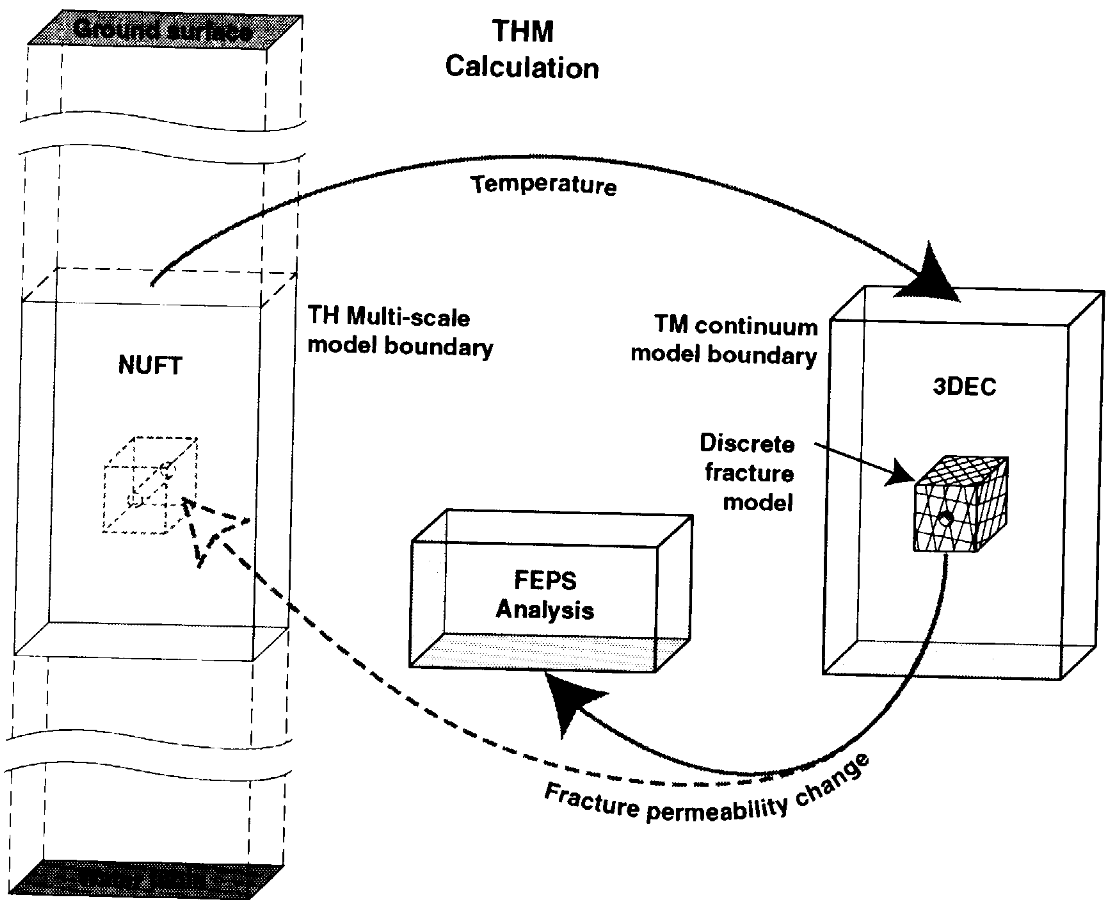
Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

- **Basis for Resolution (Continued)**
  - Modeling Approach: Distinct Element Analysis (DEM)
    - Incorporates discrete fractures
    - Provides stress redistribution due local shearing along fractures
    - Shear effects on permeability are incorporated via fracture dilation with slip
    - "Cubic" Law is used to relate fracture deformation to permeability change
    - Temperatures provided by Thermal-Hydrological Model (NUFT)

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

- **Basis for Resolution (Continued)**
  - Analysis of emplacement drift cross-section (two-dimensional)
    - Conduct analysis in three dimensions then project onto two-dimensional cross sections for performance assessment (at 3 locations along drift)
    - Shear incorporated via fracture dilation with slip
  - Validation:
    - Compare measured and simulated deformations for the Drift Scale Test

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

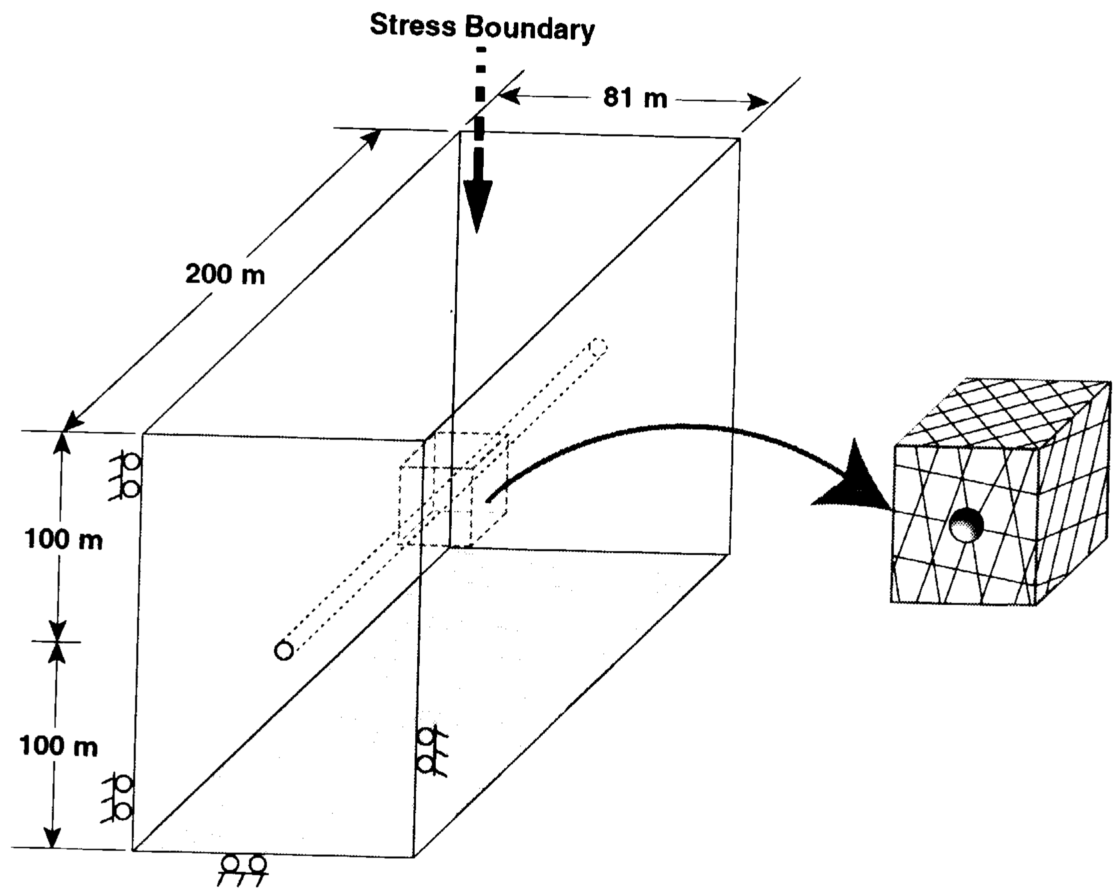


Reference: Work in progress

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

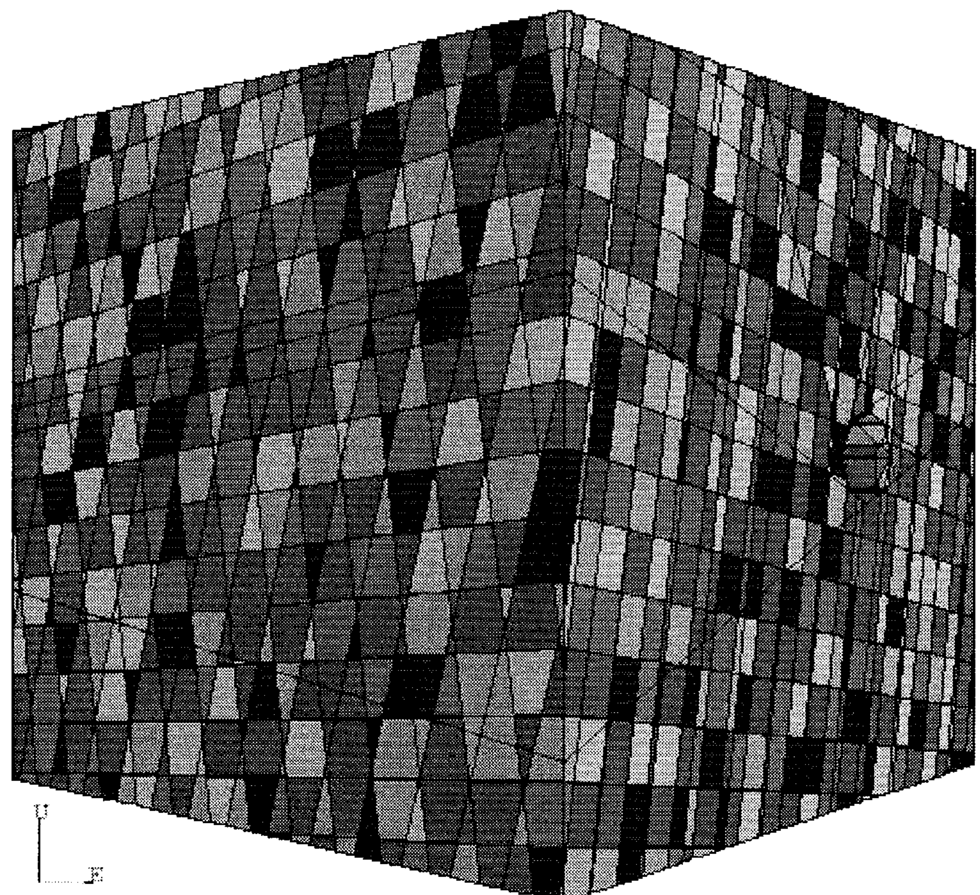
Boundary Conditions for Simulation

- Roller boundaries at mid-pillar



Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

Simulated block showing fractures and emplacement drift



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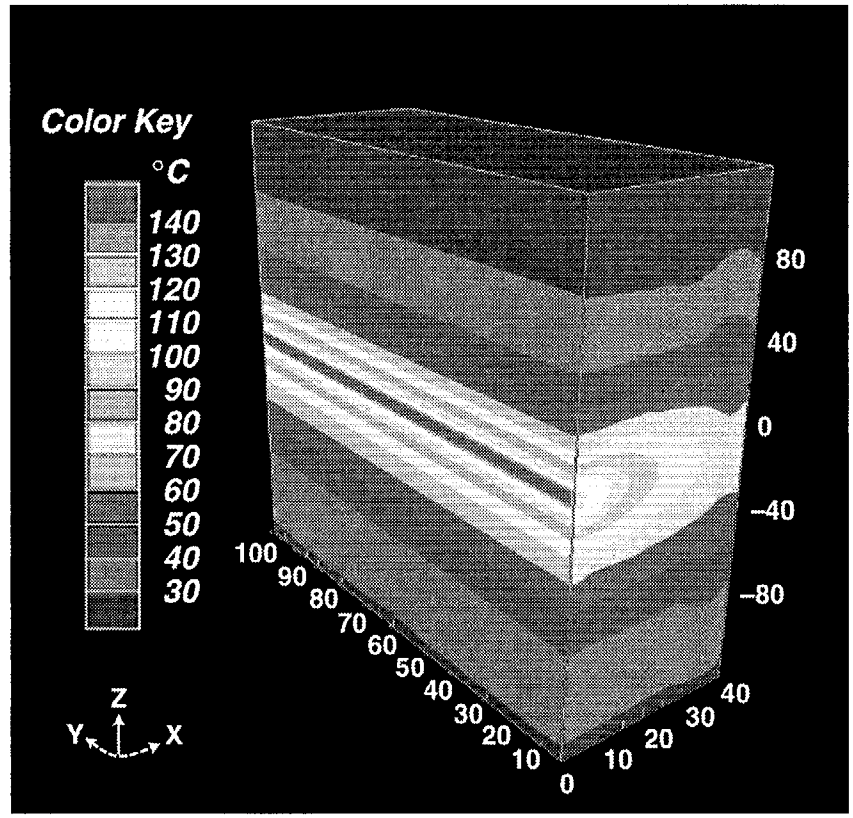
Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

Line Source Drift Scale Thermal Hydrology model temperatures



Temperature field at 100 years

Column L4C4, 56 MTU/acre

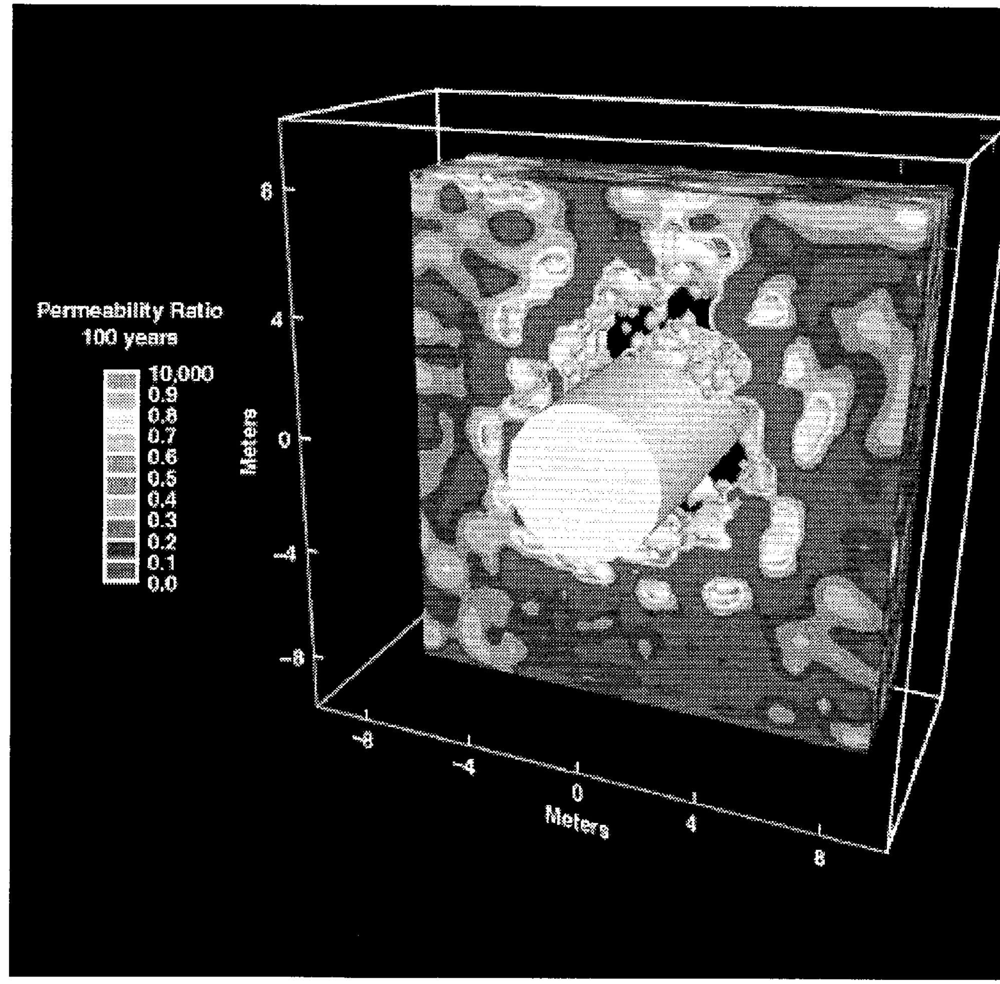
Reference: work in progress

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

Preliminary estimate of permeability change at 100 years

Brown = increased permeability

Purple
↓ = decreased permeability
Yellow



Reference: work in progress

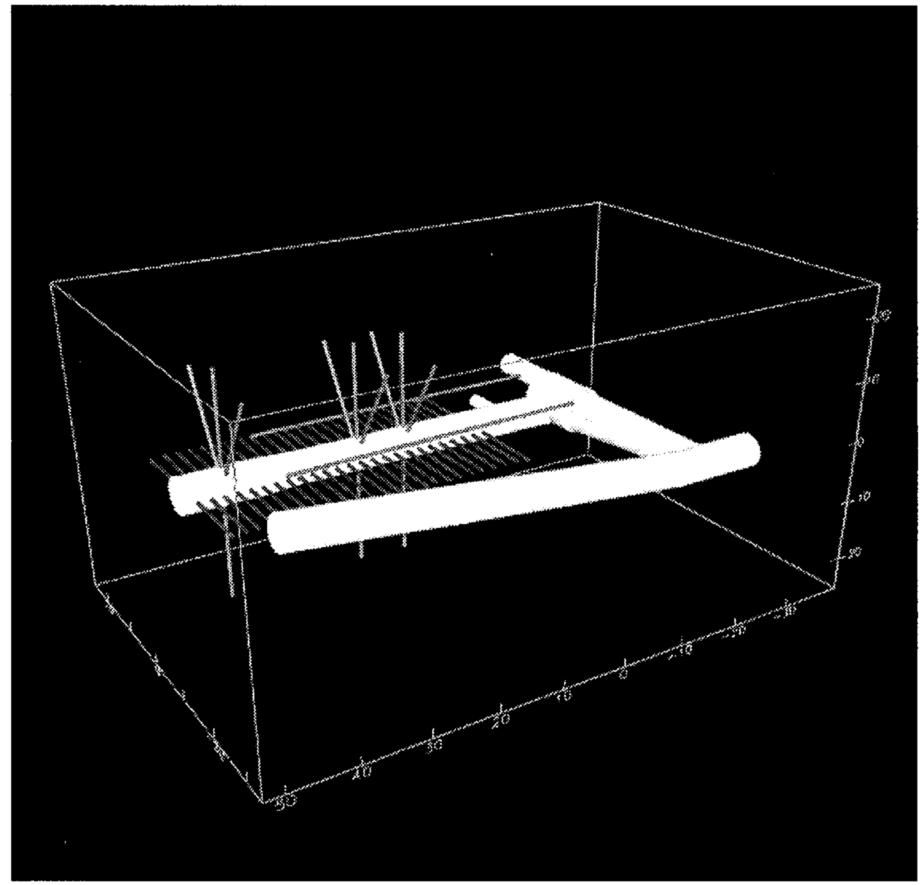
Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

- **Basis for Resolution (Continued)**
  - Ongoing model validation
    - Preliminary validation via simulation of the Drift-Scale Test
    - Incorporates fractures observed in the field
    - Includes simulation of multi-point borehole extensometer data for mine-by and heating phases

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

Model validation via comparison of measured and predicted deformation in Drift-Scale Test

Figure shows Multi-Point Borehole Extensometer (MPBX) measurement holes

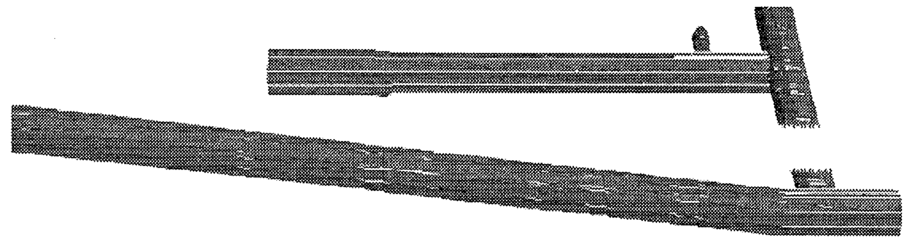


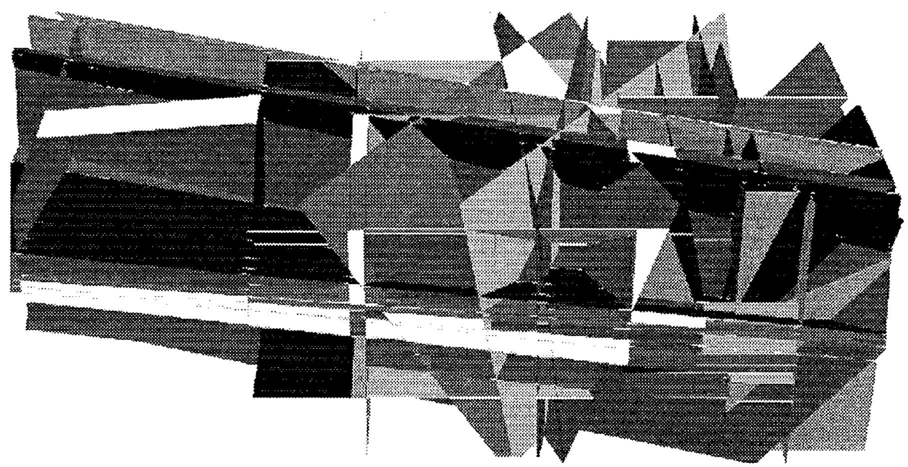
Reference: work in progress

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

Model Validation

Drift-Scale Test Model Excavations and Fractures

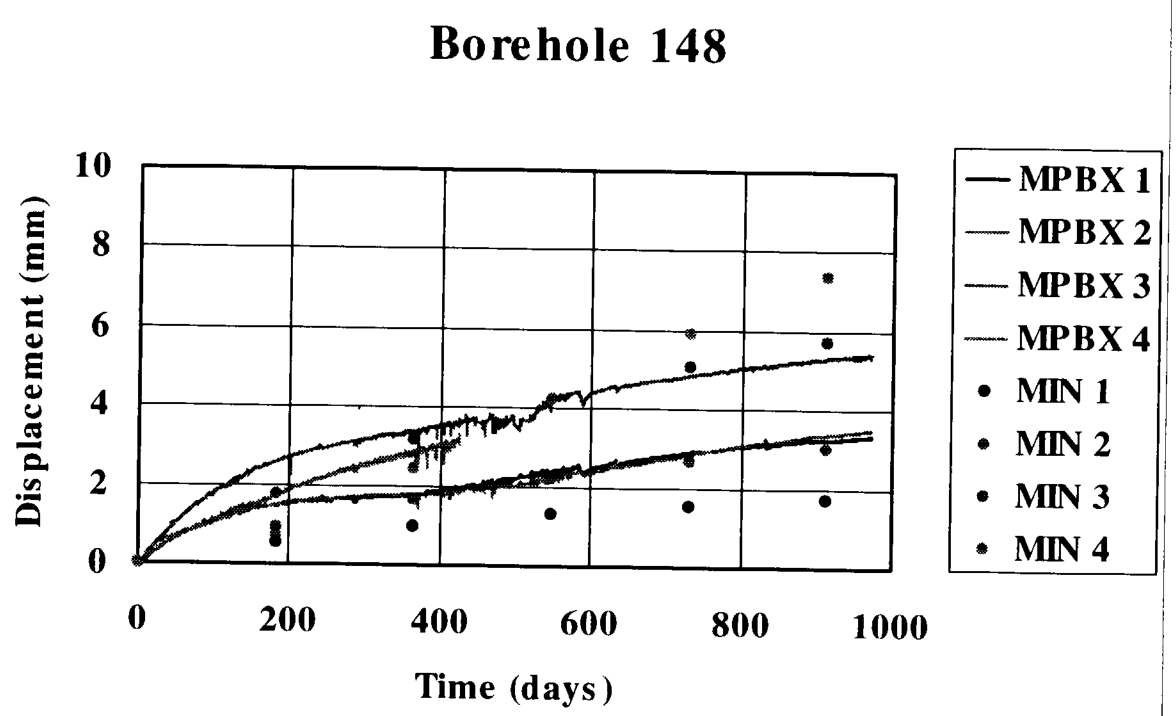




Reference: work in progress

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

Preliminary Validation Results:
Comparison of simulation and measured deformation shows agreement within a factor of 2 or better



Reference: work in progress

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

- **Basis for Resolution (Continued)**
  - Sensitivity analysis under consideration:
    - Boundary conditions
    - Coefficient of thermal expansion
    - Fracture distributions
    - Rock properties
    - Drift degradation
  - Additional validation analyses of field tests under consideration
    - Measured temperatures
    - Additional fractures
    - Analysis of multi-point borehole extensometer data

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

- **References**
  - *Calculation of Permeability Change due to Coupled Thermal-Hydraulic-Mechanical Effects*, CAL-NBS-MD-000002 Rev 00
  - *Features, Events, and Processes in Thermal Hydrology and Coupled Processes*, ANL-NBS-MD-000004 Rev 00 ICN 01
  - *Coupled Thermal Hydrologic Mechanical Effects on Permeability*, ANL-NBS-HS-000037 (Draft)

Technical Basis for Parameters Used to Assess Thermal-Mechanical Effects on Hydrological Properties (Continued)

- **Conclusion**
  - Discrete element model is being applied to analysis of thermal-hydrologic-mechanical effects on flow in fractures
    - Shear is incorporated directly
    - Model uses temperature from thermal-hydrologic analyses
  - Models have been developed for emplacement drifts and for the Drift-Scale Test
  - Validation results indicate that model is appropriate for the analyses

Technical Basis for Temperature Distributions used in Ventilation Design

- **Basis for Resolution**
  - The feasibility of the ventilation system removing 70% of heat during ventilation period has been demonstrated in the Ventilation Model analysis and model report
  - The ventilation process was modeled in the Multiscale Thermal-Hydrology Model as a reduction of the heat output by 70%
    - This assumption will bound expected behavior since, during the short time that the initial conditions would affect simulation results, the simulations would over-predict liquid fluxes and seepage due to the higher saturations around the drift
  - The ongoing ventilation tests will provide additional data to confirm the ventilation model approach
  - Water that would be removed by the ventilation process was included in the initial conditions for the thermal-hydrologic models

Technical Basis for Temperature Distributions used in Ventilation Design
(Continued)

- **References**
  - *Features, Events, and Processes in Thermal Hydrology and Coupled Processes AMR*, ANL-NBS-MD-000004, Rev 00 ICN 01
  - *Multiscale Thermohydrologic Model*, ANL-EBS-MD-000049 Rev 00
  - *Ventilation Model*, ANL-EBS-MD-000030 Rev 00
- **The current approach of reducing the heat input into the thermal-hydrologic models by 70% during the 50-year ventilation period reasonably represents heat removal by ventilation. The ventilation model demonstrates the ventilation design can remove 70% of the waste-generated heat during the ventilation period**

Acceptance Criterion 2: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms*

Sufficient data on design features (including drip shield, backfill, waste package, 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 Total System Performance Assessment. The data are also sufficient to assess the degree to which Features, Events, and Processes related to the quantity and chemistry of water contacting waste packages and waste forms and which affect compliance with post-closure performance objectives have been characterized and to determine whether the technical bases provided for inclusion or exclusion of these Features, Events, and Processes are adequate. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the abstraction process

Acceptance Criterion 2: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Action or Information Need**
  - None other than those discussed for Component 1 of this Subissue
- **Basis for closure**
  - DOE considers that thermal-hydrologic-chemical and thermal-hydrologic-mechanical processes are important, but four-way thermal-hydrologic-chemical-mechanical coupling is of secondary importance based on laboratory testing by others and thermal testing at Yucca Mountain
  - The Engineered Barrier System, Unsaturated Zone, and Near-Field Environment process model reports are expected to provide the basis for this position
  - The bases and justification for modeling coupled thermal-hydrological-chemical processes in the Total System Performance Assessment were presented at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001

Acceptance Criterion 2: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **References**
  - *Near-Field Environment Process Model Report*, TDR-NBS-MD-000001 Rev 0 ICN 3
  - *Engineered Barrier System Degradation, Flow and Transport Process Model Report*, TDR-EBS-MD-000006 Rev 0 ICN 1
  - *Unsaturated Zone Flow and Transport Process Model Report*, TDR-NBS-HS-000002 Rev 0 ICN 2
- **DOE considers that sufficient data have been obtained and evaluated for abstraction into performance assessment analysis. DOE considers this criterion Closed-Pending completion of documentation in process model reports**

Acceptance Criterion 3: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms*

- Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the Total System Performance Assessment 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

Acceptance Criterion 3: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Action or Information Need**
  - None other than those discussed for Component 1 of this Subissue
- **Basis for closure**
  - Thermal-hydrological-mechanical coupling is screened out of the Total System Performance Assessment (Unsaturated Zone and Near-Field Environment Features, Events, Processes analysis and model reports, to be verified)
  - The bases and justification for modeling coupled thermal-hyrological-chemical processes in the Total System Performance Assessment were presented at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001

Acceptance Criterion 3: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **References**
  - *Near-Field Environment Process Model Report*, TDR-NBS-MD-000001 Rev 0 ICN 3
  - *Unsaturated Zone Flow and Transport Process Model Report*, TDR-NBS-HS-000002 Rev 0 ICN 2
- **DOE considers the approach to coupled processes that is used for the current Total System Performance Assessment to be valid and sufficient. DOE considers this criterion Closed-Pending accomplishment of the agreements from the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January, 2001**

Acceptance Criterion 4: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms*

- 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 Package and Waste Form. DOE has provided sufficient evidence that alternative conceptual models of Features, Events, and Processes 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 Assessment has been evaluated

Acceptance Criterion 4: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Action or Information Need**
  - Alternative conceptual models to assess effects of changes in drift geometry
  - Alternative conceptual models to assess effects of changes in rock mass hydrological properties
  - Alternative conceptual models to assess effects of changes in ventilation on water chemistry and quantity

Acceptance Criterion 4: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Basis for closure**
  - Thermal-hydrological-mechanical coupling is screened out of the Total System Performance Assessment (Unsaturated Zone and Near-Field Environment Features, Events, and Processes analysis and model reports, to be verified)
  - Alternative modeling approaches for coupled thermal-hydrological-chemical processes in the Total System Performance Assessment were presented at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001
  - Alternative conceptual models used in the Drift Seepage Model include a large number of combinations of permeability-capillarity values
    - Current simulations underway include alternative emplacement geometries: (1) initial drift geometry, (2) worst-case geometry and (3) degradation shape at the 75th percentile

Acceptance Criterion 4: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **References**
  - *Engineered Barrier System Degradation, Flow and Transport Process Model Report*, TDR-EBS-MD-000006 Rev 0 ICN 1
  - *Near-Field Environment Process Model Report*, TDR-NBS-MD-000001 Rev 0 ICN 3
  - *Unsaturated Zone Flow and Transport Process Model Report*, TDR-NBS-HS-000002 Rev 0 ICN 2
  - *Drift Seepage Model*, MDL-NBS-HS-000002 Rev 01
- **DOE has considered a range of credible alternative models and documented that the choice of models for the Total System Performance Assessment is appropriate. DOE considers this criterion Closed-Pending accomplishment of the agreements at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001**

Alternative Conceptual Models to Assess Effects of Changes in Drift Geometry

- **Basis for Resolution**
  - Alternative models for drift degradation are provided in the Drift Degradation Analysis (refer to presentations for Subissue 3, Component 2)

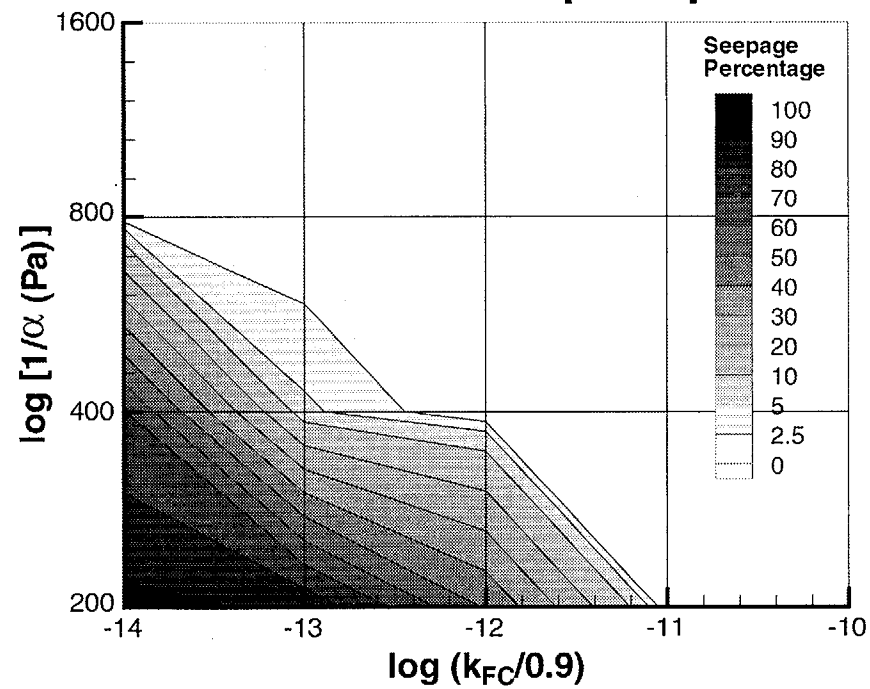
Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties

- **Basis for Resolution**
  - Alternative models have been addressed in current analyses
  - Drift seepage analyses have evaluated
    - Partially collapsed drifts
    - Excavation effects
    - Changes in permeability
  - The effects of thermal-hydrologic-chemical induced changes in hydrologic properties on flow in the host rock were shown to be relatively small
  - Thermally driven thermal-hydrologic-chemical processes in the host rock were shown in the Evolution of the Near-Field Environment Technical Exchanges, January 2001 to result in seepage water compositions that:
    - Are not strongly concentrated, and
    - When concentrated, produce solution conditions that are represented by the range of corrosion test conditions

Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

- **Drift Seepage Calculations**
  - Seepage accounting for excavation effect on near-drift permeability changes has been done through calibration
  - Calibration yields permeability and van Genuchten alpha parameter that include effect of coupled hydrologic-mechanical processes
  - Seepage results have been obtained for a wide range of combinations of permeability and alpha values (alternative models)

Typical result of seepage percentage as a contour surface over K-alpha space

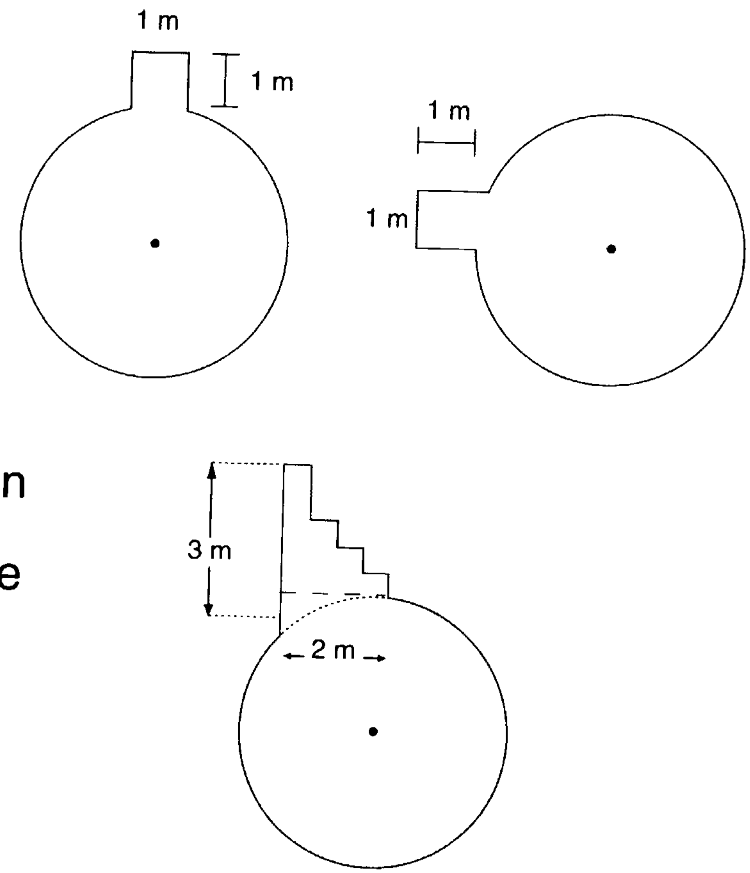


K_{FC} = Fracture Permeability
α = van Genuchten alpha parameter

Reference: Seepage Model for PA Including Drift Collapse MDL-EBS-HS-000002

Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

- **Degraded Seepage Geometries**
  - Seepage as a function of drift degradation has been evaluated for a number of degradation geometries:
    - Small rockfall (~1 m^3) near drift crown
    - Small rockfall (~1 m^3) near spring line
    - Large rockfall in drift ceiling

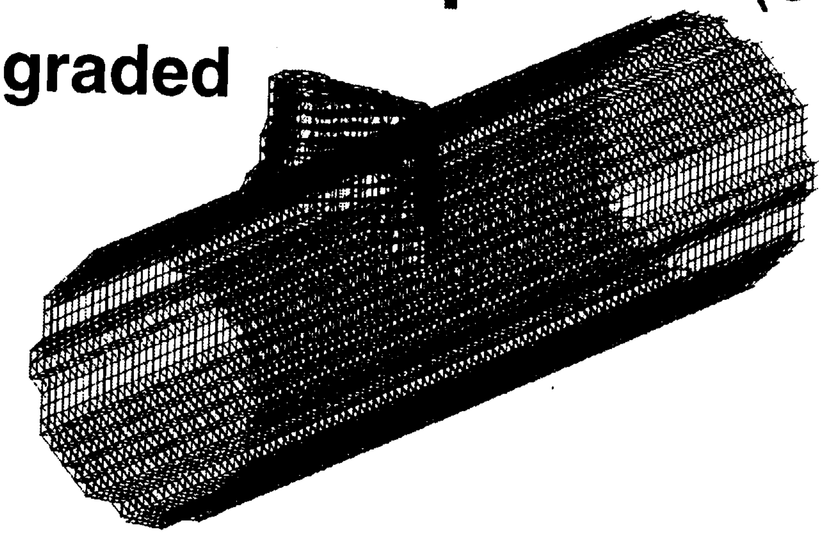


Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

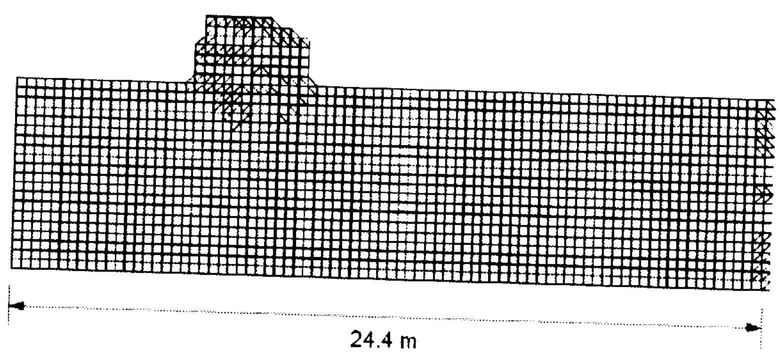
- **Current Drift Geometries Being Simulated**
  - Seepage simulation as a function of degradation now underway
    - Worst-case geometry for middle non-lithophysal (Tptpmn) from Drift Degradation Analysis
    - Drift geometry for 75th percentile for Tptpmn
    - Worst-case geometry for lower lithophysal (Tptpll) from Drift Degradation Analysis
    - Drift geometry for 75th percentile for Tptpll
  - This will be coupled with probability of degradation to arrive at uncertainty range for impact on seepage due to drift degradation

Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

- **Example of Degraded Drift Shape**



(a) Isometric View



(b) Side View

(c) Cross Section View

Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

- **Incorporation of Data Information**
  - Excavation effects: coupled hydromechanical processes
  - Niche AMR (ANL-NBS-HS-000005) shows that air permeability changes above the niche before and after excavation is about two orders of magnitude
  - Recent measurements of air permeability at Enhanced Characterization of the Repository Block indicate permeability increase above the drift but little increase on the sides
  - Thermal-hydrologic-mechanical models need to be calibrated against these data before they can be used to calculate impact on seepage

Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

- **Assumption that Thermal-Mechanical Effects are Reversible**
  - The assumption in the *Unsaturated Zone Flow and Transport Features, Events, and Processes* analysis and model report that thermal-mechanical effects are reversible is identified as TBV - to be verified
  - Thermal-hydrological-mechanical analysis indicates that fracture permeability may increase or decrease by one or two orders of magnitude due to thermal-hydrological-mechanical effects
  - If shear is important, fracture permeability may locally increase, and this change is mostly permanent
  - If shear is not important, fracture permeability will decrease due to fracture closure, and the change is mostly reversible

Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

- **Current Seepage Modeling**
  - Changes in permeability will be taken from thermal-hydrologic-chemical and thermal-hydrologic-mechanical models as a function of distance from drift and orientation
  - Seepage calculations made for two alternatives:
    - Permeability uncorrelated with capillarity
    - Permeability-capillarity obeying Leverett's relation
  - Change in seepage will be evaluated for a time sequence of hydrologic property changes due to thermal-hydrologic-chemical and thermal-hydrologic-mechanical processes

Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

- **References**
  - *Calculation of Permeability Change due to Coupled Thermal-Hydraulic-Mechanical Effects*, CAL-NBS-MD-000002 Rev 00
  - *Drift-Scale Coupled Processes (DST and THC Seepage) Models*, MDL-NBS-HS-000001 Rev 00
  - *Seepage Model for PA Including Drift Collapse*, MDL-NBS-000002 Rev 00
  - *Abstraction of Drift Seepage*, ANL-NBS-MD-000005 Rev 00

Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

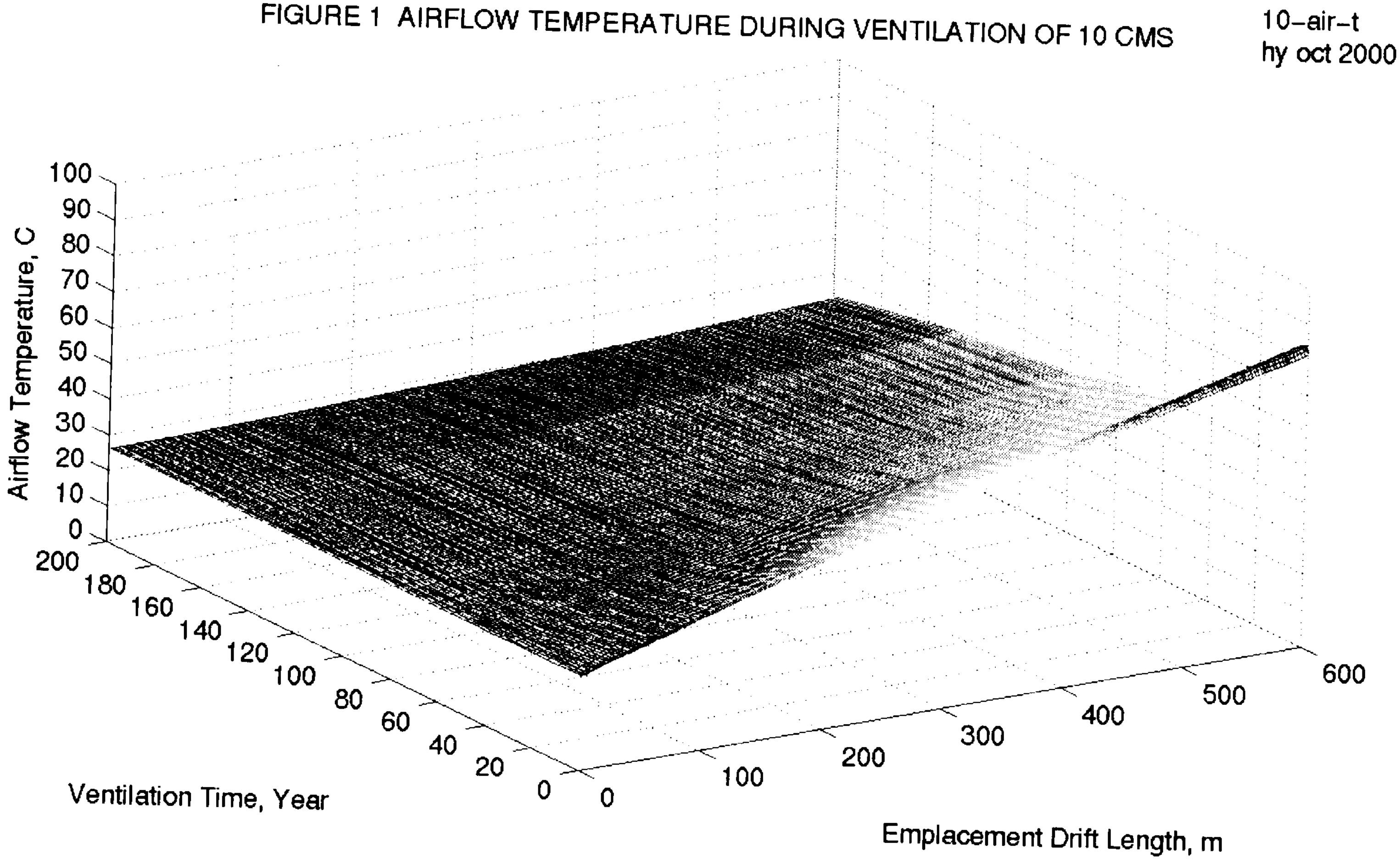
- Current model results indicate that the effects of thermal-hydrologic-chemical processes on porosity and permeability are small. Thermal-hydrologic-mechanical effects may increase or decrease fracture permeability that may adversely affect seepage if permeability decreases are large
- Additional thermal-hydrologic-mechanical analyses are ongoing or planned on both a drift and mountain scale. The results of these analyses will be assessed to evaluate the effect on seepage if fracture permeability is permanently decreased

Alternative Conceptual Models to Assess Effects of Changes in Rock Mass Hydrological Properties (Continued)

- **Basis for Resolution**
  - The most important alternative model for ventilation effects considers water removed from the host rock by preclosure ventilation (not accounted in current models that support performance assessment)
  - Rock dryout from preclosure ventilation will be limited to the rock within a few meters of the drift openings
  - Scoping calculations show that the ventilation effect decreases over a few tens or hundreds of years after closure
  - Chemical effects will be limited to the effects of porewater evaporation *within* the rock (because the fractured host rock behaves as a dual permeability medium)
  - Efflorescence on the drift wall has not been prevalent in the Exploratory Studies Facility, although evaporation occurs within the rock around ventilated openings

Alternative Conceptual Models to Assess Effects of Changes in Ventilation on Water Chemistry and Quantity

FIGURE 1 AIRFLOW TEMPERATURE DURING VENTILATION OF 10 CMS

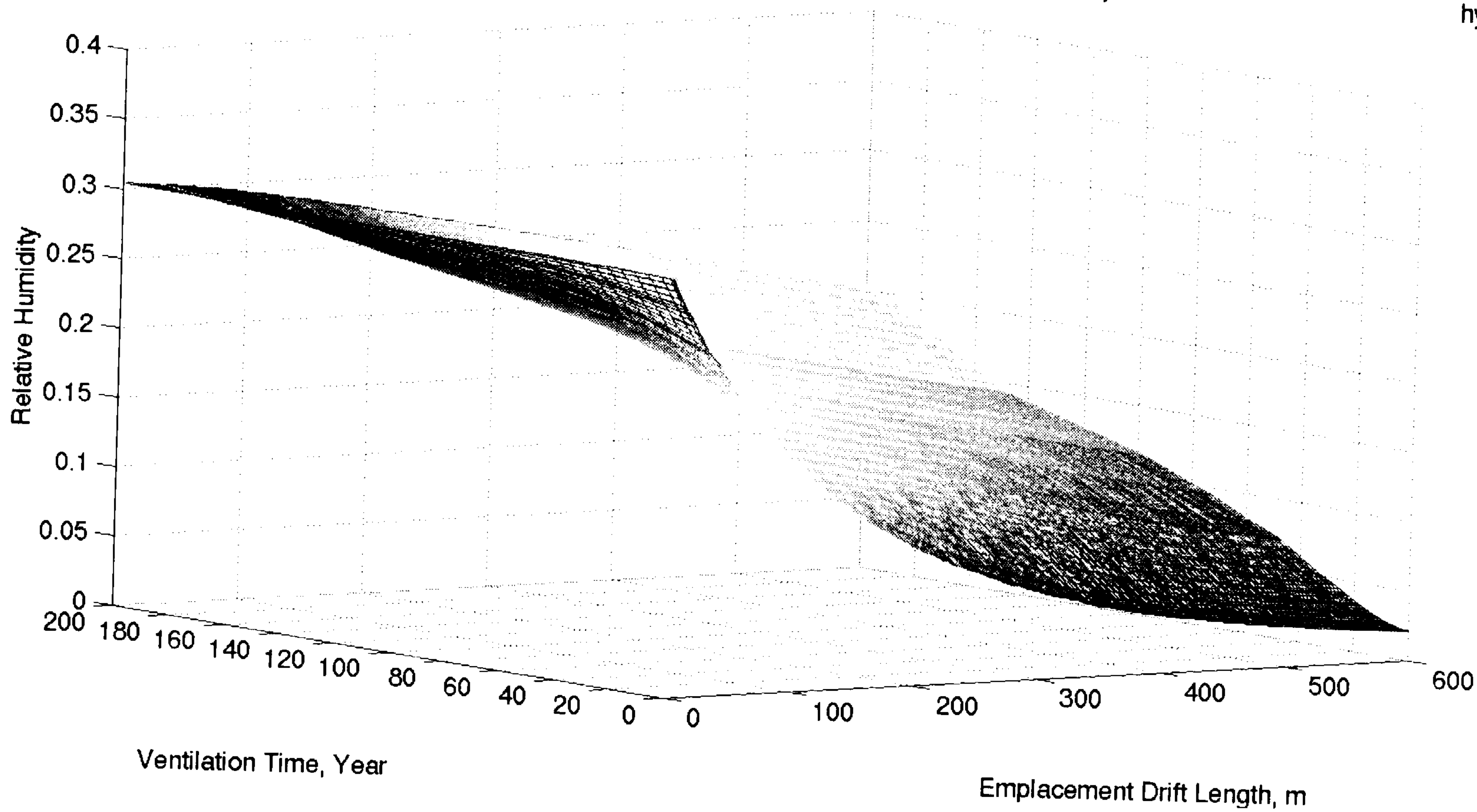


Reference: Ventilation Model (ANL-EBS-MD-000030 Rev 01 is work in progress)

Alternative Conceptual Models to Assess Effects of Changes in Ventilation on Water Chemistry and Quantity (Continued)

FIGURE 9 RELATIVE HUMIDITY OF AIRFLOW (10 CMS)

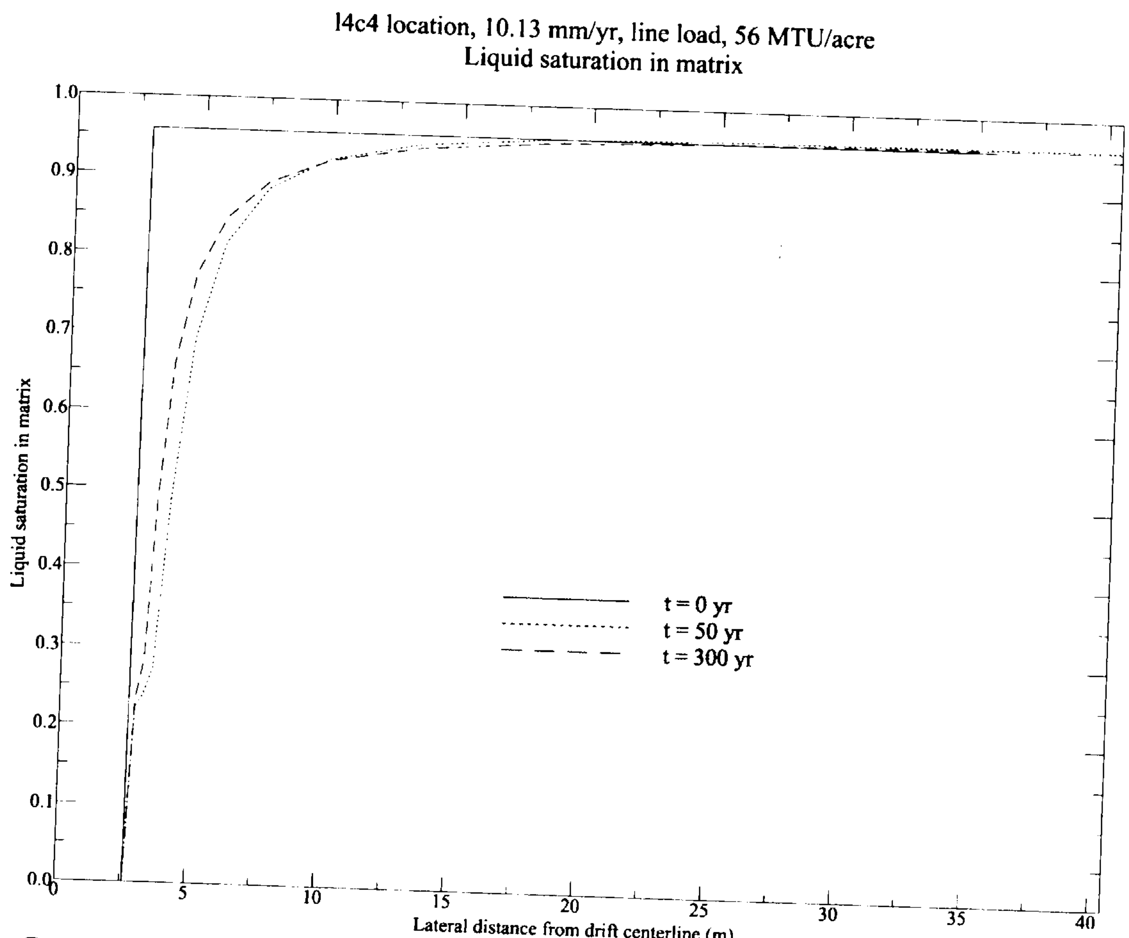
10-air-rh
hy oct 00



Reference: Ventilation Model (ANL-EBS-MD-000030 Rev 01 is work in progress)

Alternative Conceptual Models to Assess Effects of Changes in Ventilation on Water Chemistry and Quantity (Continued)

Dryout Effect from Preclosure Ventilation



Two-dimensional NUFT calculation with relative humidity = 30% during preclosure ventilation, and 70% heat removal (other inputs same as TSPA-SR Rev 00 models)

Result: Ventilation effect extends 5 to 10 meters from drift wall, and persists for a few hundred years (depending on ambient hydrologic conditions)

Reference: *Multiscale Thermohydrologic Model* ANL-EBS-MD-000049 Rev 01

Alternative Conceptual Models to Assess Effects of Changes in Ventilation on Water Chemistry and Quantity (Continued)

- **References**
  - *Ventilation Model* ANL-EBS-MD-000030 Rev 01 is work in progress
  - *Multiscale Thermohydrologic Model* ANL-EBS-MD-000049 Rev 01 is work in progress

- **DOE has developed alternative models for moisture removal and evolution of temperature and relative humidity in the drifts, from preclosure ventilation. Chemical effects will be limited to those associated with evaporation that occurs within a few meters of drift openings, and have been investigated by the fully coupled thermal-hydrologic-chemical models discussed at the January, 2001 Technical Exchange on the Evolution of the Near-Field Environment**

Acceptance Criterion 5: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Total System Performance Assessment abstraction of quantity and chemistry of water contacting waste packages and 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)**
- **Action or Information Need**
  - None other than those identified in previous Acceptance Criteria

Acceptance Criterion 5: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **Basis for closure**
  - Thermal-hydrological-mechanical coupling is screened out of the Total System Performance Assessment (Unsaturated Zone and Near-Field Environment Features, Events, and Processes analysis and model reports, to be verified)
  - The bases and justification for modeling coupled thermal-hydrological-chemical processes in the Total System Performance Assessment were presented at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001

Acceptance Criterion 5: *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms* (Continued)

- **References**
  - *UZ Flow and Transport FEPs*, ANL-NBS-MD-000001 Rev 00 ICN 01
  - *Near-Field Environment FEPs*, ANL-NBS-MD-000004 Rev 00 ICN 01
- **DOE believes the approach used for the current Total System Performance Assessment is valid and sufficient. DOE considers this criterion Closed-Pending accomplishment of the agreements from the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001**

Acceptance Criterion 1: *Spatial and Temporal Distribution of Flow*

- **Important design features, site-specific physical phenomena and couplings, and consistent and appropriate assumptions have been incorporated into the spatial and temporal distribution of flow abstraction in the performance assessment and the technical bases are provided. The Total System Performance Assessment abstraction in the DOE License Application identifies and describes aspects of spatial and temporal distribution of flow that are important to waste isolation and includes the technical bases for these descriptions**
- **Action or Information Need**
  - Assumption that thermal-mechanical effects are reversible

Acceptance Criterion 1: *Spatial and Temporal Distribution of Flow*

- **Basis for closure**
  - Important design features and processes have been incorporated into the spatial and temporal distribution of flow abstraction in the performance assessment
    - Thermal-hydrological-mechanical coupling is screened out of the Total System Performance Assessment (Unsaturated Zone and Near-Field Environment Features, Events, and Processes analysis and model reports, to be verified)
    - The bases and justification for modeling coupled thermal-hyrological-chemical processes in the Total System Performance Assessment were presented at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001
    - The Multiscale Model includes design features, and variation in hydrologic stratigraphy and boundary conditions. Model outputs are abstracted directly for use in performance assessment, as presented in the Thermal Effects on Flow Technical Exchange, January 2001
    - The coupling between thermal-hydrological-mechanical-chemical processes is of secondary importance based on laboratory analysis by others and thermal testing at Yucca Mountain

Acceptance Criterion 1: *Spatial and Temporal Distribution of Flow*

- **Basis for closure** (Continued)
  - Important design features and processes have been incorporated into the spatial and temporal distribution of flow abstraction in the performance assessment (Continued)
    - Effects of thermal-hydrologic-chemical processes in the host rock on the spatial and temporal distribution of flow have been shown to be negligible in the Thermal-Hydrologic-Chemical Seepage Model

Acceptance Criterion 1: *Spatial and Temporal Distribution of Flow*

- **References**
  - *UZ Flow and Transport FEPs*, ANL-NBS-MD-000001 Rev 00 ICN 01
  - *Near-Field Environment FEPs*, ANL-NBS-MD-000004 Rev 00 ICN 01
  - *Drift-Scale Coupled Processes (DST and THC Seepage) Models*, MDL-NBS-HS-000001 Rev 00
  - *Multiscale Thermohydrologic Model*, ANL-EBS-MD-000049 Rev 00 ICN 01
- **DOE believes the approach to analysis of spatial and temporal distribution of flow used for the current Total System Performance Assessment is valid and sufficient. DOE considers this criterion Closed-Pending accomplishment of the agreements from the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001**

Assumption that Thermal-Mechanical Effects are Reversible

- **Basis for Resolution**
  - Refer to discussions under Acceptance Criterion 4 in this presentation for alternative conceptual models to assess effects of changes in rock mass hydrological properties

Acceptance Criterion 3: *Spatial and Temporal Distribution of Flow*

- **Determine that parameter values, assumed ranges, probability distributions, and/or bounding assumptions used in the spatial and temporal distribution of flow abstraction 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 performance assessment have been provided**
- **Action or Information Need**
  - None other than those identified under Acceptance Criterion 1 for Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms

Acceptance Criterion 3: *Spatial and Temporal Distribution of Flow* (Continued)

- **Basis for closure**
  - Thermal-hydrological-mechanical coupling is screened out of the Total System Performance Assessment (Unsaturated Zone and Near-Field Environment Features, Events, and Processes analysis and model reports, to be verified)
  - The bases and justification for modeling coupled thermal-hydrological-chemical processes in the Total System Performance Assessment were presented at the Thermal Effects on Flow/Evolution of the Near-Field Environment Technical Exchanges, January 2001
- **References**
  - *UZ Flow and Transport FEPs*, ANL-NBS-MD-000001 Rev 00 ICN 01
  - *Near-Field Environment FEPs*, ANL-NBS-MD-000004 Rev 00 ICN 01

Acceptance Criterion 3: *Spatial and Temporal Distribution of Flow* *(Continued)*

- **DOE believes the approach to account for uncertainty and variability used for the current Total System Performance Assessment is valid and sufficient. DOE considers the agreements from the Evolution of the Near-Field Environment Technical Exchanges, January 2001 sufficient to close this criterion**

Conclusions

- **DOE considers the status of Subissue 3, Repository Design and Thermal - Mechanical Effects, Component 3 to be Closed-Pending:**
  - *Degradation* of *Engineered Barriers*
    - Acceptance Criterion 1: Closed-Pending resolution of need for additional rockfall verification
  - *Quantity and Chemistry* of *Water Contacting Waste Packages and Waste Forms*
    - Acceptance Criterion 1: Closed-Pending completion of ongoing work in progress
    - Acceptance Criterion 2: Closed-Pending documentation in process model reports
    - Acceptance Criterion 3: Closed-Pending completion of agreements from the Evolution of the Near-Field Environment Technical Exchange
    - Acceptance Criterion 4: Closed-Pending completion of agreements from the Evolution of the Near-Field Environment Technical Exchange
    - Acceptance Criterion 5: Closed-Pending completion of agreements from the Evolution of the Near-Field Environment Technical Exchange

Conclusions
(Continued)

- **DOE considers the status of Subissue 3, Repository Design and Thermal - Mechanical Effects, Component 3 to be Closed-Pending (Continued):**
  - *Spatial and Temporal Distribution of Flow*
    - Acceptance Criterion 1: Closed-Pending completion of agreements from the Evolution of the Near-Field Environment Technical Exchange
    - Acceptance Criterion 3: Closed-Pending completion of agreements from the Evolution of the Near-Field Environment Technical Exchange

Analysis of the Resolution Status for the Key Technical Issue on Repository Design and Thermal-Mechanical Effects

Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance

Component 1: Thermal-Mechanical Effects on Design of Underground Facility

Importance to System Performance: The TSPA analyses show no significant impacts of thermal-mechanical effects on postclosure performance and these have not been identified as principal factors of the postclosure safety case. However, heat produced by radioactive decay of the waste, whether the repository is operated in an above-boiling or lower-temperature range, would add uncertainty to estimates of postclosure performance. The higher the temperature, the greater the disparity from the range explored during site characterization. Uncertainties due to heat generated by the waste are addressed in part through a robust waste package whose performance is expected to be relatively insensitive to thermal-mechanical effects. However, the need to assure contribution of other barriers and prevent undue reliance on the waste package requires attention to uncertainties associated with these thermal effects. The primary concerns in this regard are related to coupled processes. These include thermally driven changes to mechanical properties of the rock. Additional work is needed to address these coupled processes for the postclosure safety case for the site recommendation and licensing considerations.

Acceptance Criterion (AC) 1: Design assumptions, codes, and standards used for the design of subsurface facility SSCs important to safety are acceptable.

- Applicable design codes, standards, or other detailed criteria used for the design of the subsurface facility are specified. Codes and standards are equivalent to and consistent with those accepted by the NRC for design of nuclear facilities with similar hazards and functions. If nonstandard approaches are used, adequate technical bases are provided to justify why they are used.
- Assumptions made for the design of the subsurface facility are technically defensible.
- Designs for steel and concrete structures and components, air-controlled systems, electrical power systems, and ventilation systems use applicable standards.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** At the time of preparing this revision (Rev. 3) of the RDTME KTI IRSR, the design codes, standards, and other applicable detailed criteria identified or determined by DOE for the design of the subsurface facility are not available for staff review. Neither are the assumptions made for the design of the subsurface facility. Consequently, the staff is unable to determine if codes and standards used for subsurface design are equivalent to and consistent with those accepted by the NRC for design of nuclear facilities with similar hazards and functions, if assumptions in subsurface design are technically defensible, and if the design of other components uses applicable standards.	DOE considers this criterion is **CLOSED**. Appropriate design codes and standards are used in the design process. DOE considers these codes and standards to be equivalent to and consistent with those accepted by the NRC for the design of other nuclear facilities. Any potential license application will be based on applicable industry codes and standards that are generally accepted by NRC and industry. The design requirements for the subsurface excavations are specified in the Subsurface Facility System Description Document, (CRWMS M&O 2000a, REV 01). Specific design criteria are specified in section 1.2 and design assumptions are specified in Section 2.2. The design requirements for the ground control system are specified in the Ground Control System Description Document, (CRWMS M&O 2000b, REV 01), and specify the applicable codes, standards, in section 1.2.6. Specific design criteria are specified in section 1.2 and the design assumptions are identified in Section 2.2.	No additional work required.

Analysis of the Resolution Status for the Key Technical Issue on Repository Design and Thermal-Mechanical Effects

Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance		
Component 1: Thermal-Mechanical Effects on Design of Underground Facility		
	The design requirements for the subsurface ventilation system are specified in the Subsurface Ventilation System Description Document, (CRWMS M&O 2000c, REV 01), and specify the applicable codes, standards, in section 1.2.6. Specific design criteria are specified in section 1.2 and the design assumptions are identified in Section 2.2. The waste package and drip shield are addressed by the Container Life and Source Term Key Technical Issue.	

Analysis of the Resolution Status for the Key Technical Issue on Repository Design and Thermal-Mechanical Effects

Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance

Component 1: Thermal-Mechanical Effects on Design of Underground Facility

Acceptance Criterion (AC) 3: Materials and material properties used for the subsurface facility design are appropriate.

- The selection of materials and the properties of these materials are appropriate for the anticipated subsurface environment.
- Materials and material properties are consistent with applicable design criteria, codes, standards, and specifications. If no standards are used, appropriate technical bases are provided.
- Applicable American Society for Testing and Materials (ASTM) standard specifications are used.
- The selection of ground support materials accounts for degradation of such materials under elevated temperature and thermal loading. Plausible mechanisms for material degradation are identified and properly incorporated in assessments of subsystem SSC performance.
- Fire resistant materials are incorporated into the design of the subsurface ventilation systems (e.g., fire resistant filters) to protect against fires occurring inside or outside the systems. Ventilation equipment/components are designed to withstand prolonged high temperature conditions, effects of potential sudden blast cooling, and potentially wet and corrosive environments.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** Information related to this AC will be evaluated once it becomes available and results documented in subsequent revisions.	DOE considers this criterion is **CLOSED-PENDING** selection of any potential license application reference design and completion of the introduced materials, analyses and testing program, and completion of SDD(s). Applicable ASTM standards are specified in SDD documents and used in *Longevity of Emplacement Drift Ground Support Materials* (CRWMS M&O 2000d, REV 01). The analyses to date have shown fitness for service for the materials selected for the postulated loading conditions, including thermal effects. (see CRWMS M&O 2000d, REV 01). The fire hazards analyses will show fitness for service for the materials selected for the postulated fire loading conditions. These analyses will be updated for any potential license application reference design is selected to reflect completion of introduced materials analyses and testing.	No additional work required beyond that already planned.

Analysis of the Resolution Status for the Key Technical Issue on Repository Design and Thermal-Mechanical Effects

Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance

Component 1: Thermal-Mechanical Effects on Design of Underground Facility

Acceptance Criterion (AC) 4: Design analyses use appropriate load combinations for normal and Category 1 and 2 event sequence conditions.

- The arrangement of WPs within the subsurface facility satisfies the thermal load design criteria.
- The magnitude and temporal history of the applied thermal loading are consistent with the anticipated characteristics of the proposed nuclear waste, repository design configurations, and design areal mass loading.
- Thermal analyses have an appropriate technical basis, use site-specific thermal property data, consider temperature dependency and uncertainties of thermal property data, and use thermal models and analyses that are properly documented. If credit is taken for use of ventilation, assessments of the effects of ventilation are adequate.
- Design analyses consider appropriate in situ stresses and potential running ground conditions.
- The dynamic loads used in design analyses are consistent with seismic design ground-motion parameters including any repeated seismic effects, consider faulting effects, and are consistent with accepted methodologies for assessing faulting hazards.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** No design analysis reports based on the current design concept (EDA-II) are available for staff review and evaluation, except information obtained from an Appendix 7 meeting on ground control held in November 1999. In considering in situ stresses, DOE proposed modeling horizontal to vertical stress with a ratio of 0.3 to 1.0 and considers the stress ratio of 1.0 as "bounding cases." This range of stress ratio adequately covers the possible in situ stress ratio; however, as discussed in the Appendix 7 meeting, they may not necessarily represent bounding cases after superimposing thermal load. A more realistic stress ratio should be used.	DOE considers this criterion is **CLOSED PENDING**. NRC now has the emplacement drift ground support analysis for SR, which is based on the modified EDA-II design scenario and its corresponding thermal load and design configurations. Any potential license application reference design analyses will continue to address the thermal management issues as presented in the first three bullets under AC 4. In the SR design, the in situ stress ratio range of 0.3 to 1.0 was used. Both hydraulic fracturing data and Goodman Jack measurements show that the in situ stress ratio values of 0.3 and 1.0 are lower and upper bounds, respectively, at the repository host horizon (DTN MO0007RIB00077.000, Item 00077). A lower value of 0.2 could be inferred from USW G-4 borehole measurements to a depth of 250 m from the ground surface, but this is outside the repository horizon. In any potential license application reference design analyses, the range of 0.3 to 1.0 for the in situ stress ratio will be used. Use of 0.3 is conservative under the in situ and seismic loads while use of 1.0 is conservative under the thermal loading condition. The design loading combinations and acceptance criteria will consider the	Complete reference design analysis for any potential license application.

Analysis of the Resolution Status for the Key Technical Issue on Repository Design and Thermal-Mechanical Effects

Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance		
Component 1: Thermal-Mechanical Effects on Design of Underground Facility		
	ranges for each component of load for any potential LA design.	

Analysis of the Resolution Status for the Key Technical Issue on Repository Design and Thermal-Mechanical Effects

Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance		
Component 1: Thermal-Mechanical Effects on Design of Underground Facility		
Thermal load calculations depend on details of repository design. As the repository design evolves, thermal load calculations need to be updated and the updated calculation needs to be considered in ground support design and drift stability analyses. In the cases where such analyses take credit for ventilation, the acceptability of thermal load calculation also depends on whether the ventilation model is acceptable.	Ground support design analyses always consider a bounding scenario for thermal loads, as shown in Ground Control for Emplacement Drifts for SR (CRWMS M&O 2000e, REV 00). Any updated thermal loading analysis will be accommodated in ground support analyses for LA.	If warranted, thermal load calculations will be updated for any potential license application to ensure compliance with 10CFR63.

Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance		
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Design values for seismic ground-motion are still to be developed. The evaluation of input seismic loads used for design depends on the acceptability of DOE seismic TR-3. The modeling approach, however, can be established in advance. Recent analyses conducted at the CNWRA indicate that it may be necessary to consider both velocity and acceleration as input ground-motion in seismic design analyses (Chen, 2000). It is also desirable to perform analyses in both the time domain and frequency domain, because the effect of frequency may be affected by the input waveform. Chen (2000) also shows that incorporating input ground-motion parameters into ground support design and drift stability analyses can be very difficult, depending on available software. The preliminary representative design ground-motion time histories developed by DOE (CRWMS M&O, 1998) have over 60 s of strong motion. Using these time histories as input for ground support design and drift stability analyses using numerical modeling could be a challenging task. DOE should ensure that selected numerical design analyses tools are capable of handling these time histories. Design spectra should also be developed so that the engineers and designers can take them for frequency-domain analyses. In the final Seismic TR-3, design ground-motion time histories should be developed for all the frequency ranges of interest [instead of only 1-2 Hz presented in CRWMS M&O (1998)].	The seismic design loads will conform with the approved seismic topical reports TR-1, TR-2, and TR-3. As indicated by the NRC, DOE will present its inputs for seismic design and analysis in its third topical report on seismic issues (STR3). The suite of seismic inputs to be developed consists of horizontal and vertical ground motion response spectra, horizontal and vertical design time histories, horizontal and vertical peak ground accelerations (PGA), horizontal and vertical peak ground velocities (PGV), and the variation in peak motions, strains and curvatures as a function of depth from the surface to 300 m. Design inputs will be developed for both horizontal and vertical motions and target preclosure hazard exceedance probabilities of 10^{-3} and 10^{-4}. Postclosure ground motions are being discussed as part of the Structural Deformation and Seismicity Key Technical Issue. The duration of strong motion has not been determined for design earthquake levels. Design time histories will be provided consistent with design response spectra and derived following USNRC guidelines. The seismic design inputs will be based on site-specific data and will take into account variability and uncertainty in ground motion hazard as well as site-specific geotechnical parameters. The methodology and results will be documented in an Analysis/Model Report and will be presented to the NRC in STR3.	Provide Seismic Topical Report #3 to the NRC.

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The design seismic load proposed during the NRC/DOE Appendix 7 meeting on ground control held in November 1999 includes only PGV and peak ground acceleration. These may not be sufficient. The analyses conducted at the CNWRA (Chen, 2000) show that seismic waveform and other input ground-motion parameters affect the load acting on ground support. Such effects need to be analyzed using time domain and frequency domain analyses. Further evaluation will be conducted once the documents related to DOE methodologies for considering load and load combinations for design analyses become available to the staff.	It is not DOE's objective to include only PGV and PGA parameters for seismic analyses of the ground control system. Ground motion time histories and response spectra used in performing ground support analyses for the license application design include frequency range, duration, and waveform.	Complete ground support analysis for any potential license application reference design

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Acceptance Criterion (AC) 5: Design analyses use appropriate models and site-specific properties of the host rock and consider spatial and temporal variation and uncertainties in such properties.

- Appropriate combinations of continuum and discontinuum modeling as well as 2D and 3D modeling are conducted to assess the behavior of a fractured rock mass under prolonged heated conditions and identified Category 1 and 2 event sequences. The bases for the choice of specific models and model combinations are adequate. Appropriate bases for the assumptions and limitations of the modeling approach are provided.
- Principles formulating the design analyses, the underlying assumptions, and the anticipated limitations are documented, are consistent with modeling objectives, and are technically sound.
- Values for the rock mass thermal expansion coefficient are consistent with properly interpreted site-specific data, and such interpretation accounts for likely scale effects and temperature dependency. The uncertainty in the thermal expansion coefficient is adequately assessed and considered in the thermal stress calculation.
- For continuum rock-mass modeling, the values for rock-mass elastic parameters (Young's modulus and Poisson's ratio) and strength parameters (friction angle and cohesion) are consistent with properly interpreted site-specific data. If the parameter values are obtained through empirical correlations with a rock-quality index, the empirical equations used are appropriate for the site and are applied correctly and the values of the index are consistent with site-specific data. If intact-rock-scale values are used, the bases for application of the values to the rock-mass scale are adequate.
- For discontinuum rock mass modeling, the selection of fracture patterns for numerical modeling is appropriate for the objectives of the design and analyses and the interpretation of modeling results adequately considers effects of simplification of the characteristics of the modeled fracture network compared to those of the in situ fracture network.
- For discontinuum modeling, the selection of stiffness and strength parameters for rock blocks between any fractures that are explicitly represented in the model are appropriate and account for fractures that are not explicitly represented.
- For discontinuum modeling, the values for fracture stiffness and strength parameters are consistent with properly interpreted site-specific data.
- For both continuum and discontinuum modeling, time-dependent mechanical degradation of the rock mass, fractures, and ground support that may occur following the emplacement of nuclear waste is adequately accounted for in thermal-mechanical analyses. The bases for the magnitude and rate of mechanical degradation applied in the analyses are appropriately established and are technically defensible.
- Uncertainties in rock mass and fracture mechanical properties are adequately estimated and considered in both continuum and discontinuum modeling.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** No design analyses based on the current design concept (EDA-II) are available for staff review and evaluation, except information obtained from an Appendix 7 meeting on ground control held in November 1999. Therefore, staff evaluation of	DOE considers this criterion is **CLOSED-PENDING.** **The following discussions address the bullets under AC5:** The ground support analyses have considered the site conditions, postulated loadings, and available modeling approaches (CRWMS M&O 2000e, REV 00).	The analyses to support any potential license application design will address the appropriateness of design parameters, modeling approaches, and loading conditions by performing sensitivity studies.

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design analyses is based on information from the Appendix 7 meeting and ground support design analyses for VA (CRWMS M&O. 1998d). During the Appendix 7 meeting, it was announced that both continuum and discontinuum model analyses will be performed. It was proposed that such calculations will use FLAC and UDEC. No actual analyses or results, however, were presented. Section 4.3.2 of this IRSR summarizes data needs and characterization for a continuum approach and demonstrates a 2D site-scale continuum analysis model. The analysis illustrated methodologies for considering spatial and temporal variations in rock mass properties and the effects of fractures on rock-mass properties for continuum analyses. Section 4.3.2 also summarizes rock mass and fracture property data required in discontinuum analyses. Chen, et al. (2000) and Chen (2000) further illustrated important factors, parameters, and modeling limitations that affect drift stability and ground support design analyses, using a discontinuum approach. Similar and more complete analyses should be performed and documented by DOE using well-justified site-specific properties and models. In the evaluation of DOE approaches in drift stability and ground support design analyses, the staff has the following concerns: (i) Input rock mass and fracture mechanical properties have not been consistent and may not be conservative (also see Section 4.3.2). Specifically, rock-mass friction angle ranging from 56 degrees for a RMQI rock mass to 58 degrees for a RMQ5 rock mass (as proposed for the TM analyses	The ground support analyses have considered combinations of continuum and discontinuum modeling methods (CRWMS M&O 2000e, REV 00). The 2D modeling has been used for the general evaluation of emplacement drifts and is considered to be conservative in general. The 3D modeling has been used in local areas such as emplacement drift turnouts and intersections among emplacement drifts and non-emplacement openings (CRWMS M&O 2000e, REV 00). The ground support analyses have assessed the behavior of a fractured rock mass under prolonged heated conditions and assumed Category 1 and 2 seismic events (CRWMS M&O 2000e, REV 00). The specific models, assumptions and limitations of the modeling approach, and model combinations are addressed and considered to be appropriate (CRWMS M&O 2000e, REV 00). Values for the rock mass thermal expansion coefficients used in the analyses bound the site conditions. This will be further verified by site testing. Work on the definition of rock mass properties (e. g., thermal expansion coefficients, Young's modulus, Poisson's ratio, and friction angle and cohesion) is currently underway (CRWMS M&O 2000e, REV 00). Selection of representative fracture patterns has been taken from the extensive mapping of the ESF tunnels and ECRB cross drift (DTN: MO0002SPAFRA06.002). Variations in discontinuum model can be addressed by bounding properties used in the model. For example, rock mass mechanical properties will be considered for the intact rock between joints. When deemed appropriate and necessary, time-dependent drift	

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during the November, 1999 Appendix 7 meeting) is too high and not realistic. These values are even higher than DOE laboratory testing results on intact TSw2 rock (48 degrees, CRWMS M&O 1997a). Rock mass Young's moduli ranging from 9.22 MPa for a RMQ1 rock mass to 24.90 MPa for a RMQ5 rock mass, proposed at the Appendix 7 meeting, are not consistent with the previously used range of 7.76 for a RMQ1 rock mass to 32.61 for RMQ5 rock mass (CRWMS M&O 1998d). No bases for selecting these parameters were provided. DOE rock mass friction angles and Young's moduli deviate significantly from those obtained from CNWRA independent implementation of the same empirical procedure based on rock mass quality (Ofoegbu, 1999,2000; Ofoegbu, et al., 2000). Also, a fracture friction angle of 41 degrees proposed at the Appendix 7 meeting is too high and not consistent with available laboratory testing data (e.g., Hsiung, et al., 1993). (ii) Rock-mass properties for the lithophysal zone were proposed at the November 1999 Appendix 7 meeting. However, no bases for these parameter values are available for staff review. These parameter values need to be justified, particularly because a large portion of the repository will be in the lithophysal unit. (iii) DOE has based its design analyses largely on approaches developed from mining and tunneling. Such design analyses may be appropriate for ambient conditions but they may not be appropriate for emplacement drifts in heated conditions. Recent analyses performed at the CNWRA show that rock	degradation addressed in the Drift Degradation Analysis AMR (CRWMS M&O 2000f) will be considered in ground support analyses for any potential license application design. **The following responses address the concerns of the NRC staff:** The NRC now has the emplacement drift ground support analysis for SR, which is based on the modified EDA-II design scenario. (i) Internal friction angles for the rock mass have been derived using the rock mass quality index approach and field mapping data (DTN: MO0001SEPSRMPC.000). The derived values are very sensitive to the range of confining stress used. Use of a confining stress range of 0 to 3 MPa will lead to a friction angle of 56 to 58 degrees, while a confining stress range of 0 to 42 MPa will result in a friction angle of 37 to 43 degrees. The friction angles based on both confining stress ranges were used and discussed in *Ground Control for Emplacement Drifts for SR*. (CRWMS M&O 2000e, REV 00). Approaches and technical bases, including properties such as Youngs Modulus, for determining all the design parameters will be re-examined and documented in a Design Parameter Analysis report to be completed by early 2002. (ii) Rock mass properties for the lithophysal zone were used in an analysis entitled *Ground Control for Emplacement Drifts for SR* (CRWMS M&O 2000e, REV 00). Technical bases for these properties will be documented in a technical document entitled *Rock Mass Classification Analysis* to be completed by the mid-June, 2001, and will be summarized in another technical report entitled *Design Parameters Analysis* to be completed by 2002. (iii) Analyses have shown that thermal load induces higher	

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mass responses in heated conditions expected at the proposed YM repository are different from their responses in ambient conditions (Chen, et al., 2000; Chen, 2000). Under thermal load, rock mass deformation and load acting on ground support may be much greater in a strong (RMQ-5) rock mass than in a weak (RMQ-1) rock mass. This phenomenon contradicts observations from conventional underground mining and tunneling in ambient conditions. These observations show that a weaker rock mass would experience greater deformation than a stronger rock mass under the same loading conditions. Consequently, design approaches, particularly empirical design approaches using rock mass classification, that have been developed from underground mining and tunneling in ambient conditions may not apply to the design of emplacement drifts and ground support in YM. (iv) Analyses at the CNWRA also show that rock mass deformation under thermal load may be controlled by different mechanisms in different quality rock masses (Chen, et al., 2000; Chen, 2000). In a strong (RMQ-5) rock mass, deformation is controlled mainly by high thermal stresses and failure occurs along subhorizontal fractures in roof and floor areas. In a weak (RMQ-1) rock mass, deformation is controlled mainly by preexisting structures and failure occurs along subvertical fractures in sidewall areas. (v) Rock mass thermal properties have been shown to have varying degrees of effect on the magnitude and distribution of thermal stresses and,	stress on ground support installed in more competent rock (i.e., RMQ 5) rather than in weak rock (i.e., RMQ 1), as shown in *Repository Ground Support Analysis for Viability Assessment* (CRWMS M&O 1998). Since thermal loads for SR are much lower than those for VA, thermally-induced stress differences due to different rock mass categories are less pronounced, as shown in *Ground Control for Emplacement Drifts for SR.* (CRWMS M&O 2000e, REV 00). The design of a ground support system has considered the analysis results and will result in a system adequate to cover the range of ground conditions analyzed. (iv) Similar analysis results are shown in DOE *Ground Control for Emplacement Drifts for SR.* (CRWMS M&O 2000e, REV 00). Drift stability is addressed in the Drift Degradation Analysis (CRWMS M&O 2000f). (v) In lieu of the coefficients of thermal expansion (CTE) for the rock mass, the CTE values obtained from laboratory tests on small intact specimens have been used in ground control analyses involving the drift-scale rock mass. The rationale is that the CTE values for the rock mass, if determined by in situ tests, will be lower than those from small laboratory samples (i.e., the in situ rock mass may contain all the open discontinuities that will be closed first, making net thermal expansion less than that for the intact rock). In terms of thermally induced stresses in a rock mass, use of higher CTE values leads to higher stresses, rendering the thermal-mechanical calculations conservative. Issues related to thermal properties will be examined in performing ground control analyses for LA. (vi) Effects of fracture patterns on numerical results will be examined by performing a sensitivity analysis based on in-	

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consequently, drift stability. The effect of thermal expansivity is direct and significant because thermal stresses are directly proportional to rock mass thermal expansivity. Such an effect was illustrated by a simple numerical experiment (Chen, 2000). Future DOE drift stability and ground support design analyses need to use realistic and well-based thermal expansivity values. Temperature-dependent thermal conductivity and specific heat capacity also affect thermal stresses (Ofoegbu, 2000). Inconsistent values have been reported and used in previous DOE analyses. (vi) Previous DOE analyses often used very simplified fracture patterns consisting of two sets of through going fractures with constant orientation and spacing. The effect of in sift fracture network characteristics has not been addressed. CNWRA analyses show that fracture pattern has a controlling effect on drift stability, particularly in terms of rockfall and drift collapse (Chen, 1999). Fracture pattern also affects load acting on ground support. Whereas it is acknowledged that no currently existing discontinuum tools could incorporate fracture network characteristics to the level of complexity observed at YM, the potential effect of fracture pattern on drift stability and ground support design analyses should be evaluated.	situ property variations. Numerical results generated by considering irregular fracture patterns will be compared to those obtained by considering regular fracture patterns. The rationale will be established regarding the fracture patterns to be considered for any potential license application design.	
With regard to seismic design, the analyses conducted at the CNWRA (Chen, 2000) show that dynamic modeling using UDEC is difficult and, in some cases, impractical because it is time consuming. Modeling results show that dynamic load has various degrees of impact on drift stability and ground support performance. The extent of such	In regard to seismic design analyses using FLAC and UDEC as numerical analysis tools, DOE considers these numerical tools as adequate for seismic analyses (CRWMS M&O 2000e). The applicability of these codes will be verified with ITASCA, the software developer, regarding NRC's statements regarding FLAC and UDEC as documented in IRSR *Key Technical Issue: Repository Design and Thermal-Mechanical Effects* Rev 3, pp. 75 –	Ground support analyses for any potential license application design will show the equivalency of using either acceleration, velocity or stress wave forms when proper FLAC and UDEC models are used for dynamic analyses.

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effects depends on many factors, including fracture pattern, input ground-motion parameters (particularly frequency), and, to a lesser degree, rock mass properties. Such effects need to be evaluated in drift stability and ground support design analyses for preclosure design. DOE has proposed using UDEC and FLAC to conduct its seismic design analyses. UDEC and FLAC treat dynamic input in a similar fashion. The staff is skeptical of the capability of these numerical tools. There are problems with UDEC dynamic modeling which must be resolved before it could be used for ground support design: (i) The form of input ground-motion that UDEC accepts is limited to stress history converted from velocity history based on rock-mass properties. A stress time history may not be appropriate for a highly prestressed model. If input acceleration is to be used rather than velocity, the acceleration needs to be converted to velocity, and frequency has a huge effect on such conversion. A factor of 10 difference is introduced in input stress amplitudes in the frequency range of 1 and 10 Hz ground-motions. These conversions make it difficult to interpret modeling results and distinguish true frequency effects from modeling artifacts. (ii) Drift stability under dynamic load depends largely on simulated fracture pattern. When the fracture patterns are simplified, almost no response can be observed. For a more complicated fracture pattern, however, there are numerical problems such as numerical instability. A complicated fracture pattern also increases the size of the problem and	76, indicates that further discussion regarding the capabilities of the software is warranted. (i) Velocity, acceleration, and stress history as seismic load input are numerically equivalent, resulting in equivalent response of rock mass and ground supports to seismic load. In the ground control design for SR, the single frequency velocity time history was used (CRWMS M&O 2000e). In response to the factors noted by the NRC, any potential license application reference design will examine and document these factors through sensitivity studies. (ii) Considering the vast total length of emplacement drifts, fracture patterns have to be idealized or simplified such that least favorable patterns expected from the field are considered. The corresponding results are conservative, and ground support is designed for such scenarios. Proper use of simplified regular joint patterns is believed to be conservative for any potential license application reference design. Seismic analyses based on a realistic fracture pattern consistent with field mapping data will be made in comparison to regular pattern results in any potential license application reference design. The potential maximum extent of seismic disturbance surrounding an opening will be sought through sensitivity and parameter studies. Ground support systems will be so designed that the maximum seismic disturbance will have no significant consequential effects. (iii) A frequency domain analysis is equivalent to a time domain analysis, if the latter is limited to linear material response. In the ground control analysis for SR (CRWMS M&O 2000e), the time domain analysis was performed because nonlinear response of jointed rock mass was	

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often makes it impractical to do sensitivity analyses or to use a time history that is longer than a few seconds. (iii) A time history is only a particular case in **a** spectrum of ground-motions. It may be necessary in ground support design to conduct frequency-domain analyses. UDEC is not capable of such analyses. (iv) A geological model may respond differently to different forms of dynamic input. The differences in model responses to velocity, stress, or acceleration inputs need to be examined and UDEC is not capable of such examinations.	expected. The frequency domain analysis does not do a nonlinear analysis. The factors noted by the NRC will be examined through sensitivity studies based on in-situ property variations. Velocity, acceleration, and stress history as seismic load input are equivalent in terms of the response of rock mass and ground supports if these three types of inputs are equivalent, meaning that use of either of them will lead to an equivalent result. According to ITASCA, the UDEC developer, UDEC is able to handle all three types of seismic inputs. The factors noted by the NRC will be examined through sensitivity studies based on in-situ property variations.	

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Acceptance Criterion (AC) 6: The design of ground support systems is based on appropriate design methodologies and interpretations of modeling results. • Design methodologies or combinations of design methodologies are properly applied to the design of ground support systems. When used, the empirical design approach is consistent with accepted technology in the underground tunneling and mining industry. The evaluation and selection of ground support systems are supported by analyses that satisfy the previous two AC and that provide mechanical evaluation of ground support systems under thermal and dynamic loads. • The ground support system responses are adequately evaluated, based on the results of model analyses. If the ground support system is explicitly modeled, the ground support responses include an adequate assessment of deformation and potential failure of the ground support systems. The interaction between the ground support system and the host rock units is adequately considered in the analysis. If the ground support system is not explicitly modeled, the anticipated ground support system responses from the modeling results are reasonably estimated and the technical bases for these estimates are adequate. • The geometrical, thermal, and mechanical characteristics of the support system used in the TM analyses are consistent with design and construction specifications. The time-dependent mechanical degradation of the support system under heated conditions is adequately accounted for in the analyses. • Stability of drifts, shafts, and ventilation tunnel is adequately assessed both with and without ground support. Such assessment includes identification of rock blocks that have potential to fall in the drift; the potential for cave-in, collapse, or closure of the emplacement drifts; and the extent and severity of rock-mass disturbance in the vicinity of the drift. The selection of a ground support system is consistent with the anticipated rock-mass responses and potential failure mechanisms of the rock mass in the vicinity of the drifts.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: **OPEN** DOE has proposed to use both empirical and numerical approaches for the design of ground support. The emphasis has been on empirical approaches based on rock mass classifications. Numerical approaches have been used for confirmation purposes. Empirical design approaches have been developed mainly from experiences gained from conventional underground mining and tunneling in ambient conditions. As mentioned in the evaluation of the previous acceptance criterion, rock mass response in a heated environment is different from that in an ambient thermal environment. Ground support analyses conducted at the CNWRA, using rock bolt and steel sets as examples, show that load acting on ground support is much greater in a strong (RMQ-5) rock	DOE considers this criterion is **CLOSED-PENDING**. Design of ground support systems for emplacement drifts and other non-emplacement openings has largely relied on numerical analyses, in reference to the recommendation by empirical approaches. Ground support analyses for both VA (CRWMS M&O 1998) and SR (CRWMS M&O 2000c, REV 00) have shown that under the thermal loading a strong (RMQ-5) rock mass tends to exert much higher loads on ground support than a weak (RMQ-1) rock mass. These results are consistent with the CNWRA results. DOE has focused on the development of a ground support system that is robust enough to accommodate the range of rock mass quality at the repository host horizon. Ground support design analyses for any potential will show the adequacy of such a ground support system. Any potential license application reference design ground support design will conform with extensions of standard design practices.	The analyses to support any potential license application will address appropriate design parameters.

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mass than in a weak (RMQ-1) rock mass (Chen, 2000). This phenomenon appears to contradict with observations on rock mass deformation from conventional underground mining and tunneling in ambient conditions. It implies that a stronger rock mass in heated conditions needs more ground support than a weaker rock mass. The empirical design approach, on the other hand, states that a weaker rock mass needs more ground support. DOE needs to address this behavior and factor this into ground support design as appropriate. Also, as indicated in the evaluation in previous acceptance criterion, the deformation and failure of different quality rock masses under thermal load may be controlled by different mechanisms. Consequently, different strategies in ground support design may need to be applied in different quality rock masses.	Ground support analyses will consider in-situ, thermal, dynamic, and other postulated loads. Any potential license application reference design ground support analyses will consider interaction between the ground support and the ground. Analyses are performed with and without ground support. Construction specifications will be determined based on the results of the analyses. Analyses will be completed on the time-dependent mechanical degradation of the support system. Numerical approaches (which include thermal responses) are the primary means of developing ground support design and are compared against the empirical approach (CRWMS M&O 2000e).	

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Acceptance Criterion (AC) 7: The subsurface ventilation systems are adequately designed. • The design of subsurface ventilation system is consistent with accepted design criteria, codes, standards, and specifications or with those specifically developed by DOE. • The subsurface ventilation systems including their power sources identified as important to radiological safety (reviewed using section 4.1.1.6 of the YMRP) are designed to continue functioning under normal subsurface operating conditions, as well as under Category 1 and 2 event sequences. • Applicable ventilation design guidance is met for the subsurface ventilation design. • Subsurface ventilation equipment important to safety has backup or standby equivalents and fail-safe mechanisms, where required, or DOE's ventilation design and analysis adequately shows that such equipment is not required. • There is an adequate periodic inspection. testing, and maintenance program to assure that concentrations of radioactive materials meet the limits specified in 10 CFR Part 20 and 10 CFR Part 63 as practicable. • The subsurface ventilation design is adequate to seal off or isolate airborne radiation within areas that could have a potential release. • The ventilation design analysis is based on accepted industry codes or methods, incorporates site specific data and is based on an accurate representation of the subsurface drift structure. The ventilation design analysis shows that subsurface ventilation flows from the least contaminated areas to the most contaminated areas and meets all other specified design criteria.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: **OPEN** As described previously, the staff has questions on the methodology and. consequently, results of the DOE ventilation analyses model. The main concern is that the numerical stability of the explicit stepping algorithm applied in the analyses to advance the solution along the drifts was not investigated and, consequently, calculated air and drift-wall temperatures and the predicted amount of heat removal by ventilation may not be correct. Staff independent confirmatory analyses found inconsistency in DOE calculated drift-wall temperature and air temperature. The assumptions and methodology of the DOE ventilation model need to be further assessed and modeling results need to be supported. Also, the model needs to be	DOE considers this criterion is **CLOSED-PENDING.** Any potential license application reference design for the ventilation system will comply with the appropriate codes, standards, and specifications as specified in the Subsurface Ventilation System SDD (CRWMS M&O 2000c). The emplacement drifts will have lower pressure than other parts of the respository. The subsurface ventilation system and power sources do not have a required safety function. In the event of power interruption, alternate power sources will be brought on line within the required time span. The allowable time span for ventilation interruption will be determined by analysis. The subsurface ventilation model results will be compared against an independently developed model (UNR – Dr. Danko) for validation of heat removal. Both models are to be calibrated/validated based on	The subsurface ventilation model will be calibrated and validated by comparing the results from Atlas Facility testing and an independently developed model (UNR – Dr. Danko).

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reanalyzed as the repository design changes.	ventilation testing to be completed at the Atlas facility as a part of work to undertaken in FY 01 The design of the subsurface facilities, equipment, and waste packages precludes unacceptable airborne releases of radiation during the preclosure period (CRWMS M&O 2000a).	

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Component 2: Effects of Seismically Induced Rockfall on Engineered Barrier System Performance		
Importance to System Performance: The TSPA screening analyses show no significant impacts of seismically induced rockfall on postclosure performance and this has not been identified as principal factors of the postclosure safety case.		
Acceptance Criterion (AC) 1: Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of mechanical disruption of EB components (MDEB) and other related abstractions in the TSPA and the technical bases are provided. The TSPA abstraction in the DOE LA identifies and describes aspects of MDEB that are important to waste isolation and includes the technical bases for these descriptions. • DOE identifies the EB components (e.g., backfill, drip shield) that may: (i) mitigate the effects of mechanically disruptive events on WP performance or (ii) adversely affect WP performance. DOE sufficiently describes these influences and the technical bases provided for their inclusion or exclusion in the MDEB abstraction. • DOE identifies the materials used in the construction of the WP and other relevant EB components. DOE defends the technical basis for including or excluding various behavioral characteristics and properties (e.g., corrosion, SCC, hydrogen embrittlement, fracture toughness, ultimate strength, etc.) of these materials in the MDEB abstraction in the DOE LA. • DOE justifies the environmental effects (e.g., temperature, water chemistry, humidity, radiation, etc.) included or excluded in the MDEB abstraction. • DOE identifies pertinent design features and dimensions of the relevant EB components accounted for in the MDEB abstraction. • DOE justifies the mechanically disruptive events considered in the development of the MDEB. DOE considers, at a minimum, seismicity, seismically induced rockfall, faulting, transient criticality, and igneous intrusion. • DOE identifies the mechanical failure processes and concomitant failure criteria used for the individual EB components included in the MDEB abstraction. • DOE defends the technical bases used to demonstrate that the failure processes and criteria are consistent with the material behavioral characteristics and anticipated loading conditions derived from the disruptive events. • DOE justifies the TSPA models of seismicity, seismically induced rock fall, faulting, and igneous intrusion relies on consistent and appropriate assumptions throughout the TSPA abstraction process. • DOE demonstrates the impact of internal pressure and temperature build-up on the integrity of the WP. • DOE justifies the earthquake vibration effect on the EB and in particular the WP and its support (the invert). • DOE considers appropriate components such as WP internal structures and WF (i.e., SNF matrix, cladding, structural support) that effect mechanical integrity under disruptive events.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: **OPEN**	DOE considers this criterion is **CLOSED-PENDING** completion of additional rock fall verification analyses. DOE has determined the important design features, assumptions, and processes for incorporation into performance assessment abstractions. Waste package and drip shield design are covered by the Container Life and Source Term Key Technical Issue and were discussed at the	This criterion is closed pending. DOE considers that data collected to date, analyses performed, and planned work captured in existing agreements with the NRC at the Container Life and Source Term Technical Exchange are sufficient to close this criterion

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	Container Life and Source Term Technical Exchange. EBS components that could adversely effect WP performance are considered in program documents. The rock blocks, the drip shield, and the emplacement pallet are the EBS components that affect WP performance. These influences are described in the following system description documents: Uncanistered Spent Nuclear Fuel Disposal Container System Description Document (CRWMS M&O 2000g, REV 01), Defense High Level Waste Disposal Container System Description Document (CRWMS M&O 2000h, REV 01), Naval Spent Nuclear Fuel Disposal Container System Description Document (CRWMS M&O 2000i, REV 01), and Emplacement Drift System Description Document (CRWMS M&O 2000j, REV 01). The effects of these EB components on WP performance are evaluated in the following AMRs: Design Analysis for UCF Waste Packages (CRWMS M&O 2000k, REV 00), Design Analysis for the Defense High Level Waste Disposal Container (CRWMS M&O 2000l, REV 00), Design Analysis for the Naval SNF Waste Package (CRWMS M&O 2000m, REV 00), and Design Analysis for the Ex-Container Components (CRWMS M&O 2000n, REV 00). The materials used in the construction of the WP and other relevant EB components are identified in WP Design AMRs. Material selection criteria and the technical basis are identified in the materials selection reports (CRWMS M&O 2000o, 2000p, 2000q) and Engineered Barrier System Degradation, Flow, and Transport Process Model Report (CRWMS M&O 2000aq). The environmental conditions are addressed in the AMR, *Environment On The Surfaces Of The Drip Shield And Waste Package Outer Barrier*, (CRWMS M&O 2000s, REVISION 0, ICN 1). This document is used in the TSPA-SR subsystem model for evaluating degradation of the waste package and drip shield in the Waste Package Degradation (WAPDEG) model (CRWMS M&O 2000t). Design features and dimensions of the relevant EB components, as they relate to seismically induced rockfall, are addressed in the Disruptive Events FEPs AMR (CRWMS M&O 2000u). A key design feature is	Additional rock fall verification analyses are being considered, along with the subsequent revision of the Drift Degradation Analysis.

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	the drip shield, which shields the waste package from rockfall. The drip shield design will address seismically induced rockfall. The mechanically disruptive events are addressed in the Disruptive Events FEPs AMR, *Engineered Barrier System Features, Events, and Processes and Degradation Modes Analysis*, (CRWMS M&O 2000v), and *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS 2000w). The effect of internal pressure as a function of temperature is determined and evaluated in the AMRs, *Design Analysis for UCF Waste Packages* (CRWMS M&O 2000k), *Design Analysis for the Defense High-Level Waste Disposal Container* (CRWMS M&O 2000l), *Design Analysis for the Naval SNF Waste Package* (CRWMS M&O 2000m), and their supporting calculation documents. The waste package (with emplacement pallet) and the drip shield analyses addressing seismic excitation will be consistent with the seismic hazard analysis discussed in the SDS KTI. The same seismic evaluations of waste packages and drip shield [revision of AMRs, *Design Analysis for UCF Waste Packages* (CRWMS M&O 2000k) and *Design Analysis for the Ex-Container Components* (CRWMS M&O 2000k)] will both support the SDS KTI and the CLST KTI; therefore, consistency is ensured. This was discussed in the CLST KTI, under Subissue 2.	
DOE disruptive events FEPs screening analysis (CRWMS M&O. 2000b) has concluded that mechanical disruption of the WP due to rockfall will not be considered in the TSPA because of the presence of the drip shield and/or backfill. According to the Engineered Barrier System Degradation, Flow, and Transport PMR (CRWMS M&O, 2000a), Table 3-47, however, "...a design change prompted by thermal considerations,	EBS components that mitigate the effects of mechanically disruptive events on WP performance are considered in the report *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000u). The latest version (Rev 00, ICN 01) of this Analysis/Modeling Report (AMR) addresses the no-backfill case. The design basis rock size requirement is identified in Emplacement Drift System Description Document, (CRWMS M&O 2000j REV 01). The effect of rockfall on the drip shield is evaluated in the AMR; *Design Analysis for the Ex-Container Components* (CRWMS M*O	No additional work required. If warranted, the affected documents will be updated in response to proposed rock fall verification analyses.

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was initiated to remove backfill." Consequently, backfill needs to be removed from the screening arguments used by DOE as an EB component that will mitigate the effects of rockfall on the WP. In addition, backfill should no longer be used as justification for excluding rockfall effects as they pertain to the drip shield. The NRC staff does recognize that the presence of the drip shield will play a significant role in protecting the WP from rockfall. In the absence of backfill, however, the drip shield will be susceptible to extensive damage potential because of rock block impacts. Of particular concern is the continued ability of the drip shield to act as a water infiltration barrier once it has been damaged by falling rock blocks.	2000n, REV 00) and its supporting calculation documents. Rockfall effects on the waste package and drip shield were discussed at the Container Life and Source Term Technical Exchange.	
The NRC staff is also concerned that the use of the Drift Degradation Analysis (CRWMS M&O, 1999d) as a screening argument for excluding seismically induced rockfall from the TSPA code is premature and misrepresents the significance of the analysis results presented. For example, the areal coverage and sizes of the key blocks are reportedly quite small when the emplacement drifts are oriented at an azimuth of 75 degrees. This result is being independently verified by the NRC staff. The preliminary results indicated that the key block trace area (projected on the emplacement drift wall) to the emplacement drift surface area is about 1.4 to 2.2 percent for the TSw2 lower lithophysal unit. Although the drift length affected by	With respect to mechanical disruption of EB components, the percent of emplacement drift area subject to rockfall is not a design consideration and not used in design calculations. This is because all EB components are designed to withstand a design basis rockfall (CRWMS M&O 2000k, REV 00; CRWMS M&O 2000l, REV 00; CRWMS M&O 2000m, REV 00, and CRWMS M&O 2000n, REV 00). The percentage reported was selected to illustrate that rockfall is an isolated condition with respect to the total emplacement area.	No additional work required. Additional rock fall verification analyses are being considered, along with the subsequent revision of the Drift Degradation Analysis.

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rockfall was not specifically calculated, the trace plots of the key blocks show a much higher percentage than the 1.0 percent reported in the DOE Drift, Degradation Analysis report (e.g., Figure 21). Consequently, the 1.0 percent value does not appear to be appropriate or conservative.		
Furthermore, in determining block sizes, the Drift Degradation Analysis report assumes that a joint surface is represented, by a circular disc with a radius equal to twice the mapped trace length. This assumption may potentially underestimate the block size. Shorter joint length indicates less persistency; thus, the rock blocks will be bigger and their shapes will become more irregular, as shown in Goodman and Shi (1985). Consequently, the pyramid shape will be much less dominant as suggested in the DOE Possible Rock Block Geometry, Dimension, Orientation, Probability, and Masses report (CRWMS M&O, 2000c). A preliminary analysis indicates that a reduction of joint length to half could cause the maximum rock block size to increase by as much as 30 to 40 percent. In the Drift Degradation Analysis report, Monte Carlo simulations were used to model a 24.4-m-long tunnel in 3D space to generate rock blocks for conducting key block analysis. The use of a 24.4-m-long tunnel for analysis is not justified in the report. The complete dimension of the model domain is not given. The potential "boundary effect" is not discussed, either.	Revision 1 of the *Drift Degradation Analysis* (CRWMS M&O 2000f) provides the evaluation of the sensitivity of joint trace length. The joint trace length represents some portion of the overall joint plane. The use of shorter trace lengths in the DRKBA rock fall model would lead to less fracture connectivity and therefore fewer blocks would form. The use of shorter trace lengths does not cause the formation of larger blocks since the blocks must be kinematically feasible to move into the opening. The non-connected fracture planes provide restraining surfaces that prevent block movement. Therefore, the use of shorter trace lengths in the rock fall model would not be conservative. The size and frequency of blocks observed in the ESF agrees with the static results from the key block model, thus validating the assumption that the radius of the joint plane in the rock fall model is equal to twice the mapped joint trace length. Individual joints within each joint set are represented as circular discs in three-dimensional space. Mean disc radii are typically 4 m or less. A 26.8 x 26.8 x 26.8-m rock mass volume was modeled represented by a mesh of 680,000 grid points. A 5.5-m diameter, 24.4-m length tunnel was modeled through the center of the rock mass. The modeled rock mass was sufficiently large to include the full extent of rock failure. Potential "end effects" on block development can be neglected since numerous Monte Carlo simulations provide repeated combinations of the joint data, which adequately accounts for the range of block development.	No additional work required.

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The effects of thermal load and long-term degradation of rock-mass was considered in the Drift Degradation Analysis report by reducing joint cohesion. The report indicates that time-dependent and thermal effects have a minor impact on rockfall. This finding is intuitive since the value used to represent joint cohesion is very small to start with. The report neglected the potential effects of reduction in joint friction angle. Furthermore, the thermal stress induced in the rock-mass surrounding the emplacements drift could potentially fracture the intact rock and consequently cause additional rockfalls due to rock fracturing and subsequently increase the possibility for other rock blocks to fall. The Drift Degradation Analysis report does not take this aspect into consideration. The rock block size and potential emplacement drift affected by rockfall could increase if mapped trace length is used, and long-term and thermal effects on joint friction angle and intact rocks are factored into consideration. The concern regarding use of a pseudostatic approach to address seismic effect on rockfall using the key block analysis is discussed Change in Emplacement-Drift Geometry, U.S. Department of Energy Approach subsection of this section.	The approach for thermal and long-term degradation of joint strength is based on a fracture mechanics approach in which cohesion was determined to contribute to a crack growth process. Since friction was not considered a crack growth process, there was less physical basis for considering the degradation of friction with time. Additional induced fractures (e. g., thermal, seismic, or other) would result in smaller block size than the current design basis. To validate the current approach that considers thermal loading through a reduction in joint cohesion, additional analyses are being considered using an approach that explicitly applies thermal loads. To account for time dependent frictional slip, a long-term degradation of both friction angle and cohesion is being considered.	Additional rock fall verification analyses are being considered, along with the subsequent revision of the Drift Degradation Analysis.
It does not appear that the Drift Degradation Analysis report considered potential joint sampling biases. Accurate characterization	The issue of joint sampling bias was discussed extensively at the Structural Deformation and Seismicity Technical Exchange in October 2000 and the issues identified were essentially resolved with an	No additional work required. An analysis of small trace length data is being considered for inclusion in the next

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of fracture networks at YM requires that several important sampling biases common to fracture analyses be accounted for. If left uncorrected, these sampling biases could potentially lead to under-representation of fracture intensity, porosity, permeability, and connectivity and an incorrect statistical determination of dominant and subordinate fracture distributions. A detailed examination of sampling biases in the YM fracture data sets is given in the SDS IRSR Revision 2.0 (U.S. Nuclear Regulatory Commission, 1999). Some of the pertinent points are summarized in the following paragraph. First, the lengths of the longest fractures in a population are often unconstrained because the ends of the fracture are obscured (blind). This bias can lead to underestimation of fracture connectivity. Second, the orientation of a one-dimensional sampling line (e.g., borehole or detailed line survey scan line) or two-dimensional sampling surface (e.g., pavement or road cut) inherently biases sampling against discontinuities parallel to the sampling line or surface, and in favor of sampling discontinuities at a high angle to the sampling line or surface. Mathematical corrections (e.g., Terzaghi, 1965) can partially compensate for this sampling bias. Third, because measuring every fracture from microscale to megascale is impractical or impossible for large sample areas, fracture studies usually have a size (e. g.,	agreement by NRC to review the new AMR, *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000x), which has been provided to NRC. To account for fracture length bias, the *Drift Degradation Analysis* (CRWMS M&O 2000f, REV 01) has assumed that the radius of the joint plane in the rock fall model is equal to twice the mapped joint trace length. This assumption results in a sufficient fracture connectivity as verified by the comparison of the size and frequency of blocks observed in the Exploratory Studies Facility (ESF) to the static results from the rock fall model (CRWMS M&O 2000f, REV 01, Table 44). To account for orientation bias, the fracture geometry data used in the Drift Degradation Analysis does not rely on a one-dimensional sampling line, but includes both detailed line survey and full-periphery mapping from the North Ramp, Main Drift, South Ramp, and Cross Drift within the ESF, which includes a range of tunnel orientations. The exclusion of small trace length joints in the rock fall model is conservative in terms of block size since the inclusion of small trace length joints truncates block formation resulting in an increased number of smaller blocks. An analysis of small trace length data is being considered for inclusion in the next revision of the Drift Degradation Analysis (CRWMS M&O 2000f) to confirm this effect.	revision of the Drift Degradation Analysis.

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length) cutoff. Fractures smaller than a given dimension are not counted. Consequently, small fractures are under-represented in fracture characterization. Exclusion of fractures less than 1-m from the ESF data set may lead to an incorrect interpretation of fracture intensity. For example, interpretations near faults such as the Ghost Dance fault in the ESF, where the1-m cutoff for trace length was used, leads to extremely variable fracture intensity estimates over a wide zone (Sweetkind, et al., 1997a,b).		
DOE has indicated that the drip shield will be fabricated using Titanium Grades 7 and 24. The WP, according to the EDA-II design, will employ Alloy 22 for the outer barrier and stainless steel 316NG for the inner barrier of the WP. In anticipation of loads that would cause the drip shield materials to exceed their respective yield stress limits, the drip shield materials were modeled using bi-linear stress-strain curves in the preliminary DOE analysis of rockfall on the drip shield (CRWMS M&O, 2000k). The material properties required to construct a bi-linear stress-strain curve are the yield stress, ultimate strength, Young's modulus, and minimum elongation. The actual material properties used for the two materials to construct these curves were derived from empirical data obtained at room temperature (i.e., approximately 20 °C). As tables 4 and 5 indicate, however, the mechanical	The effects of temperature on the drip shield structural performance under rock fall have been discussed in the CLST KTI, under Subissue 2. The CLST KTI agreement states that the next revision of the AMR, *Design Analysis for the Ex-Container Components* (CRWMS M&O 2000n, REV 00], will include the effects of temperature with appropriate material properties. Metals Handbook (ASM International 1990), tenth edition, volume 2, page 626 states: "... between 200 and 315 °C, the deformation of many titanium alloys loaded to the yield point does not increase with time. Thus, creep strength is seldom a factor in this range. Above 315 °C, creep strength becomes an important_selection criterion". Page 628 of the same reference states: "The stability of commercial alpha-beta alloys depends on composition and heat treatment. In the mill-annealed condition, the alloys may be considered stable up to 315 to 370 °C, although measurable changes in properties will usually accompany exposure to stress and temperature for long times". The maximum drip shield temperature will be 216 °C (at time equals 35 years) in the emplacement drift under the most conservative conditions of minimum ventilation and minimum waste package spacing (CRWMS M&O 2000y). Since this temperature is at the lower end of the temperature range that is considered to be "seldom a factor" in creep strength, creep related failure is not applicable to the drip shield design.	This criterion is closed pending. DOE considers that data collected to date, analyses performed, and planned work captured in existing agreements with the NRC are sufficient to close this criterion.

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material properties for Titanium Grade 7 are strongly dependent on temperature. In addition, note that the yield stress values for Titanium Grade 7 published in the 1995 and 1998 versions of the ASME Boiler and Pressure Vessel (B&PV) Code, Section II, Part D-Properties (American Society of Mechanical Engineers, 1995; 1998) are not in agreement. The temperature-dependent values for the yield stress, ultimate strength, and Young's modulus of Titanium Grades 5 or 24 are not provided in the ASME B&PV Code. Note that the composition of Titanium Grades 5 and 24 are the same except that Grade 24 contains 0.04 to 0.08 percent palladium. As a result, it is expected that these two grades will exhibit similar mechanical behavior (i.e., mechanical properties). The Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures (U.S. Department of Defense, 1998) and Material Properties Handbook: Titanium Alloys (American Society for Metals International, 1994) provide extensive material data for Titanium Grade 5. As Table 6 illustrates, the values for the yield stress, ultimate strength, and Young's modulus that were extracted from graphical data provided in the Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures (U.S. Department of Defense, 1998) are also strongly dependent on temperature. Even though Titanium Grade 5 exhibits much higher strengths than	The potential loss of material ductility in the immediate area of the closure lid welds has been discussed in the CLST KTI, under Subissue 2. The CLST KTI agreement states that the next revision of the AMR, *Design Analysis for UCF Waste Packages* (CRWMS M&O 2000k) will include the rock fall calculations addressing the potential embrittlement of the waste package closure weld. The acceptance criteria for the EB components are identified in the following AMRs/PMRs: *Design Analysis for UCF Waste Packages* (CRWMS M&O 2000k, REV 00), *Design Analysis for the Defense High Level Waste Disposal Container* (CRWMS M&O 2000l, REV 00), *Design Analysis for the Naval SNF Waste Package* (CRWMS M&O 2000m, REV 00), *Design Analysis for the Ex-Container Components* (CRWMS M&O 2000n, REV 00, *Waste Package Design Methodology Report* (CRWMS M&O 2000z, REV 00), and *Waste Package Degradation Process Model Report* (CRWMS M&O 2000aa, REV 00, ICN 02). The effects of seismicity, seismically induced rock fall, and faulting have been excluded from TSPA, except for cladding failure, as documented in the Disruptive Events FEPs AMR (CRWMS M&O 2000u). Seismic cladding failure and igneous intrusion were included in the TSPA. Treatment of disruptive events FEPs included in TSPA was discussed at the Igneous Activity and SDS Technical Exchanges, August and October 2000. For preclosure, the effects of internal pressure and temperature build up of the WP are addressed in the WP Design AMR (CRWMS M&O 2000k). For postclosure, the drip shield protects the WP from rockfall. Seismic vibration analysis of the EB and in particular the WP, WP pallet, and invert will be completed prior to submittal of any potential license application. For preclosure, the effects of rockfall on the WP internal structures and	

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Titanium Grade 7, the relative effects of temperature are still significant and must be considered when assessing the ability of the drip shield to withstand rock block impacts. Because the potential reductions in yield stress and ultimate strength for Titanium Grades 7 and 24 as a result of elevated emplacement drift temperatures are significant, there is some concern by the NRC staff that these materials will also be susceptible to creep related failures arising from the support of dead loads (e.g., backfill and/or fallen rock blocks). Further justification for the staff concerns pertaining to creep failure of the drip shield materials can be found in Fracture Mechanism Maps for Titanium and its Alloys (Rao et al., 1986) and Material Properties Handbook: Titanium Alloys (American Society for Metals International, 1994). Consequently, DOE should provide the technical basis for excluding creep as a potential failure mechanism from the MDEB abstraction within its TSPA code. No DOE analyses pertaining to the assessment of the new EDA II design for the WP when subjected to rockfall were available at the time this report was prepared. Specific aspects of the new WP design of interest to the NRC staff are (i) the potential loss of material ductility in the immediate area of the closure lid welds; (ii) the design provisions made to account for the significant difference in thermal	WF will be addressed prior to any potential license application. For postclosure, the drip shield helps protect the WP from rockfall.	

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expansion between the inner and outer barriers of the WP; and (iii) the failure criteria used to assess the structural integrity of the WP. Potential failure mechanisms related to rockfall include breaching of the WP barriers and SCC potential arising from the residual stresses attributable to rock block impacts. To address these and other potential concerns, DOE indicated during the Container Life and Source Term (CLST) KTI Technical Exchange (TE) held September 12-13, 2000, Las Vegas, Nevada, that in-progress rockfall calculations are: (i) using temperature dependent material properties; (ii) considering rock block impacts above the region of the WP closure welds; (iii) including the effects of seismic ground motion on the relative velocity between the EB component (i.e. drip shield and WP) and the impacting rock block; (iv) using a Tresca shear stress failure criterion; (v) coupling the mechanical stresses caused by rockfall to SCC and hydrogen embrittlement; and (vi) assessing the potential for water infiltration pathways being generated when rock block impacts occur on the interconnecting region between individual drip shield units. In addition, DOE also indicated during the aforementioned CLST TE that future rockfall calculations will assess the effects of: (i) potential embrittlement of the WP closure lid weld material and Alloy 22; (ii)		

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drip shield wall thinning due to corrosion; (iii) hydrogen embrittlement of the titanium drip shield; (iv) multiple rock blocks falling on the drip shield and WP; and (v) dead loads (caused by emplacement drift collapse) on the drip shield during seismic events.		

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Acceptance Criterion (AC) 2: Sufficient data (e.g., field, laboratory, and natural analog data) pertaining to the EB materials, mechanical failure processes, and the characterization of potential disruptive events are available to adequately define relevant parameters and conceptual models necessary for developing the MDEB abstraction in the TSPA. The data are also sufficient to assess the degree to which FEPs related to MDEB and which affect compliance with 10 CFR 63.113(b) have been characterized and to determine whether the technical bases provided for inclusion or exclusion of these FEPs are adequate.

- DOE demonstrates that the data for mechanical failure models of the EB are based on laboratory measurements and tests designed to simulate or appropriately bound conditions that can be expected during a given mechanically disruptive event.
- DOE considers the effects of prolonged exposure to the expected emplacement drift environment (e.g., the effects of temperature, corrosion degradation, hydrogen embrittlement, radiation exposure, etc) in the constitutive models and their concomitant properties and failure criteria for the different EB component materials.
- DOE justifies that the use of material test results not specifically designed or performed for the YM repository program incorporates or appropriately bounds environmental conditions expected to prevail in the emplacement drift at the proposed YM repository.
- DOE demonstrates that sufficient data are presented to support the conceptual models, process-level models, and alternative conceptual models of mechanical disruption of MDEB.
- DOE identifies the data that support the technical bases for FEPs related to MDEB that have been included or excluded in the DOE LA.
- DOE demonstrates the effects design features and/or fabrication methods for the WP and other relevant EB components have on mechanical stresses and material properties. These effects may include, but are not limited to, residual stresses and/or structural flaws introduced during fabrication, stresses induced by differential thermal expansion, and material strain hardening.
- DOE adequately evaluates seismic source characterization, recurrence, and ground-motion attenuation. For example, DOE justifies seismic source data, including: (i) the geologic and tectonic settings of the site and region; (ii) local and regional faults (Type I faults); (iii) areal sources; (iv) the historic earthquake record; (v) fault slip rates, (vi) recurrence activity rates; (vii) clustered events; and (viii) earthquake and strong motion data used to develop ground-motion attenuation models, are geologically consistent and reasonable, compatible with current understanding of the YM tectonic framework, and adequate to support the TSPA abstraction of MDEB, such that reasonable projections can be made of future YM seismic activity.
- DOE adequately evaluates rock block sizes, contact surface geometry of the rock, and relative impact velocities between the rock block and EB components. For example, DOE's interpretations of rock block size from surficial and underground mapping and geophysical or analog investigations are geologically consistent and reasonable, are compatible with current understanding of the YM joint spacing and orientation framework, and are adequate to support conceptual models, attendant assumptions, and boundary conditions such that reasonable projections can be made on how future rock fall within the emplacement drifts will affect EB integrity.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN**	DOE considers this criterion is **CLOSED-PENDING** the fulfillment of agreements already established at the container life and source term and structural deformation and seismicity technical exchanges.	No additional work required beyond that already planned. DOE considers that agreements already established at the container life and source term and structural deformation and seismicity

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	DOE considers that sufficient data and analysis have been conducted. The material properties data of the waste package materials are documented in *Waste Package Materials Properties* (CRWMS M&O 1999). The environmental conditions are addressed in the AMR, *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier* (CRWMS M&O 2000s). The information contained in this AMR is utilized in the AMRs *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (CRWMS M&O 2000ab) and *General Corrosion and Localized Corrosion of Drip Shield* (CRWMS M&O 2000ac). Hydrogen embrittlement effects on the drip shield are addressed in the AMR, *Hydrogen Induced Cracking of Drip Shield* (CRWMs M&O 2000ad). Stress Corrosion effects are addressed in the AMR, *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (CRWMS M&O 2000ae) Material test results not specifically designed or performed for the YM repository program are acceptable and are used as corroborative information in the AMRs and the waste package degradation PMR.. Sufficient data are presented to support the conceptual models, process-level models, and alternative conceptual models of mechanical disruption are acceptable. The Disruptive Events FEPs AMR ((CRWMS M&O 2000u) documents exclusion of rockfall from the TSPA analysis (see discussion under Acceptance Criterion 1). DOE has comprehensively considered the effects of fabrication methods (residual stresses, structural flaws, stresses induced by	technical exchanges are sufficient to resolve this criterion.

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	differential thermal expansion, etc) on the EB components (WP and drip shield). These effects are addressed in *Design Analysis for UCF Waste Packages* (CRWMS M&O 2000k, REV 00), *Design Analysis for the Defense High Level Waste Disposal Container* (CRWMS M&O 2000l, REV 00), *Design Analysis for the Naval SNF Waste Package* (CRWMS M&O 2000m, REV 00), *Design Analysis for the Ex-Container Components* (CRWMS M&O 2000n, REV 00, *Waste Package Degradation Process Model Report* (CRWMS M&O 2000aa, REV 00, ICN 02), and supporting AMRs. Seismic source characterization, recurrence, and ground motion attenuation are documented in the probabilistic seismic hazard assessment for Yucca Mountain (Wong and Stepp, 1998) and have been addressed in the Structural Deformation and Seismicity (SDS) Technical Exchange (TE). As part of site characterization activities at Yucca Mountain, DOE has studied regional and site faults with known and suspected Quaternary activity. DOE has also studied regional and local seismicity and the generation and attenuation of ground motion (e.g., CRWMS M&O 2000af, Section 12.3). Geologic studies have ranged from reconnaissance surveys to excavation and detailed mapping of multiple trenches across faults (e.g., Whitney 1996). Geophysical studies have ranged from regional seismic and potential field surveys to high-resolution surveys across faults in the immediate vicinity of Yucca Mountain (e.g., Majer et al. 1996). Seismic studies have included compilation of information on historical seismicity, monitoring of contemporary seismicity, and analysis of ground motion attenuation in extensional regimes. These data, as well as results obtained by non-YMP investigators, were made available to teams of experts who participated in the expert elicitation underlying the *Probabilistic Fault Displacement and Ground Motion Hazard Analyses* (Wong and Stepp, 1998). The experts evaluated the sufficiency of available data and incorporated appropriate uncertainties into their interpretations of seismic sources, faulting, and ground motion. The expert elicitation process ensured that	

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	data were considered and that interpretations forming the basis of the results (including uncertainties) were developed consistent with the available data. Results are subsequently used to examine the consequences of faulting and ground motion on the Engineered Barrier System (EBS) and on transport in the unsaturated zone, and are used in evaluating features, events, and processes for inclusion in Total System Performance Assessment (TSPA). Rock block sizes, contact surface geometry of the rock, and the relative impact velocities between the rock block and EB components have been addressed in the Drift Degradation Analysis (CRWMS M&O 2000f) and Design Analysis for the Ex-Container Components (CRWMS M&O 2000n).	
The mechanical properties of Titanium Grades 7 and 24 have a significant influence on the overall structural behavior of the drip shield. Specific mechanical properties of interest include yield stress, ultimate strength, Young's modulus, minimum elongation, and creep rate. These same mechanical properties are dependent on temperature and these temperature effects should be accounted for in the design analyses. Given the lack of consistency and/or absence of published data for Titanium Grades 7 and 24, independently qualified tests may have to be conducted to establish the variability of these mechanical properties over the temperature range expected to exist within the proposed repository emplacement drifts. No discussion was provided in the Rock Fall on Drip Shield report detailing which components or types of strain measure were used in concluding that "... no crack develops in the drip shield due to the dynamic impact of a rock on the drip shield for any of the rock sizes..." For generalized three-dimensional stress states, failure criteria are	The effects of temperature on the drip shield structural performance under rock fall have been discussed in the CLST KTI, under Subissue 2. The CLST KTI agreement states that the next revision of the AMR, Design Analysis for the Ex-Container Components (CRWMS M&O 2000n) and its supporting calculations will include the effects of temperature with appropriate material properties and a detailed discussion of the stress components and appropriate failure criteria. The AMR on stress corrosion cracking of the drip shield and the outer barrier and the stainless steel structural material (CRWMS M&O 2000ae, Rev 00 ICN 01) has been revised to address the potential for the stress corrosion cracking of the drip shield due to rockfall induced residual stresses. This AMR also addresses the experimental crack growth data obtained on the drip shield materials using constant load tests.	No additional work required beyond that already planned. DOE considers that agreements already established at the container life and source term and structural deformation and seismicity technical exchanges are sufficient to resolve this criterion.

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typically based on maximum shear stress, octahedral shear stress, Von Mises stress, or strain-energy density. These measures are used because they can be readily employed to discern failure when complex stress states exist using data derived from simple tension tests. FE analysis results were used to assess the potential for the initiation of SCC in the drip shield arising from the residual stresses developed as a consequence of the rock block impact. The results indicated that the drip shield may be susceptible to SCC. No discussion was provided in the report detailing which components or types of stress were used in making this assessment. As pointed out in the Threshold Stress Level for Initiation of Stress Corrosion Cracking (SCC) in Alloy 22, Ti Grl and Ti Gr24 (CRWMS, M&O, 2000d), "... no experimental test results on SCC initiation stress threshold (IST) values are available for any of the corrosion-resistant alloys selected for the drip shield (Ti Gr7 and Ti Gr 24) and for the waste package (Alloy 22 and 316NG) under expected bounding waste 'package/drip shield surface environments and temperatures. ...However, a review of the literature indicates that SCC IST evaluation test results obtained in boiling magnesium chloride solutions performed in accordance with ASTM G36 or similar test procedures are very likely lower bound values as compared to the range of IST values expected in bounding waste package/drip shield surface environments. Consequently, the lower bound IST values obtained in boiling magnesium chloride tests reported in the literature for similar		

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classes of alloys should be conservatively used for design and PA [Performance Assessment] purposes until directly measured alloy/environment relevant IST values are generated in currently planned test programs. In particular, IST values of 20 to 30 percent of room temperature yield stress (reported for stainless steels Types 304, 304L, and 316) will be used for the subject drip shield alloys (Ti Grade 7 and Ti Gr24) and waste package alloys (Alloy 22, 316NG) for design and PA purposes; This lower bound IST range is assumed to be uniformly distributed between 20 and 30 percent of room temperature yield stress" Although a literature search pertaining to IST values for SCC was apparently conducted, no supporting references were cited in the report to justify the assumption that the lower bound IST range is uniformly distributed between 20 and 30 percent of room temperature yield stress. Moreover, there was no information provided that addresses the recommended procedure for how generalized 3D stress states obtained from engineering analyses should be interpreted to properly determine whether the 20 to 30 percent of yield stress criterion for IST has been exceeded. In other words, should the Von Mises or first principle stress be used for comparison with the 20 to 30 percent of yield stress criterion. In addition, given the significant reduction in yield stress for Titanium Grades 7 and 24 at emplacement drift temperatures relative to the values at room temperature, the assumed IST criterion does not appear to be conservative or technically defendable.		

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Acceptance Criterion (AC) 3: Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the TSPA abstraction of MDEB 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 TSPA abstraction are provided.

- DOE justifies the process-level models used to determine corrosion-dependent parameter values that define the relevant behavioral characteristics and properties (e.g., SCC, hydrogen embrittlement, fracture toughness, ultimate tensile strength, etc.) of the materials of the EB components considered important to waste isolation and susceptible to mechanical disruptions. DOE adequately defines a range of variations for these parameter values that accounts for the effects of and uncertainties associated with fabrication flaws, accumulated damage caused by multiple disruptive events, and the temporal and spatial changes in the emplacement drift environment (e.g., temperature, redox conditions, pH, chemical composition of water contacting the relevant EBS, etc.). These variations: (i) have been incorporated into the MDEB abstraction such that the model will not underestimate the failure of the relevant EB components subjected to mechanically disruptive events and (ii) are consistent with the requirements of the CLST KTI IRSR (NRC 2000).
- DOE justifies, through appropriate methods for nondestructive examination of fabricated EB, the type, size, and location of fabrication defects that may lead to premature failure as a result of rapidly initiated EB degradation. The parameter values used in the analysis are consistent with the results of the nondestructive examination. DOE considers these defect when evaluating rock fall.
- DOE addresses, through appropriate sensitivity analyses or conservatively chosen bounds, uncertainty and variability in the relevant EB component corrosion models and their effects on the response of the EB component to mechanically disruptive events.
- DOE justifies the process-level models used to represent seismic conditions within the emplacement drifts at the proposed YM repository. DOE parameter values are adequately constrained by YM seismicity data such that the effects of seismicity on EB integrity are not underestimated. DOE identifies parameters within conceptual models for seismicity are consistent with the range of seismicity characteristics observed at YM.
- DOE's seismicity model parameters account for variability in data precision and accuracy. For example, DOE adequately accounts for uncertainty and verified parameter distributions of (i) maximum magnitude, (ii) depth of seismogenic crust, (iii) earthquake recurrence or activity rates, (iv) fault recurrence and dip, (v) wave propagation characteristics between earthquake sources and the YM site, and (vi) empirical and theoretical factors controlling directivity and other near-field effects.
- DOE identifies the seismic hazard inputs used to estimate rockfall potential are consistent with the inputs used in the repository design criteria and TSPA.
- DOE demonstrates with adequate consideration of associated uncertainties that the size distribution of rocks that may potentially fall on the WP and other relevant EB components is estimated from site-specific data (e.g., distribution of joint patterns, spacing, and orientation in three dimensions).
- DOE appropriately establishes that possible correlations between parameters are included in the TSPA abstraction.
- Where sufficient data do not exist, the definition of parameter values and conceptual models are based on appropriate use of other sources such as expert elicitation conducted in accordance with appropriate guidance such as NUREG-1563.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** Materials related to this AC will be reviewed and the results documented in subsequent revisions.	DOE considers this criterion is **CLOSED-PENDING** Process level models which address corrosion related issues for the EBS are included in, Environment on the Surfaces of the Drip	No additional work required beyond that already planned. DOE considers that agreements already established at the container life and source term and

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	Shield and Waste Package Outer Barrier (CRWMS M&O 2000s), Calculation of General Corrosion Rate of Drip Shield and Waste Package Outer Barrier to Support WAPDEG Analysis (CRWMS M&O 2000ag), Abstraction of Models for Pitting and Crevice Corrosion of Drip Shield and Waste Package Outer Barrier (CRWMS M&O 2000ah), General Corrosion and Localized Corrosion of Waste Package Outer Barrier (CRWMS M&O 2000ab), and Abstraction of Models of Stress Corrosion Cracking of Drip Shield and Waste Package Outer Barrier and Hydrogen Induced Corrosion of Drip Shield (CRWMS M&O 2000ai). These items have already been discussed during the Container Life and Source Term KTI Technical Exchange meeting and agreement has been reached with the NRC on the path forward items to resolve the issues. These documents are used in the TSPA-SR subsystem model for evaluating degradation of the waste package and drip shield in the *Waste Package Degradation* (WAPDEG) model (CRWMs M&O 2000t). The WAPDEG Model is based on a stochastic simulation approach and provides a description of waste package and drip shield degradation, which occurs as a function of time and repository location for specific design and thermo-chemical-hydrologic exposure conditions. The effects of seismically induced rockfall are excluded from the TSPA based on the results of screening in the Disruptive Events FEPs AMR (CRWMS M&O 2000u). Inputs for seismic design and analysis will be based on the results of a probabilistic seismic hazard analysis (Wong and Stepp 1998). Experts who provided the inputs upon which the PSHA is based considered seismicity data and various conceptual tectonic models of seismicity in developing their interpretations. Thus, the seismic design inputs used for analyses are appropriately consistent with and constrained by the available data and models. Documentation will be provided to the NRC in Seismic Topical Report #3 (STR3).	structural deformation and seismicity technical exchanges are sufficient to resolve this criterion.

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	The drip shield response to rock fall effects were addressed in the CLST KTI, under Subissue 2: the next revision of the AMR, *Design Analysis for the Ex-Container Components* (CRWMS M&O 2000n), will revise the effects of rock fall considering the effects of SCC, hydrogen embrittlement, wall thinning due to corrosion, multiple rock falls, and change in strength as a function of temperature. Furthermore, the effects of potential embrittlement of the WP closure weld material after stress annealing due to aging and multiple rock falls on the WP will be included in the next revision of the AMR, *Design Analysis for UCF Waste Packages* (CRWMS M&O 2000k). Waste package early failures are analyzed in the AMR, *Analysis of Mechanisms for Early Waste Package Failure* (CRWMS M&O 2000aj). This AMR shows that there will be no early failures during the postclosure period. The fabrication defects when evaluating rock fall will be addressed in the future revisions of the AMR, *Design Analysis for UCF Waste Packages* (CRWMS M&O 2000k). Conservatively selected bounding values of corrosion rates are currently being used for the WP and the drip shield; these will be included in the next revisions of the AMRs, *Design Analysis for UCF Waste Packages* (CRWMS M&O 2000k) and *Design Analysis for the Ex-Container Components* (CRWMS M&O 2000n), respectively. Therefore, no additional work is required.	

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Acceptance Criterion (AC) 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 MDEB. DOE has provided sufficient evidence that ACMs of FEPs 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 ACMs on TSPA has been evaluated.

- DOE adequately considers the temporal and spatial variations of parameters relevant to the response of the EBS to mechanically disruptive events (e.g., fracture toughness, dimensional changes, residual stresses, and SCC).
- DOE investigates alternative modeling approaches for seismicity, such as recurrence relationships or ground-motion attenuation relationships. For example, DOE models adequately consider uncertainties in: (i) geologic and tectonic conditions, (ii) seismic activity of independent and clustered events, (iii) recurrence-magnitude models, or (iv) ground-motion attenuation models.
- DOE identifies alternative conceptual models for seismically induced rockfall on the WP and other relevant EBS. DOE demonstrates that the analytical models used in the estimation of impact load due to rock fall on the WP and other relevant EB components are: (i) based on reasonable assumptions and site data, (ii) consistent with the underground facility (e.g., emplacement drift geometry and backfill) and EB component designs, and (iii) defensible with respect to providing realistic or bounding estimates of impact loads and stresses. DOE considers the rock fall analyses, as functions of ground-motions: (i) the possibility of multiple blocks falling onto the EBS simultaneously and (ii) the extent of the potential rock-fall area around the individual emplacement drifts and the entire repository. Within the rockfall dynamic analyses, DOE considers the TM effect and time-dependent jointed rock behavior and provides the background conditions on which seismic loads are superimposed.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** Materials related to this AC will be reviewed and the results documented in subsequent revisions. For evaluation of the last item of this AC, refer to the discussion provided for AC1.	DOE considers this criterion is **CLOSED-PENDING** completion of additional rock fall verification analyses. DOE has evaluated alternative modeling approaches and applicable features, events, and processes consistent with available data. DOE has adequately addressed the effects of rockfall on the stress corrosion cracking susceptibility of the drip shield in the revised AMR (CRWMS M&O 2000ae, Rev 00, ICN01). This AMR also addresses the stress corrosion cracking of the outer barrier due to manufacturing flaws and weld induced residual stresses and the proposed stress mitigation effects. These were also discussed in the Container Life and Source Term Key technical Issue Technical Exchange meeting and agreement was reached with the NRC on the proposed path forward items of work. Inputs for seismic design and analysis will be based on the results	In addition to previously planned work (i.e., submittal of Seismic Topical Report #3), additional rock fall verification analyses are being considered, along with the subsequent revision of the Drift Degradation Analysis.

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	of a probabilistic seismic hazard analysis (Wong and Stepp 1998). Experts who provided the inputs upon which the PSHA is based considered seismicity data and various conceptual tectonic models of seismicity in developing their interpretations. The experts also quantitatively characterized the uncertainty in their interpretations of geologic and tectonic conditions, dependency of earthquakes, earthquake recurrence, and ground motion attenuation. Thus, the seismic design inputs used for analyses are appropriately consistent with and constrained by the available data and models and appropriately take into account uncertainties. Documentation will be provided to the NRC in Seismic Topical Report #3 (STR3). Alternative rock fall models were considered in the *Drift Degradation Analysis.* (CRWMS M&O 2000f, REV 01, Section 6.5) including the use of deterministic methods, such as UNWEDGE, UDEC, and 3DEC. These methods were not used as the primary method for determining block size distributions since they are limited in their ability to analyze the full range of fracture geometry within the repository horizon. The primary rock fall model selected (i.e., DRKBA) can analyze the full range of fractures as mapped in the ESF. DRKBA can analyze progressive rock failure, and the block size distributions developed include multiple blocks at one location. The Drift Degradation Analysis presents the technical basis and approach for analyzing time-dependent, thermal, and seismic effects on rock fall, which is includes a reduction in the joint strength properties in the rock fall model. Additional analyses are under consideration to extend the validation of the DRKBA rock fall model using an approach that can explicitly apply thermal and seismic loads while modeling a realistic fracture pattern.	

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Acceptance Criterion (AC) 5: Output from the TSPA abstraction of the degradation of EB is justified through comparison with output from detailed process-level models and empirical observations arising from laboratory tests and field measurements. • DOE defends modeling results for MDEB by seismicity by comparison to output from detailed process-level models, empirical observations, or both. DOE demonstrates that results of assessments of the seismic disruption of the WP and other relevant EB components used in TSPA models were verified against results from empirical observations (including appropriate analogs). DOE appropriately adopts acceptable and documented procedures to construct and test empirical and physical models used to estimate the seismic hazard. DOE defends the effectiveness of proposed models in quantifying ground-motion at YM as it relates to earthquake-induced rock fall and repository performance. • DOE justifies the output from the abstraction of the effect of seismically induced rock fall on the WP and other relevant EB components, and compares the results with a combination of corrosion degradation, rock block size and shape, impact velocities, and temperature adjusted EB component material characterizations. DOE identifies detailed models of mechanical failure to evaluate the PA abstractions of MDEBS.		
NRC Staff Analysis	**DOE Status**	**DOE-Proposed Path Forward**
Acceptance Criterion Status: **OPEN** Materials related to this AC will be reviewed and the results documented in subsequent revisions.	DOE considers this criterion is **CLOSED-PENDING** completion of additional rock fall verification analyses. DOE has evaluated the results of performance assessment abstractions. DOE does not consider this criterion to be applicable. The effects of rockfall have been excluded from TSPA by the *Disruptive Events FEPs AMR* (CRWMS M&O 2000u), therefore, there is no applicable TSPA abstraction to be compared with process models. The methods utilized to estimate the seismic hazards were discussed extensively as part of the Structural Deformation and Seismicity Technical Exchange, October 2000, in Las Vegas. These issues are addressed by the SDS KTI. An expert elicitation process was used to assess seismic hazard. Available data were provided to the experts to use as a basis for their interpretations. The experts characterized seismic sources, faulting, and ground motion, including quantification of uncertainties. Results of the probabilistic ground motion hazard analysis provide the basis for developing the inputs used to assess seismically induced rockfall. Results of the seismic hazard analysis and development of seismic design inputs will be documented in Seismic Topical Report #3.	In addition to previously planned work (i.e., submittal of Seismic Topical Report #3), additional rock fall verification analyses are being considered, along with the subsequent revision of the Drift Degradation Analysis.

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Importance to system performance: The TSPA analyses show no significant impacts of thermal or thermal-mechanical effects on postclosure performance and these have not been identified as principal factors of the postclosure safety case. However, heat produced by radioactive decay of the waste, whether the repository is operated in an above-boiling or lower-temperature range, would add uncertainty to estimates of postclosure performance. The higher the temperature, the greater the disparity from the range explored during site characterization. Uncertainties due to heat generated by the waste are addressed in part through a robust waste package whose performance is expected to be relatively insensitive to thermal or thermal-mechanical effects, either directly or indirectly (e.g., in terms of effects on flow into the emplacement drifts). However, the need to assure contribution of other barriers and prevent undue reliance on the waste package requires attention to uncertainties associated with these effects. The primary concerns in this regard are related to coupled processes. These include thermal effects on the distribution and flow patterns of water in the host rock and thermal effects on the mineralogy affecting the flow of water. Additional work is needed to address these coupled processes for the postclosure safety case for the site recommendation and licensing considerations.

Acceptance Criterion (AC) 1- Degradation of Engineered Barriers - 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 EBS and other related abstractions in the TSPA, and the technical bases are provided. The TSPA abstraction in the DOE LA identifies and describes design features of the EBS and aspects of the degradation of EBS that are important to waste isolation and includes the technical bases for these descriptions.

- DOE; (i) considers the effects of TM processes and thermohydrologic processes on the EB environment, taking into account heterogeneities such as joints and faults; (ii) bounds the range of thermally driven flux; and (iii) considers the possibility of water reflux during cool-down.
- DOE considers the effects of TM processes on ground movement (including rock fall, rock deformation, and alterations to porosity and existing fractures) and changes to the drift geometry that may affect the EB chemical environment.
- DOE's thermohydrologic models used to assess the effects of evaporation, thermally driven flow, and groundwater condensation on the EB environment include significant repository design features and evaluate the following potential thermohydrologic phenomena: (i) multidrift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and condensate drainage through fractures.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** Change in emplacement-drift geometry (from roof and sidewall collapse and floor heave) is screened out from the abstraction of degradation of EBS (CRWMS M&O, 2000i) based on conclusions from the Drift Degradation Analysis report (CRWMS M&O, 1 999d). These conclusions are of limited use because thermal and seismic loadings are not considered satisfactorily in the analyses. Therefore, the conclusions from the report cannot be used as a	DOE considers this criterion is **CLOSED-PENDING** completion of additional rock fall verification analyses. DOE has evaluated the significant design features, processes and phenomena for abstraction into performance assessment analyses. The effect of floor heave on EBS response has been screened out for the following reasons. Calculations have demonstrated that the vertical displacement of the floor due to in situ stress and thermal response will be on the order of 10mm (CRWMS M&O 2000ak REV 00, ICN 01]. This displacement will produce only minor shifting in the drip shields and will not compromise their integrity because the	Additional rock fall verification analyses are being considered, along with the subsequent revision of the Drift Degradation Analysis.

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basis to screen out TM processes from the abstraction of degradation of EBS.	overlap between drip shields is much larger, between 200 mm and 600 mm. The effect of floor heave on the position of the waste packages is also minor. The *Drift Degradation AMR* (CRWMS M&O 2000f, Rev 1) addresses changes in drift geometry resulting from rockfall. Additional analyses are under consideration to extend the validation of the DRKBA rock fall model presented in the Drift Degradation AMR using an approach that can explicitly apply thermal and seismic loads while modeling a realistic fracture pattern. Refer to discussions for Subissue 3, component 2, acceptance criterion 1.	
TM-induced changes in hydrological properties are included in the abstraction of degradation of EBS through changes in the drift-seepage flux. Therefore, the treatment of TM effects on hydrological properties is evaluated as part of the abstraction of Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms (CRWMS M&O, 2000i). The assessment of TH effects on the EB environment is documented in a CRWMS M&O report (CRWMS M&O, 1 999e), which ignored the first 50 or 100 years of thermal loading in the calculations. This report did not explain how the distributions of temperature, saturation, and relative humidity at 50 or 100 years (i.e., the initial conditions used in the analyses) were obtained without considering thermal loading during the earlier period (of 50 or 100 year). The thermal-load characterization of the emplaced waste and ventilation are significant design features that need to be considered in the assessment of TH effects on the EB environment.	A preliminary estimate shows that the permanent TM effects on the fracture system increase the permeability approximately an order of magnitude in the regions above and below the drift and a factor of three higher in the regions to the side of the drift (CRWMS M&O 2000al, REV00). The permeability increase is due to shear in fractures. Other analysis evaluating mountain-scale THM effects shows one to two orders of magnitude reduction in fracture permeability due to thermal expansion of rock into fractures. This analysis assumes that shear effects are negligible as they result in only localized increases in fracture permeability. (This work will be documented in the "Mountain-scale coupled processes AMR") The seepage model shows the trend that the seepage into the drift decreases with increasing fracture permeability since increasing the fracture permeability allows more water to flow around the drift. If THM induced shear effects dominate, fracture permeabilities will increase and subsequently seepage will decrease. In this case, THM effects on seepage can be screened from the TSPA (CRWMS M&O 2000am, REV 00 ICN 01). On the other hand, if shear effects are not important, fracture permeabilities will likely decrease and the effects on seepage must be evaluated. The *Coupled Thermal Hydrologic Mechanical Effects on Permeability Analysis and Models Report* (Draft - ANL-NBS-HS-000037) that is now underway will revisit the estimate in fracture	The Coupled Thermal Hydrologic Mechanical Effects on Permeability Analysis and Models Report (Draft - ANL-NBS-HS-000037) will be provided to NRC when completed. The subsurface ventilation model will be calibrated and validated by comparing the results from Atlas Facility testing and an independently developed model (UNR – Dr. Danko).

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	permeability over time resulting from thermal mechanical effects, and will include normal and shear deformation of discrete fractures. This is a 3 Dimensional study, which incorporates fracture sets used in the Drift Degradation Analysis (CRWMS M&O 2000f). Additional analyses are under consideration to extend the validation of the Drift Scale Thermal-Hydro-Mechanical Model that is presented in this AMR. The effects of drift degradation on seepage are included in the *Drift Seepage Model AMR* (CRWMS M&O 2000an, REV01) and therefore the TSPA. Seepage is evaluated accounting for (a) near-drift excavation effects through calibration; (b) for smaller rockfall (~ 1 m^3) and (c) deeper degradation in the drift ceiling. Current studies underway will study impact on drift seepage due to different degrees of degradation with its probability levels. During repository construction and operation, the excavation disturbed zone will partially desaturate and the local hydrological regime may be disturbed. Ventilation between the time of tunnel boring, through the emplacement of waste packages, and up until closing will result in the removal of some moisture from the system. After the waste cools over time, groundwater re-enters host rock zones. The initial conditions for all process-level TH models were found by equilibrating the models both thermally and hydrologically. Thermal equilibration was achieved by setting the upper and lower boundaries of the models to a fixed temperature, and hydrologic equilibrium was achieved by adding the infiltration water into the uppermost rock elements and saturating the rock elements at the top of the water table. The ventilation process was modeled as a reduction of the preclosure heat output by 70%. Water that would be removed by the ventilation process was not included in the initial conditions for the thermal-hydrologic models. This assumption will bound expected behavior since, during the short	

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	time that the initial conditions would affect simulation results, the simulations would over-predict liquid fluxes and seepage due to the higher saturations around the drift (CRWMS M&O 2000am, REV 00, ICN 01).	

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Acceptance Criterion (AC) 1- Quantity and Chemistry of Water Contacting WPs and WFs - 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 WP and WF in the PA and other related abstractions in the TSPA, and the technical bases are provided. The features, phenomena and couplings, and assumptions used to abstract the quantity and chemistry of water contacting WP and WF have been provided. The TSPA abstraction is consistent with the identification and description of those aspects of the quantity and chemistry of water contacting WP and WF that are important to waste isolation. The TSPA abstraction is also consistent with the technical bases for these descriptions of barriers important to waste isolation. Specifically:

- DOE evaluates the potential for focusing of water flow into drifts caused by coupled THMC processes.
- DOE abstractions, including dimensionality of the abstractions, appropriately account for the various design features, site characteristics, and alternative conceptual approaches.
- DOE spatial and temporal abstractions appropriately address the physical couplings (thermal-hydrologic-mechanical-chemical).
- DOE provides the bases and justification for modeling assumptions and approximations where simplifications for modeling coupled THMC effects on seepage and flow and the WP chemical environment are used for PA.
- 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.
- DOE uses important design features, including WP 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 WP and WF.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** CRWMS M&O (CRWMS M&O 2000e,f) proposed an approach based on drift surface area for including drift-geometry changes in the abstraction of Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms. The long-term emplacement-drift geometry required as input to the abstraction needs to be estimated using a procedure that accounts for the rock-mass geomechanical response to thermal and seismic loading. The Drift Degradation Analysis report (CRWMS M&O, I 999d) is unable to provide this information because the analyses did not consider thermal and seismic loadings satisfactorily.	DOE considers this criterion is **CLOSED-PENDING**. The effects of drift degradation on seepage are included in the *Drift Seepage Model* (CRWMS M&O 2000ao, REV 00) and therefore the TSPA. The Drift Seepage Model does use input from the Drift Degradation AMR (CRWMS M&O 2000f). The Drift Degradation AMR address changes in drift geometry resulting from rockfall. Additional analyses are under consideration to extend the validation of the DRKBA rock fall model presented in the Drift Degradation AMR using an approach that can explicitly apply thermal and seismic loads while modeling a realistic fracture pattern. If these additional analyses are completed and it is concluded that drift geometries are significantly changed, then this information will used in an evaluation of seepage changes and factored into the Drift Seepage Abstraction (CRWMS M&O 2000ao).	The *Coupled Thermal Hydrologic Mechanical Effects on Permeability Analysis and Models Report* (Draft - ANL-NBS-HS-000037) and *Seepage Model Studies Report* (CRWMS M&O 2000an, REV01) will be provided to NRC when completed.

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TM effects on hydrological properties are screened out of the abstraction of Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms for two reasons (CRWMS M&O, 2000h: First, TM effects on fracture permeability were considered to be small based on the Berge, et al. (1998) analyses (see Change in Rock-Mass Hydrological Properties, U.S. Department of Energy Approach of this section). The upper bound permeability increase suggested by Berge, et al., (1998) is, however, too small and can be exceeded as discussed in Change in Rock-Mass Hydrological Properties, U.S. Department of Energy Approach of this section. Second, analyses presented by CRWMS M&O (2000e) indicate that an increase in fracture permeability would result in decreased water flow into emplacement drifts. Alternative model calculations summarized in the Change in Rock-Mass Hydrological Properties, U.S. Department of Energy Approach of this section (Ofoegbu, 2000; Ofoegbu et al., 2000), however, indicate that lateral flow of moisture can be expected within a TM-altered zone and would cause increased vertical percolation flux and, therefore, drift seepage, at the downstream end of the altered zone. One difference between the two studies that may explain the divergence in the findings relates to the change in capillarity associated with a change in fracture aperture. In the study conducted by CRWMS M&O (2000e), a two-fold increase in fracture aperture (ten-fold increase in fracture permeability) was combined with a ten-fold decrease in capillarity, which effectively caused the altered zone to function as a capillary barrier. On the other hand, a change in capillarity was not applied in the alternative study (Ofoegbu, 2000;	A preliminary estimate shows that the permanent TM effects on the fracture system increase the permeability approximately an order of magnitude in the regions above and below the drift and a factor of three higher in the regions to the side of the drift (CRWMS M&O 2000al, REV00). The permeability increase is due to shear in fractures. Other analysis evaluating mountain-scale THM effects shows one to two orders of magnitude reduction in fracture permeability due to thermal expansion of rock into fractures. Most of these permeability changes are reversible. This analysis assumes that shear effects are negligible as they result in only localized increases in fracture permeability. (This work will be documented in the "Mountain-scale coupled processes AMR") The seepage model shows the trend that the seepage into the drift decreases with increasing fracture permeability since increasing the fracture permeability allows more water to flow around the drift. If THM induced shear effects dominate, fracture permeabilities will increase and subsequently seepage will decrease. In this case, THM effects on seepage can be screened from the TSPA (CRWMS M&O 200am, REV 00 ICN 01). On the other hand, if shear effects are not important, fracture permeabilities will likely decrease and the effects on seepage must be evaluated. The *Coupled Thermal Hydrologic Mechanical Effects on Permeability Analysis and Models Report* (Draft - ANL-NBS-HS-000037) that is now underway will revisit the estimate in fracture permeability over time resulting from thermal mechanical effects, and will include normal and shear deformation of discrete fractures. This is a 3 Dimensional study, which incorporates fracture sets used in the Drift Degradation Analysis. Additional analyses are under consideration to extend the validation of the Drift Scale Thermal-Hydro-Mechanical Model that is presented in this AMR. Seepage model studies (CRWMS M&O 200an, REV01) underway will also include evaluation of the effect of changes in permeability due to THM processes, using two alternative approaches where the permeability is or is not anticorrelated with capillarity.	The analyses to support any potential LA design will address the appropriateness of parameters, modeling approaches, and loading conditions by performing sensitivity studies.

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Ofoegbu et al., 2000) in which an increase in fracture aperture by a factor of up to 10 was applied. DOE needs to provide the technical bases for the parameter values used to assess the effects of TM-altered hydrological properties on the abstraction of the Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms.		
As discussed previously (in the Characterization of Repository Thermal Loading and Ventilation, U.S. Department of Energy Approach subsection of this section), process level models that develop input information for the abstraction of the Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms implement preclosure ventilation by using only 30 percent of waste-generated heat as input thermal load during the first 50 years after waste emplacement. Thereafter, the models use 100 percent of the waste-generated heat (CRWMS M&O, 2000h). To justify this representation of ventilation, DOE needs to demonstrate that: (i) the ventilation design would actually remove 70 percent of the waste-generated heat during the ventilation period, and (ii) the temperature distributions calculated using 30 percent of the heat source adequately represent the temperature distributions that would be calculated using 100 percent of the heat source with a proper representation of the ventilation design.	The current approach of reducing the heat input into the TH models by 70% during the 50-year ventilation with no heat output reduction after 50 years is a reasonable approach since the ventilation design will remove 70% of the waste-generated heat during the ventilation period (CRWMS M&O 2000ap, REV 00, ICN 01). Any potential license application reference design for the ventilation system will comply with the appropriate codes, standards, and specifications as specified in the Subsurface Ventilation System SDD. The emplacement drifts will have lower pressure than other parts of the repository. In the event of power interruption, alternate power sources will be brought on line within the required time span. The allowable time span for ventilation interruption will be determined by analysis. The subsurface ventilation model results will be compared against an independently developed model (UNR – Dr. Danko) for validation of heat removal. Both models are to be calibrated/validated based on ventilation testing to be completed at the Atlas facility as a part of work to undertaken in FY 01.	The subsurface ventilation model will be calibrated and validated by comparing the results from Atlas Facility testing and an independently developed model (UNR – Dr. Danko).

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Acceptance Criterion 2: Quantity and Chemistry of Water Contacting WPs and WFs - Sufficient data on design features (including drip shield, backfill, WP, cladding, other EB 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 WP and WF in the TS PA. The data are also sufficient to assess the degree to which FEPs related to the quantity and chemistry of water contacting WP and WF and which affect compliance with post-closure performance objectives have been characterized and to determine whether the technical bases provided for inclusion or 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:

- 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 thermal-hydrologic-mechanical-chemical coupled processes that affect seepage and flow and the WP chemical environment, as well as the chemical environment for radionuclide release.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** There are concerns regarding data used to define potential changes in: (i) emplacement-drift geometry; (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loading; and (iii) the characterization of repository thermal loading and ventilation. The information needed to address these concerns is discussed in Sections 4.3.2 and 5.3.1.	DOE considers this criterion is **CLOSED-PENDING**. DOE's natural system models are based on extensive site characterization data (CRWMS M&O 2000aq and CRWMS M&O 2000ar). The type, quantity, and reactivity of engineered materials has been evaluated in the UZ PMR (CRWMS M&O 2000as). The results of the large-block (LBT) and drift-scale heater and niche tests (DST) are used in the modeling of water chemistries and are documented in the AMR Summary of In-Package Chemistry (CRWMS M&O 2000at, Section 6.2). This AMR is currently undergoing revision. Section 3.6 of the NFE PMR (CRWMS M&O 2000ar) describes in situ and field thermohydrologic testing, including the LBT and the DST. Section 6.1 of the Thermal Test AMR (CRWMS M&O 2000au) 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.	No additional work required beyond that already planned.

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	The *THC Process AMR* (CRWMS M&O 2000au, 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 nearly 200°C. The *EBS PMR* (CRWMS M&O 2000aq) 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 2000av, Rev. 01.)	

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Acceptance Criterion 3: Quantity and Chemistry of Water Contacting WPs and WFs - Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the TSPA abstraction of quantity and chemistry of water contacting WP and WF, such as the pH, chloride concentration, and amount of water flowing in and out of the breached WP, 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 variability's. The technical bases for the parameter values used in the TSPA abstraction are provided. Specifically,

- DOE demonstrates that input values used in the quantity and chemistry of water contacting EBS (e.g., drip shield, WP, and cladding) calculations in TSPA are consistent with the initial and boundary conditions and the assumptions of the conceptual models and design concepts for the YM site, such as WP and EBS design (including backfill, drip shield, ground support, and cladding), WP degradation (corrosion and mechanical disruption), cladding degradation, deep percolation flux, important thermal-hydrologic-mechanical-chemical 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.
- DOE establishes that reasonable or conservative ranges of parameters or functional relations are used to determine effects of coupled thermal-hydrologic-mechanical-chemical processes on seepage and flow and the WP chemical environment, as well as on the chemical environment for radionuclide release.
- DOE shows that the parameters used to define initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THMC effects on seepage and flow and the WP chemical environment, as well as on the chemical environment for radionuclide release, are consistent with available data.
- 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 seepage and flow and the WP chemical environment, as well as the chemical environment for radionuclide release.

NRC Staff Analysis	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** There are concerns regarding data used to define potential changes in: (i) emplacement-drift geometry; (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loading; and (iii) the characterization of repository thermal loading and ventilation. The information needed to address these concerns is discussed in Sections 4.3.2 and 5.3.1.	DOE considers this criterion is **CLOSED.** Input values for quantity and chemistry of water contacting the EBS 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 2000aw). DOE has used numerical simulation to represent THC coupled processes that will control water composition in the host rock (CRWMS M&O 2000as, Sections 3.9 and 3.10.5). Other models are used for evaporative evolution of waters in the EBS (e.g., CRWMS M&O 2000aq, Section 3.1.1). These models are consistent with the initial and boundary conditions and assumptions	No additional work required.

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	used for other important models that feed TSPA-SR. Details are provided in UZ PMR (CRWMS M&O 2000as), NFE PMR (CRWMS M&O 2000ar), and EBS PMR (CRWMS M&O 2000aq). 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 in progress. 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. 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; MOL.20010117.0339) 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 CRWMS M&O 2000aq and CRWMS M&O 2000ar.)	

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Acceptance Criterion (AC) 4: Quantity and Chemistry of Water Contacting WPs and WFs - 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 WP and WF. DOE has provided sufficient evidence that alternative conceptual models of FEPs 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 TSPA has been evaluated. Specifically:

- 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 WP environmental conditions; (iii) dehydration of hydrous phases liberating moisture that may affect the WP chemical environment and the chemical environment for radionuclide release; (iv) effects of microbial processes on the WP chemical environment and the chemical environment for radionuclide release; (v) changes in water chemistry that may result from the release of corrosion products from the WP and interactions between engineered materials and groundwater, which, in turn, may affect flow and the WP chemical environment, as well as 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 Status	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** DOE should provide adequate description of the alternative conceptual models used to assess the effects of change in: (i) emplacement-drift geometry; (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loadings; and (iii) ventilation on the abstraction of quantity and chemistry of water contacting WP and WF. For example, an alternative conceptual model for change in emplacement-drift geometry and hydrological properties may consist of two sets of abstractions, one set based on completely collapsed drifts and the other set based on the initial drift geometry with predictions from the two sets combined using a time-dependent weighting function. Similar alternative models may also be developed to	DOE considers this criterion is **CLOSED-PENDING**. The EBS PMR (CRWMS M&O 2000aq) documents the consideration of thermal effects on gas and water chemistry. Hydrothermally driven geochemical reactions are considered in the UZ PMR (CRWMS M&O 2000as, 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 2000ar, Section 3.3.3.6). Microbial processes are addressed in the EBS PMR (CRWMS M&O 2000aq) and Waste Package PMR (CRWMS M&O 2000aa). Water chemistry in the EBS is addressed in the EBS PMR (CRWMS M&O 2000aq), Waste Package PMR (CRWMS M&O 2000aa, Section 3.1.3) and Waste Form PMR (e.g., CRWMS M&O 2000ax, Section 3.2). Models of released radionuclides and EBS materials are under development. 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	No additional work required beyond that already planned.

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explore the effects of ventilation, if it is determined that it is not practical to model ventilation explicitly.	described in the waste form degradation PMR (CRWMS M&O 2000ax, 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 2000ax, sections 3.7.3, and 3.8.4). Both backfilled and no-backfill designs are addressed in SR models. Alternative conceptual models used in *Drift Seepage Model* (CRWMS M&O 2000ao, REV01) include a large number of combinations of permeability-capillarity values. Current simulations underway include alternative emplacement geometries: (1) initial drift geometry, (2) worst case geometry and (3) degradation shape at the 75 percentile. Alternative conceptual approaches to handling TH, THC and THM processes have been considered (e.g., CRWMS M&O 2000as, Section 3.10.7). DOE has considered credible alternative models and documented that the choice of models for TSPA-SR is appropriate.	

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<table>
<tr><th colspan="3">Subissue 3: Thermal-Mechanical Effects on Underground Facility Design and Performance</th></tr>
<tr><th colspan="3">Component 3: Thermal-Mechanical Effects on Flow into Emplacement Drifts</th></tr>
<tr><td colspan="3">Acceptance Criterion (AC) 5: Quantity and Chemistry of Water Contacting WPs and WFs - Output from the TSPA abstraction of quantity and chemistry of water contacting WP and WF is justified through comparison with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, natural analogs).

• DOE demonstrates that abstracted models for coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow and the WP chemical environment, as well as 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.
• DOE clearly describes changes, if any, in hydrological properties (e.g., fracture porosity and permeability) due to thermally induced ground movements, and demonstrates that the magnitudes and distributions of the changes provided are consistent with the results of TM analyses of the underground facility.</td></tr>
<tr><th>NRC Status</th><th>DOE Status</th><th>DOE-Proposed Path Forward</th></tr>
<tr><td>Acceptance Criterion Status: OPEN

DOE needs to develop estimates of changes in hydrological properties and emplacement-drift geometry that account for the anticipated geomechanical response to the proposed thermal loading and potential seismic loading.</td><td>DOE considers this criterion is CLOSED-PENDING.

The Drift Degradation AMR (CRWMS M&O 2000f) addresses changes in drift geometry resulting from rockfall. Additional analyses are under consideration to extend the validation of the DRKBA rock fall model presented in the Drift Degradation AMR using an approach that can explicitly apply thermal and seismic loads while modeling a realistic fracture pattern.

The effects of drift degradation on quantity of seepage entering the drifts is included in the Drift Seepage Model (CRWMS M&O 2000an, REV01) and therefore the TSPA. Seepage is evaluated accounting for (a) near-drift excavation effects through calibration; (b) for smaller rockfall (~ 1 m^3) and (c) deeper degradation in the drift ceiling. Current studies underway will study impact on drift seepage due to different degrees of degradation with its probability levels; more specifically: (1) initial drift geometry, (2) worst case geometry and (3) degradation shape at the 75 percentile. Impact on seepage due to THM effects are also being evaluated.

The effect of rock fall on thermal hydrology is negligible because the calculated volume of fallen rock is small (about 0.1 percent) compared with the unoccupied drift volume of 16,650 cubic meters per kilometer of emplacement drift (drift volume outside of the drip</td><td>No additional work required beyond that already planned.</td></tr>
</table>

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	shield and above the invert (CRWMS M&O 2000ay). The Drift-Scale Thermal-Hydrological-Chemical process model (CRWMs M&O 2000az) 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 (CRWMS M&O 2000ba) are used by the *Physical and Chemical Environment submodel Precipitates/Salts Analysis* (CRWMS M&O 2000bb, REV 00) to calculate the chemical environment conditions on the drip shield/waste package and in the invert for radionuclide release. A preliminary estimate shows that the permanent TM effects on the fracture system increase the permeability approximately an order of magnitude in the regions above and below the drift and a factor of three higher in the regions to the side of the drift (CRWMS M&O 2000al, REV00). The permeability increase is due to shear in fractures. Other analysis evaluating mountain-scale THM effects shows one to two orders of magnitude reduction in fracture permeability due to thermal expansion of rock into fractures. Most of these permeability changes are reversible. This analysis assumes that shear effects are negligible as they result in only localized increases in fracture permeability. (This work will be documented in the "Mountain-scale coupled processes AMR") The seepage model shows the trend that the seepage into the drift decreases with increasing fracture permeability since increasing the fracture permeability allows more water to flow around the drift. If THM induced shear effects dominate, fracture permeabilities will increase and subsequently seepage will decrease. In this case, THM effects on seepage can be screened from the TSPA (CRWMS M&O 2000am, REV 00 ICN 01). On the other hand, if shear effects are not important, fracture permeabilities will likely decrease and the effects on seepage must be evaluated.	

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	Work is in progress to enhance the approach to modeling TM coupling and to provide additional technical basis for screening out TM effects on hydrologic properties and on seepage into the drifts. One of the major parameters for assessing the effects of TH altered hydrologic properties is fracture permeability. The *Coupled Thermal Hydrologic Mechanical Effects on Permeability Analysis and Models Report* (ANL-NBS-HS-000037) that is being developed addresses changes in fracture permeability over time resulting from thermal mechanical effects, including normal and shear deformation of fractures. This is a 3 Dimensional study, which incorporates fracture sets used in drift degradation analysis. Additional analyses are under consideration that will provide validation of the model used in the above AMR, and to assess drift degradation, variability and time dependence of rock properties, and alternative boundary conditions.	

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Acceptance Criterion (AC) 1: Spatial and Temporal Distribution of Flow -Important design features, site-specific physical phenomena and couplings, and consistent and appropriate assumptions have been incorporated into the spatial and temporal distribution of flow abstraction in the PA and the technical bases are provided. The TSPA abstraction in the DOE LA identifies and describes aspects of spatial and temporal distribution of flow that are important to waste isolation and includes the technical bases for these descriptions. Specifically:

- DOE temporal abstractions of the spatial and temporal distribution of flow appropriately incorporate the physical couplings (THMC) or sufficient justification is provided for exclusion of these couplings. The DOE abstraction incorporates or conservatively bounds coupled THMC processes based on, for example, independent models, laboratory and field analyses, literature reviews, natural analog data, and other available information.
- DOE estimates of performance are not over optimistic, given the excluded set of phenomena and the implementation of coupled THMC processes in the TSPA.

NRC Status	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** TM effects on spatial and temporal distribution of flow are screened out of the DOE PA abstraction (CRWMS M&O, 2000j) using the assumptions that important TM effects would be reversible. These assumptions include that: (i) TM, effects on hydrological properties would develop during the period of increasing temperature; (ii) drift seepage would not occur during this period because of hot and dry conditions at the repository level; and (iii) the TM effects would be reversed before moisture returns to the repository level. These assumptions are questions. Permanent TM-induced changes in hydrological properties and emplacement-drift geometry can be expected as discussed under the U.S. Department of Energy Approach subsection of this section (also, Ofoegbu, 2000; Ofoegbu et al., 2000). DOE needs to develop estimates of changes in hydrological properties and emplacement-drift geometry that account for the anticipated geomechanical response to the proposed thermal loading and potential seismic loading; and account for such changes in the abstraction of spatial and temporal distribution of flow.	DOE considers this criterion is **CLOSED-PENDING**. A preliminary estimate shows that the permanent TM effects on the fracture system increase the permeability approximately an order of magnitude in the regions above and below the drift and a factor of three higher in the regions to the side of the drift (CRWMS M&O 2000al). The permeability increase is due to shear in fractures. Other analysis evaluating mountain-scale THM effects shows one to two orders of magnitude reduction in fracture permeability due to thermal expansion of rock into fractures. Most of these permeability changes are reversible. This analysis assumes that shear effects are negligible as they result in only localized increases in fracture permeability. (This work will be documented in the "Mountain-scale coupled processes AMR") The *Coupled Thermal Hydrologic Mechanical Effects on Permeability Analysis and Models Report* (Draft - ANL-NBS-HS-000037) that is now underway will revisit the estimate in fracture permeability over time resulting from thermal mechanical effects, and will include normal and shear deformation of discrete fractures. This is a 3 Dimensional study, which incorporates fracture sets used in the Drift Degradation Analysis (CRWMS M&O 2000f. Additional analyses are under consideration to extend the validation of the Drift Scale Thermal-Hydro-Mechanical Model (CRWMS M&O 2000az)that is presented in	The analyses to support any potential license application design will address the appropriateness of design parameters, modeling approaches, and loading conditions by performing sensitivity studies.

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	this AMR The seepage model shows the trend that the seepage into the drift decreases with increasing fracture permeability since increasing the fracture permeability allows more water to flow around the drift. If THM induced shear effects dominate, fracture permeabilities will increase and subsequently seepage will decrease. In this case, THM effects on seepage can be screened from the TSPA (CRWMS M&O 2000am, REV 00 ICN 01). On the other hand, if shear effects are not important, fracture permeabilities will likely decrease and the effects on seepage must be evaluated. Work is in progress to enhance the approach to modeling TM coupling and to provide additional technical basis for screening out TM effects hyfrologic properties and on seepage into the drifts. The effects of drift degradation on seepage are included in the Drift Seepage Model for PA including drift collapse (CRWMS M&O 2000an, REV 01) and therefore the TSPA. Seepage is evaluated accounting for (a) near-drift excavation effects through calibration; (b) for smaller rockfall (~ 1 m^3) and (c) deeper degradation in the drift ceiling. Current studies underway will study impact on drift seepage due to different degrees of degradation with its probability levels; more specifically: (1) initial drift geometry, (2) worst case geometry and (3) degradation shape at the 75 percentile. Impact on seepage due to THM effects are also being evaluated. Additional analyses are under consideration that will provide validation of the model used in the above AMR, and to assess drift degradation, variability and time dependence of rock properties, and alternative boundary conditions.	

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Acceptance Criterion (AC) 3: Spatial and Temporal Distribution of Flow - Determine that parameter values, assumed ranges, probability distributions, and/or bounding assumptions used in the spatial and temporal distribution of flow abstraction 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 PA have been provided. Specifically:

- Input values used in the abstraction are consistent with the initial and boundary conditions and the assumptions of the conceptual models for the YM site. For example, estimation of the deep percolation flux into the drift is based on the infiltration rate, structural control (for flow diversion via faults), thermal loading strategy (for reflux), and other design features that may affect spatial and temporal distribution of flow.

NRC Status	DOE Status	DOE-Proposed Path Forward
Acceptance Criterion Status: **OPEN** The representation of repository thermal loading and ventilation in DOE's abstraction of the spatial and temporal distribution of flow is discussed under AC1 of *Quantity and Chemistry of Water Contacting Waste Packages and Waste* Forms under the U.S. Nuclear Regulatory Commission Staff Evaluation subsection of this section. There are concerns, and an approach to address these concerns is discussed in the same section.	DOE considers this criterion is **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. Section 3.10.3 of the UZ F&T PMR (CRWMS M&O 2000as) 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 (CRWMS M&O 2000ar, R00 ICN 02). DOE considers that ranges of parameters used to determine effects of coupled processes on percolation and seepage are adequate to support the evaluations specified. 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 2000bc) 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.	No additional work required beyond that already planned.

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NRC Specific Points/Questions that need to be addressed by DOE (based on RDTME Telecons)

I VENTILATION

(1) Explain the technical basis for heat removal by ventilation using: (a) the ANSYS-based calculation in the Ventilation AMR; (b) the MULTIFLUX code; and (c)Verification/Validation of both models using test data.

RESPONSE:

a) The ANSYS-based calculational method is explained in the document: "Ventilation Model," ANL-EBS-MD-000003 Rev 00.

b) Multiflux is covered in a soon-to-be-released document, which will be revision 01 of the document cited above in (a). It is not yet available in a project approved form.

c) The Atlas facility testing has provided some data already, and will produce more as testing proceeds. The early results, not yet documented or checked, indicate that the ANSYS-based model predictions agree reasonably well with the test results. As expected, the model is conservative when compared to actual heat removal in the test. If a mixed convective heat transfer coefficient is used instead of a forced convection coefficient, the agreement is much closer. Use of the mixed convection coefficient results in higher rates of heat removal than does the forced convection coefficient. No reference is yet available for this effort as it is work in progress.

(2) Make an assessment of the effects of drift-axial temperature gradients (from ventilation, WP distribution, and other causes) on the stability of the emplacement drifts.

RESPONSE:

No specific analytical results are available at this time, but there is not likely to be much, if any, effect on stability due to axial temperature variation. The reasoning is that the temperature variations themselves are very low, due to the effects of high ventilation flow. If the variations are small, it stands to reason that any temperature differential-related stresses will also be low. Axial temperature variations are highest in the first year after emplacement, at about 10 °C difference between the warmest and coolest locations for a 1 kW/meter thermal load. This temperature differential occurs over about a twelve-meter drift length. By the 100th year, the differential is down to less than 5 degrees. These results are from a preliminary thermal modeling run which is not yet checked or published.

(3) Make an assessment of the effects of heat flow through the emplacement-drift invert (so-called thermal short-circuit problem) on the stability of the emplacement drifts.

RESPONSE:

No stability effects have been assessed at this time. There does appear to be a warmer area

in the sides of the invert caused by the "shunting" effect of the highly conductive steel members of the invert structure. As with the axial effect discussed above, however, the high rate of ventilation will tend to suppress the effect somewhat. If the invert design still contains steel members at the time of any potential license application, this effect will be evaluated.

(4) Provide a revision of the report -- Repository Thermal Load Management Analysis (B00000000-01717-0200-00135 Rev. 00). This revision should contain the current decay curves for WP thermal output in one document.

RESPONSE:
The document "ANSYS Calculations in Support of Thermal Loading Design for SR" CAL-SFS-MG-000003 Rev 00, contains the decay information currently being used. All commercial spent nuclear fuel waste packages are represented. The defense high level waste portion of the inventory is less well-defined however, and is currently treated as follows when 3-dimensional modeling is performed: An initial heat output at time of emplacement is assumed based on best available data on current plans for defense high level waste. However, the rate of decay used is that of the overall average commercial spent fuel inventory. That is, the defense high level waste is treated like a low heat output commercial spent nuclear fuel package. This injects some conservatism as the actual defense high level waste decay will proceed more quickly, essentially dying out after 300 years or so.

II DESIGN BASIS ROCK SIZE

Define design basis rock size. In the Summary Highlights of NRC/DOE Technical Exchange and Management Meeting on Structural Deformation and Seismicity, DOE stated that a bounding rock size will be used for drip shield design to account for rockfall impact loads. The current suggested design basis rock size of 6 metric tons is, however, not a bounding rock size. In the context of the above, explain: (a) the purpose of drip shield; (b) life expectancy of the drip shield; (c) assumed construction and placement details; (d) assumptions on the anticipated environment under which the drip shield is to perform; (e) what, if any, credit is taken for the performance of the drip shield in meeting the performance objectives and (f) is rockfall screened out as a result of the results of key block analyses? The answers to these questions will decide what level of review of this issue will be conducted under the RDTME KTI.

RESPONSE:
A discussion of the design basis rock size is provided in the presentation materials for subissue 3, Component 2, Acceptance Criterion 1, "Design Basis Rock Size for Drip Shield."

III. DRIFT DEGRADATION AMR

(A) Key Block Analysis

(1) Clearly define the term "key block" as the term has been used in a non-traditional way with some apparent inconsistencies.

RESPONSE: A key block in the Drift Degradation AMR is defined as a block on an excavation surface, which is both kinematically and mechanically unstable, whose failure opens up the excavation surface for further potential failures by subsequent blocks.

(2) Explain why the effects of repeated joints sets have been ignored in the analysis.

RESPONSE: DOE interprets the term “repeated joint sets” to mean repeated joints. Repeated joints have been explicitly modeled in the Drift Degradation AMR. Therefore, the effects of repeated joints have been included in the analysis.

(3) **NRC:** Seismic ground motions up to 10^{-5}/yr probabilities were used in the key block analysis for postclosure considerations. In view of the proposed rule (10 CFR Part 63) requirement that lower probability ground motions be considered for postclosure, either use lower probability events or explain the rationale for limiting to 10 E-4/year seismic hazard.

RESPONSE: The use of lower probability ground motions is under consideration.

(4) Provide information to explain how Equation V-1 was derived.

RESPONSE: Equation V-1 was derived based on the quasi-static evaluation of a block resting on a rock slope during seismic shaking. The derivation is provided in Attachment A.

(5) Long-term degradation of joint strength was represented through reduction only in joint cohesion. Why was the long-term degradation of the friction angle not considered?

RESPONSE: Joint cohesion in the rock fall model takes into account the “locked patches” that occur along joint surfaces. These locked patches are healed in some way, either due to fill in the joints or because they are portions along the joint that were never broken (non-persistent). Examples of both these kinds of locked patches are common in the joints at Yucca Mountain. These patches must be severed before removal of the block is possible. Once the excavation is made, induced stresses around the excavation will result in resolved shear and normal stresses along the joint surfaces. The breaking of patches under these resolved stresses is a crack growth process, and a time-dependent crack growth process, such as stress corrosion (Potyondy and Cundall 1998), is the most appropriate mechanism to model this process. The actual nature of the crack growth depends on the sign and magnitude of the resolved shear and normal stresses.

Since friction is thought to be caused by the microscopic roughness of the surfaces of contact, but is not a crack growth process, there is less physical basis for considering the

degradation of the friction angle with time compared to the degradation of cohesion with time. Frictional slip is, however, a time-dependent process as shown by the mechanics of creep of rock. Time-dependent frictional slip has not been taken into account in the present model. DOE considers the present model adequate for Site Recommendation, but degradation of the friction angle will be considered in the revision of the Drift Degradation Analysis to be developed to support license application.

(6) Provide clarifications for the following items: It is not clear how Equations (I-1) and (I-2) have been developed following Kemeny (1991) and Kemeny and Cook (1986). Contrary to what is assumed in Attachment I, a crack propagating under mode II shear load will not propagate in a direction along the crack axis. Equation (I-3) suggests an inherent assumption of sub-critical crack growth. However, by definition, a joint (crack) cannot continue to grow within an existing crack segment.

RESPONSE: Somewhat expanded derivations for Equations (I-1) and (I-2) are given as follows:

Consider a single asperity of width 2a contained in a body of width 2w under a far-field shear stress τ and normal stress σ_n, as shown in Figure 1a. Also, assume ϕ is the friction angle for the joint surfaces on either side of the asperity. This will result in frictional stresses along the joint surfaces of $-\sigma_n \tan\phi$.

By linear superposition, the body under the boundary conditions in Figure 1a is equivalent to the sum of the same body with boundary conditions shown in Figures 1b plus those shown in Figure 1c. In Figure 1b the body is subjected to a far-field shear stress $\sigma_n \tan\phi$ and a normal stress σ_n along with frictional stresses along the joint surfaces of $-\sigma_n \tan\phi$. In Figure 1c the body is subjected to a far-field shear stress $\tau - \sigma_n \tan\phi$ and a normal stress σ_n but no tractions along the joint surfaces. Note that Figure 1c is a frictionless problem and can be handled by standard fracture mechanics theory. The boundary conditions in Figure 1b result in no deformation and no stress intensity factor and can be discarded. Therefore from the standpoint of fracture deformation and stress intensity factor, Figure 1a is equivalent to Figure 1c. From Rooke and Cartwright (1976) the mode II stress intensity factor for the geometry and boundary conditions shown in Figure 1c is given by:

$$K_{II} = \frac{(\tau - \sigma_n \tan(\phi))2w}{\sqrt{\pi a(t)}} \qquad (1)$$

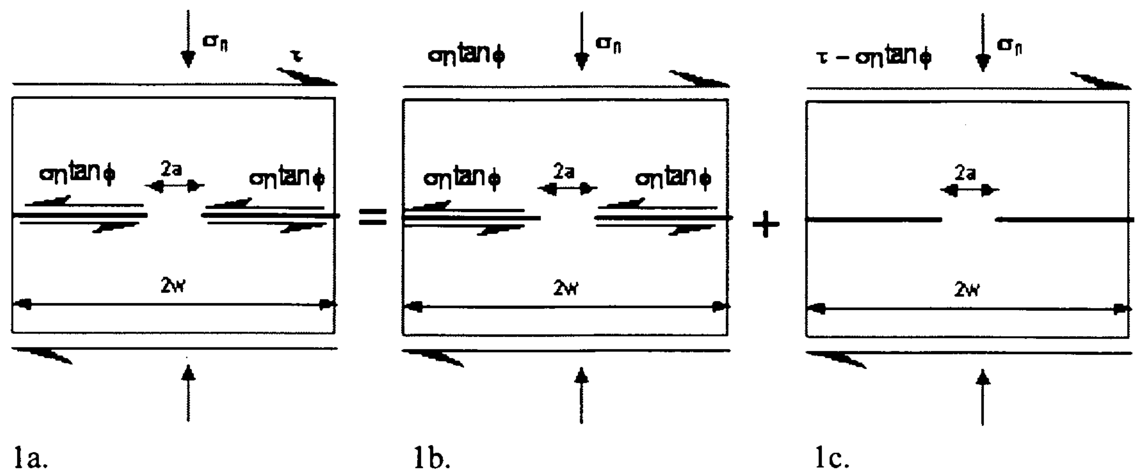

Figure 1. Parameters Used for Calculation of Mode II Stress Intensity Factor

It is assumed that shear crack growth will occur when the mode II stress intensity factor, K_{II} reaches the critical fracture toughness under mode II loading, K_{IIC}. Setting $K_{II} = K_{IIC}$ and solving Equation (1) for τ gives the following:

$$\tau = \frac{K_{IIC}\sqrt{\pi a}}{2w} + \sigma_n \tan\phi \tag{2}$$

Equation (2) is the failure criterion for the discontinuity as a whole (joint plus asperity), and is made up of two terms, a cohesion term and a fricitonal term. Thus the unbroken patches along the asperity provide a cohesion to the joint. The first term on the right hand side of the equation is the joint cohesion due to the asperity:

$$c = cohesion = \frac{K_{IIC}\sqrt{\pi a}}{2w} \tag{3}$$

It is assumed that crack growth will occur in the plane of the cracks, which is the direction of maximum shear stress around the crack tips. Experiments have shown that asperities in shear will often ultimately fail in the maximum shear direction, even though initial crack growth may be in the direction of maximum hoop tension (Bobet and Einstein, 1998; Rao et al., 1999; Sagong and Bobet, 2000; many others). This is the concept of a "shear crack", which is widely used in earthquake mechanics and is becoming more widely accepted for joint mechanics as well (Li, 1987; Kemeny, 1993). It has also been used previously in Yucca Mountain studies (EPRI, 1996). Experimentally determined values of K_{IIC} take into account the energy for both the initial extensile microcrack growth and subsequent shear failure. For samples in the laboratory, the shear fracture energy is calculated by integrating the area under

the stress strain curve after correcting for elastic deformation (Wong, 1982; Kemeny and Cook, 1987). The advantage of using shear crack growth is the computational simplicity over a full mixed-mode crack growth analysis.

(7) Explain clearly how Equation (I-5) has been derived.

RESPONSE: The effect of thermal loading on the likelihood of slip along a joint was investigated. Slip along the joint is necessary in order to cause stress concentrations at the tips to drive crack growth. The driving force for slip is the "effective" shear stress along the joint, which is the shear stress in excess of the frictional stress due to the normal stress acting on the joint:

$$\tau_{eff} = \tau - \sigma_n \tan\phi \qquad (4)$$

τ_{eff} can be positive or negative depending on the orientation of the joint relative to σ_1 and the magnitudes of σ_1 and σ_3. Joint slip can only occur for positive values of τ_{eff}. Previous studies using a thermo-mechanical finite element damage model (EPRI 1996) indicated that thermal loading would increase damage in the rock due to the slip and propagation of joints. This analysis assumed a random distribution of joint orientations in each element. For the present work, a study was conducted using UDEC, but this analysis was discontinued since it was found that the results were too dependent on the specific orientation of joints that were used.

A second analysis for the present work was conducted using thermal stresses from a finite element model along with the analytical relationship for resolved shear and normal stresses at a particular orientation relative to a set of principal stresses. Using the finite element results, the effective stresses for a range of orientations were calculated (2D analysis only). An example of the results is shown below. For these results, a circular underground tunnel was modeled and stresses were calculated with and without thermal loading (the thermal loading case assumed a maximum drift wall temperature of 165° at t=100 years). At a location close to the boundary of the excavation in the roof (radial distance of 1.1 times the radius of the opening), it was found that σ_1=4.75 MPa and σ_3=0.35 MPa for the no heating case (cool case) and σ_1=39.6 MPa and σ_3=3.6 MPa for the maximum thermal loading at t=100 years (hot case). The effective stresses at different potential joint orientations were calculated as follows:

$$\tau_{eff} = \left[\frac{\sigma_1 - \sigma_3}{2}\sin 2\beta\right] - \left[\frac{\sigma_1 + \sigma_3}{2} + \frac{\sigma_1 - \sigma_3}{2}\cos 2\beta\right]\tan\phi \qquad (5)$$

where β is the angle between the joint orientation and σ_3. The effective stress as a function of the angle between the joint and the σ_3 axis is shown in the graph below (Figure 2), for the case of ϕ = 28° (and using the specific stresses mentioned above). The average effective stress for the cool case is 0.086 MPa and 0.102 MPa for the hot case, an increase of about

18%.

Equation I-5 was then derived by finding a function that reasonably fit the maximum average increase of 18% and the overall shape of the temperature vs. time curve, which shows a relatively sharp increase up to the maximum at 100 years followed by a more gradual decrease over the next 1000 years. The following function was found to fit reasonably well:

$$f(t) = 1 + 0.00001044556 * e^{(120-t)/50} t^2 \tag{6}$$

Looking back on this analysis, the idea of using an average increase in the driving stress for joint slip is unsatisfying for several reasons. First of all, the average depends on where around the opening the calculations are made. More importantly, the average ignores the large increases in driving stress that occur for certain critical joint orientations. However, the average was required for the keyblock model, which utilizes a single cohesion value for all joints. DOE considers the present model adequate for Site Recommendation, and DOE views the inclusion of thermal effects on joint slip as a potential refinement to the analysis. DOE is considering including thermal effects on joint slip in future analyses that support the license application.

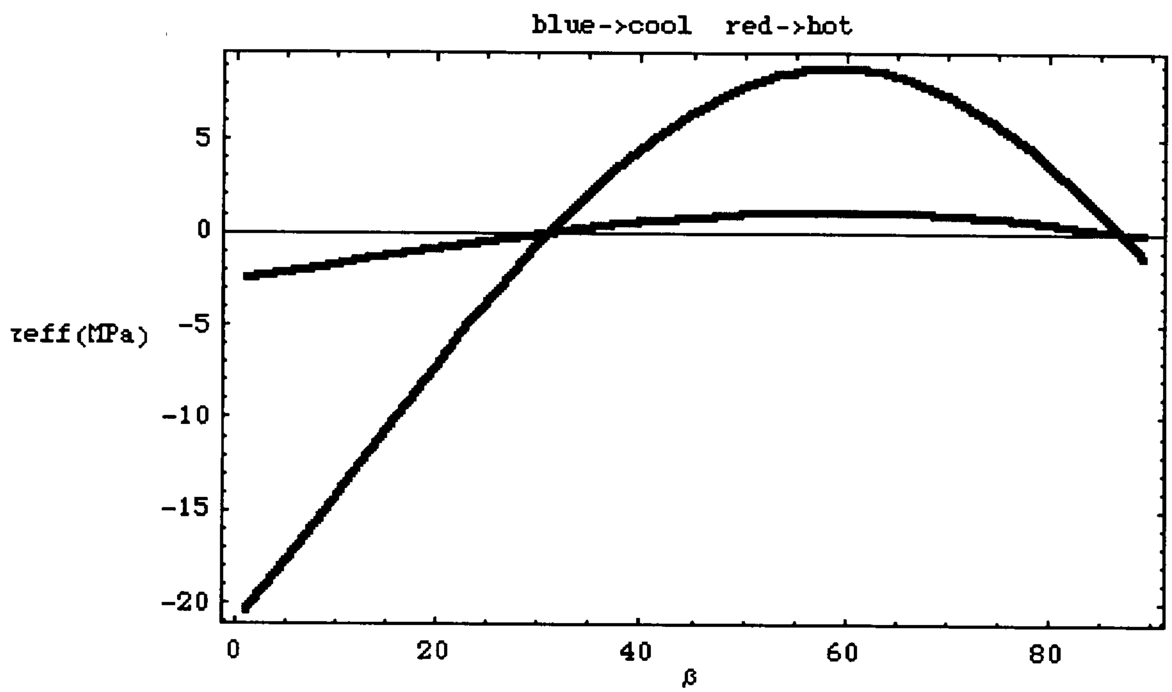

Figure 2. Effective Stress as a Function of the Angle between the Joint and the σ_3 Axis

(8) The DRKBA rock fall model assumes that the radius of a joint plane is equal to twice the

mapped trace length. We agree with the assessment presented in Appendix XIV of the Drift Degradation Analysis report that this assumption tends to be conservative in the sense that it leads to a larger number of blocks. However, number of blocks is not the only concern in this analysis. A competing concern is the size of blocks. The latter may be more important than the former. This radius assumption used may underestimate large block sizes. Why were sensitivity analyses not performed to assess the effect of this assumption on block sizes?

RESPONSE: The use of shorter trace lengths does not cause the formation of larger blocks since the blocks must have geometries that favor movement into the opening. The non-connected fracture planes provide restraining surfaces that prevent block movement. Therefore, the use of shorter trace lengths in the rock fall model would not be conservative. The size and frequency of blocks observed in the ESF agrees with the static results from the key block model, thus validating the assumption that the radius of the joint plane in the rock fall model is equal to twice the mapped joint trace length.

(9) Explain clearly how the number of blocks for various rock units was determined in the Drift degradation analysis report.

RESPONSE: DRKBA rock fall models were developed for each lithologic rock unit. The rock fall model for each rock unit includes up to 400 simulations of a 24-m length of tunnel. Each of these simulations develops a different fracture pattern based on the statistical distribution of fractures as determined from tunnel mapping of that rock unit. The DRKBA software tracks the formation of blocks, including both the number and size of blocks. Therefore, for 400 simulations, the number of blocks per kilometer (N) for a particular rock unit is:

$$N = \frac{\textit{total number of blocks in all simulations}}{(\textit{400 simulations} \times \textit{24 m/simulation})} \times \textit{1000 m/km}$$

(10) The joint mapping data used for key block analysis were collected from limited regions (within ESF and ECRB). Explain how the representativeness of these data to the entire emplacement horizon will be demonstrated.

RESPONSE: The representativeness of the DRKBA rock fall model was addressed in the Structural Deformation and Seismicity (SDS) Technical Exchange. A summary of the information discussed at the SDS Technical Exchange is provided below. The representativeness of the joint mapping data from the ESF and ECRB will be confirmed by an evaluation of joint mapping data collected during construction of the actual emplacement drifts.

Representativeness of Joint Data. The natural variability of fractures within a rock mass always represents uncertainty in the design of structures in rock. The uncertainty of fracture geometry (i.e., the orientation, spacing, and trace length of fractures) anticipated at the

emplacement drift horizon has been diminished with the construction and subsequent detailed fracture mapping of the approximately 10 km of tunnels that comprise the ESF. Two approaches were used to collect fracture data in the ESF: full-periphery geologic mapping (FPGM) and detailed line surveys (DLSs). The FPGMs present a full-periphery map of the tunnel walls as encountered in the subsurface excavation. The DLS presents a detailed inventory of fractures and associated attributes that intersect the survey line along the tunnel wall. The vast amount of fracture data collected from the north-south-trending Main Drift and the east-west-trending Cross Drift provides a very good representation of the range of fractures anticipated at the emplacement drift horizon.

The degree of fracture characterization at Yucca Mountain far exceeds that done in typical tunneling projects throughout the world. Typically, tunneling projects rely on a series of boreholes to characterize fractures anticipated at the tunnel horizon. Because of the limited exposure of the rock mass when using borehole information, the uncertainty associated with predictions from fracture geometry data for typical tunneling projects can be considerably greater than that in the DRKBA rock fall model for the Yucca Mountain Project. The fracture mapping of the tunnels in the ESF provides a high degree of confidence that the full range of fracture characteristics anticipated at the emplacement drift horizon has been sampled. Because the FPGMs depict an unrolled view of the full periphery of the subsurface excavation, they represent a true volume sampling of the rock mass. This range of fracture variability from tunnel mapping has been captured in the DRKBA rock fall model through multiple Monte Carlo simulations of the rock mass, thus providing a realistic representation of the fractured rock mass at the emplacement drift horizon.

(11) The Drift Degradation Analysis report does not consider joints with trace length smaller than 1 m because the limited data available is not considered representative. The report states that: "The effect of small trace length fractures on block development, if any, would be to either decrease the maximum block size, or decrease the probability of occurrence of the maximum block. The impact of not considering this data is that the block size distributions presented in this analysis could potentially be more conservative." These statements are in general true for rock units with small joint spacings. However, for rock unit such as Tptpll, it may not be entirely correct. By including joints with trace length smaller than 1 m for the Tptpll, more blocks and relatively larger size of blocks may develop. Explain how the analyses will be considered to be complete and technically defensible without considering joints with trace length smaller than 1 m in assessing rock blocks for Tptpll.

RESPONSE: Joint trace lengths less than 1 m were considered in the key block analyses. If joints with trace lengths smaller than 1 m were included in the key block analyses for the Tptpll, larger blocks will not develop (see explanation in response to item #8 above). Field observation of the small trace length fractures clearly shows that these fractures do not contribute to block development. Therefore, the key block analyses presented in the Drift Degradation AMR are complete and technically defensible without including the small trace length fractures in the Tptpll.

(12) **NRC:** Appendix IX of the Drift Degradation Analysis report addresses block size geometry using the UNWEDGE code. In the associated analysis, variation of joint dip direction is evaluated to determine block geometry. Is this approach complete without including the variations of dip angles? The effects of considering the variations of dip angles on block size geometry need to be assessed for the development of a defensible technical basis. The results are important to validate the assumption of invariant block apex, which is used to determine rock weight per unit length in the analysis of rock fall impact on drip shields and waste packages.

RESPONSE: DOE considers the present model adequate for Site Recommendation, and DOE views the inclusion of effects of variations in dip angles on block geometry as a potential refinement to the analysis. DOE is considering including effects of variations in dip angles on block geometry in future revisions of the Drift Degradation Analysis that support any potential license application.

(13)Section 6.4.3 of the Drift Degradation Analysis report attempts to predict "final" drift profiles after considering time-dependent and seismic effects. According to the report, the approach adopted allows for assessment of progressive block failure. Some predicted drift profiles for different rock units and under different stages of deterioration are presented in Appendix XII. Explanations are not provided, however, in the Drift Degradation Analysis report regarding the seemingly different shapes of drift degradation profiles at different stages of degradation (e.g., figures XII-1, XII-2, XII-5, XII-10, XII-13, XII-18, XII-20). For example, in Figure XII-1, the profiles at static condition and seismic level 1 condition are fundamentally different from those for seismic level 2 and seismic level 3 conditions. Another example is Figure XII-18. The drift profile at 200 years is fundamentally different from that at 0; 2,000, and 10,000 years. Explain clearly how this difference in shape can occur [e.g. Figure XII-18(a) versus Figure XII-18(b)]. If progressive block failure concept is used, should the profile in Figure XII-18(b) be developed based on Figure XII-18(a), that is, these two profiles should be related? By examining these two profiles, it can be shown that some rock blocks already fallen at 0 year [Figure XII-18(a)] were still in place at 200 years [Figure XII-18(b)].

RESPONSE: As described in Attachment XII, the worst-case profile is determined for each case, hence the four cross-sections depicted per figure may not necessarily be from the same area. As for the changes comparing top to bottom, the top part shows the static and either 1000-yr seismic event or 200-yr time period. There was typically very little change in these cases, therefore the profiles are typically similar. The bottom part of the figures show either the 5000-yr and 10000-yr events, or the 2000-yr and 10000-yr time periods. These events were typically similar, but usually different from the static case.

With the nature of probabilistic analysis, the drift profile predicted in the DRKBA rock fall model varies along the axis of the tunnel. To select the most conservative profile, or the worst case cross section, the cross section views along the drift axis were first created. The most conservative profile was then selected based on visual inspection of all the cross sections. This is the reason that Figure XII-18(a) is different from Figure XII-18(b); that is,

the cross sections depicted in each figure occurred in different simulations, or at a different location in the tunnel. The profiles in each figure are "fundamentally different" because the joint pattern in each simulation, although sampled from the same joint population, were different. It was not the intent of the analysis to show progressive failure at the same location over time, but to show the worst case failure over time given the range of joint conditions.

(14) In Section 1.3 WORK SCOPE of the Drift Degradation Analysis report, it indicates that locations of rock fall will be determined as part of the analysis. Provide related discussion in the report.

RESPONSE: "Locations" of rock fall as indicated in Section 1.3 of the Drift Degradation AMR should be considered in a broad sense, referring to the occurrence of rock fall within each lithologic unit. This will be clarified in the next revision of the Drift Degradation AMR.

(15) Assessment provided in Attachment-VII is based on incomplete information. While in general we agree that underground facilities are less prone to seismic/earthquake damage than surface facilities, there are case studies where underground facilities subjected to seismic effects received significant damage (e.g., Raney, 1988; Owen and Scholl, 1981; Sharma and Judd, 1991).

RESPONSE: Case studies where underground facilities subjected to an earthquake received significant damage are in general characterized by either shallow overburden (Sharma and Judd 1991), poor ground condition (Rowe 1992), or fault intersection (Rowe 1992 and Raney 1988). To provide more complete information, these additional case studies will be included in the next revision to the Drift Degradation Analysis.

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(B) Verification of Key Block Analysis Approach

(1) Propose an approach to verify the DRKBA rock fall model including explicitly: (a) thermal loads; (b) long-term degradation of rock mass properties; and (c) time histories of appropriate seismic motions..

RESPONSE: DOE will respond to this during the Technical Exchange for RDTME.

(2) Demonstrate how the inputs to the verification model will be reasonably identical to the inputs used for the DRKBA model with respect to the following:

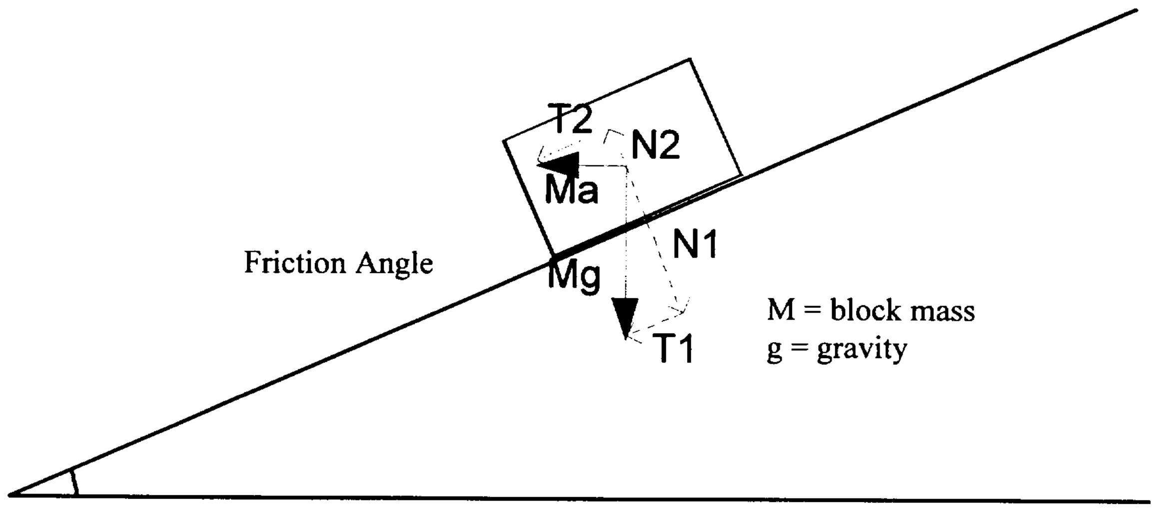
1) Fracture network

2) Thermal and mechanical properties
3) Thermal loading
4) Seismic loading
5) Calculated rockfall size distribution
6) Calculated emplacement-drift geometry

RESPONSE: DOE will respond to this during the Technical Exchange for RDTME.

Attachment A

Derivation of Equation V-1 in Attachment V of the Drift Degradation Analysis



Tangential Forces:

$$T1 = Mg * \sin\theta, \qquad T2 = Ma * \cos\theta \qquad \text{Eq (1) (2)}$$

Normal Forces:

$$N1 = Mg * \cos\theta, \qquad N2 = -Ma * \sin\theta \qquad \text{Eq (3) (4)}$$

At the incipience of block sliding, the tangential force is equal to the resisting frictional force:

θ

$$T1 + T2 = (N1 + N2) * \tan\phi \qquad \text{Eq (5)}$$

therefore,

$$Mg * \sin\theta + Ma * \cos\theta = (Mg * \cos\theta - Ma * \sin\theta) * \tan\phi$$

Eq (6)

Equation 6 can be rearranged to the following form:

$$\frac{a}{g} = \frac{\cos\theta * \tan\phi - \sin\theta}{\cos\theta + \sin\theta * \tan\phi} = \frac{\tan\phi - \tan\theta}{1 + \tan\theta * \tan\phi}$$

Eq (7)

Equation 6 can be rewritten based on the trigonometric relationship for tangent function:

$$\frac{a}{g} = \tan(\phi - \theta) = \tan(\Delta\phi)$$

Eq (8)

Equation V-1 in Attachment V is therefore derived as:

$$\Delta\phi = a\tan(\frac{a}{g})$$

Eq (9)

Additional NRC Questions on **Ground Control for Emplacement Drifts for SR (ANL-EBS-GE-000002 REV 00)**

Ground Surface Temperature

The ground surface temperature varies with elevation but a constant value is assumed for this calculation. Explain the rationale for ignoring the potential three-dimensional effects of the spatially variable ground-surface temperature.

Response: Emplacement drifts are located at about 300 m below the ground surface. Spatial variations of the ground surface temperature above the repository footprint are within a few degrees at most. For the thermal load considered for SR, it takes several hundred years for the heat front to travel from waste packages to the ground surface (DTN: MO9911SPAWAQ01.000). The peak drift wall temperature is considered to be the key factor in defining the maximum load on ground support. Spatial variations of the ground surface temperature are inconsequential. Use of a constant ground surface temperature in the ground control analysis is adequate.

Thickness of Stratigraphic Units

The thickness of each of the stratigraphic units varies spatially within the repository area but a constant thickness is assumed for each unit in the calculation. Explain the rationale for ignoring the potential three-dimensional effects of the spatially variable stratigraphic-unit thicknesses.

Response: From a thermal point of view, thickness variations of stratigraphic units may have an effect on rock temperature and its distributions. However, the temperature input used for the ground control design was bounding. Any changes in temperature caused by the variations of thickness of stratigraphic units are anticipated within the range bounded by the temperature input used (CRWMS M&O 2000. *Ground Control for Emplacement Drifts for SR.* ANL-EBS-GE-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000414.0875).

Thermal Conductivity

In the calculation, wet thermal conductivities are used for temperatures lower than 100 °C and dry thermal conductivities at temperatures higher than 100 °C, which amounts to an assumption that the rock dries up at 100 °C. Provide the technical basis for this assumption.

Response: Data were collected from TDMS (DTN: SN0003T0571897.013 and DTN: MO9911SEPGRP34.000).

Thermal Expansivity

Explain why intact-rock thermal expansivity is identified as rock-mass thermal expansivity in table 4-6 of the report.

Response: The coefficients of thermal expansion used were obtained from laboratory tests using small rock samples, and for intact rock. These coefficients are higher than those for rock mass containing fractures and joints, which may close during heating, resulting in lower effective thermal expansivity. Therefore, use of the coefficients of thermal expansion for intact rock

to evaluate the thermally-induced deformation and stress in rock mass is conservative.

Strength Parameters Dependent on Range of Confining Stress

Explain how the two sets of strength parameters for confining stress ranges of 0–3 and 0–42 MPa were implemented in the calculation.

Response: The strength parameters corresponding to a confining stress range of 0 to 3 MPa were used throughout the analysis, while those corresponding to a confining stress range of 0 to 42 MPa were for sensitivity study (CRWMS M&O 2000. *Ground Control for Emplacement Drifts for SR.* ANL-EBS-GE-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000414.0875).

Explain which set of strength parameters mentioned above is used for assessing steel set and rock bolt performance. Common sense dictates that the strength parameters for confining stress range of 0-42 MPa should be used because it represents more realistic condition in the heated emplacement drifts.

Response: The strength parameters corresponding to a confining stress range of 0 to 3 MPa were used and considered to be applicable to the immediate vicinity of an emplacement drift where the confining stress in the radial direction is low.

Include Unconfined Compressive Strength and m_i (Hoek-Brown) parameter for intact rock in Table 4.4.

Response: In general, if a parameter is not an input to the analysis, it will not be included in the report. The UCS and m_i (Hoek-Brown) parameter for intact rock were not used as input for the analysis. They may be included in the future analysis for completeness.

Explain how the rock mass elastic modulus for Lithophysal rock in Table 4-5b is greater than the intact rock elastic modulus.

Response: As mentioned, the rock mass mechanical properties were determined based on field mapping data and rock mass quality index approach. Reevaluation of the approach will be performed.

Note that there are other concerns on strength parameters that were raised in the IRSR and discussed during the telecons.

Degradation of rock properties

Long-term degradation of rock mass and joint strength properties should be included in the analysis.

Response: The analysis only addressed the issues related to the ground control during the preclosure period. Degradation of rock mass and joint properties during this period is considered negligible, and therefore, not included.

Scaling of Steel-Set and Rock-Bolt Properties

What properties of rock bolts and steel sets are scaled as described on p. 23 and 48 of the report? Provide the technical basis for the scaling.

Response: The yield strength of bolt, grout bond stiffness, and grout bond strength of rock bolts and the Young' modulus and yield strength of steel sets are scaled by the spacing between them. The technical basis for the scaling is provided in the FLAC user's manual (Itasca Consulting Group 1996a. *FLAC, Fast Lagrangian Analysis of Continua, Version 3.3*. Four Volumes. Minneapolis, Minnesota: Itasca Consulting Group. TIC: 236418; 236419; 236420; 236421).

Rock Reinforcement

Describe the criterion for identifying "zones needing rock reinforcement", as mentioned on p. 25 of the report.

Response: As discussed in the report, the rock bolts are recommended for the emplacement drifts excavated in the Tptpmn unit, which is heavily jointed and non-lithophysal rock (CRWMS M&O 2000. *Ground Control for Emplacement Drifts for SR*. ANL-EBS-GE-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000414.0875).

Seismic Loading

Provide the technical basis for representing the site-specific seismic ground motion time history as a sinusoidal velocity wave.

Response: A sinusoidal velocity wave form with its amplitude equal to PGV was considered adequate for examining the drift response to seismic loads.

Provide the technical basis for the assumption that a 10-Hz sinusoidal wave applied in a 3-s duration is an adequate representation of the design-basis seismic ground motion.

Response: Selection of a 10-Hz frequency and 3-second duration was to expose the rock mass to enough dynamic pulses and to allow for examining the dynamic response of the rock mass.

Provide references for the first two sentences of section 5.3.1 Representation of Seismic Waves.

Quasi-static analysis is usually applied to the discrete mass system, however, its application in continuum system should be referenced.

UDEC Model

Explain why rock blocks within the "jointed subregion" of the UDEC model (p. 47 of the report) were assigned intact-rock properties notwithstanding that the modeled fracture population in the "jointed subregion" represents only a subset of the *in situ* fracture population.

Response: Rock mass properties will be assigned in the future analysis.

Explain how the dimensions of the "jointed subregion" (40 m by 40 m) were determined to be appropriate for the model. Would a smaller or larger "jointed subregion" produce different calculated response.

Response: Sensitivity of the variations of the "jointed subregion" dimension will be studied in the future analysis.

Explain why rock bolts are not modeled using UDEC for both thermal and seismic analyses. The loading conditions on rock bolts under continuum approach may be different from those under discontinuum approach due to joint shear displacements.

Response: This will be assessed in the future analysis.

Explain why only the mean values of joint dips and spacings are used for UDEC analysis. Using these values produces the so-called regular joint pattern. Based on DOE joint mapping data, this regular joint pattern seldom exist in the field. Variation of both joint dip and spacing should be included in developing UDEC model.

Response: This will be assessed in the future sensitivity study.

Effect of Rock Bolts on Temperature Distributions

Explain how the effects of rock bolts on temperature distribution were accounted for in the numerical model, since the cable elements used to represent rock bolts in the FLAC model do not have heat-flow modeling capabilities.

Response: Effects of presence of rock bolts on temperature distribution are considered negligible due to its insignificant volume compared with that of the surrounding rock mass. Ongoing rock bolt analysis may support this.

Modeling of Steel Sets

Explain why steel sets are modeled only using continuum approach. Discontinuum approach may produce displacement along joints that may result in more emplacement drift closure than the continuum approach. Steel set performance should be evaluated using the more/most critical conditions.

Response: It will be very cumbersome to use UDEC to analyze steel sets with a gap between rock surface and steel sets. This will be assessed in the future analysis.

Provide more details regarding how the mechanical properties for the gap element between rock and steel sets are determined.

Response: The mechanical property for a gap element is the coefficient of friction. Other parameters, such as normal contact stiffness and sticking contact stiffness, are numerical parameters and determined, by trial and error, based on the element size, penetration tolerance and compatibility factor, etc. Details are provided on p. 24 of the report (CRWMS M&O 2000. *Ground Control for Emplacement Drifts for SR.* ANL-EBS-GE-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000414.0875).

Initial Ground Relaxation

Explain how the assumed initial ground relaxation of 60% was implemented in the numerical models. Provide the technical basis for the assumed relaxation. Explain how the relaxation was modeled.

Response: Prior to installation of ground supports, a model with an unsupported opening was run to reach mechanical equilibrium. A time.history of rock displacements at crown was recorded and

examined. The total displacement after excavation was determined. A step number which corresponded to a 60% of total displacement was selected for the number of numerical steps needed prior to the installation of ground supports. The technical basis was provided in Section 5.1.1 (CRWMS M&O 2000. *Ground Control for Emplacement Drifts for SR.* ANL-EBS-GE-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000414.0875).

Non-Emplacement Drifts

Explain the basis for the vertical symmetry plane at a horizontal distance of 50 m from the center of the exhaust main (figure 6-7 of report).

Response: A distance of 50 m is more than 10 times the main radius (3.81m), sufficient to eliminate any boundary effects on the numerical results.

Explain the basis for the vertical symmetry plane through the middle of the access main (figure 6-8). 3DEC model in Fig 6-8 shows a vertical plane of symmetry through the center of the Access Main. This model thus assumes that an emplacement drift symmetrically joins on the other side the main access drift. However, all emplacement drifts are at one side of Access main.

Response: The basis was to simplify the model representation such that numerical simulations could be done within reasonable time and numerical results were still reasonably conservative.

A 3D analysis may be required at the junction of emplacement drift, vertical raise and ventilation tunnel. This region will be under heated condition.

Response: A 3D model was constructed and analyzed in the region, results were documented in the ground support analysis for VA (CRWMS M&O 1998. *Repository Ground Support Analysis for Viability Assessment*, BCAA00000-0171-0200-00004 REV 00). Such a model in not included in this ground support analysis for SR. Similar models will be built for LA ground support analyses.

Presentation of Results

Provide temperature, stress and displacement contours in the model before and at different period of thermal loading.

Response: This could be provided in any future analysis.

NRC Questions: RESOLUTION OF ROCKFALL ANALYSIS PROBLEM

Statement of Problem

The rockfall analysis approach reported in the Drift Degradation AMR, Revision 1, is not satisfactory. The approach consists of progressive-failure analyses of the emplacement drifts using a key-block prediction code (DRKBA) with thermal and seismic loads represented through reductions of fracture-surface strength (friction angle and cohesion).

Basis

Thermal and seismic loads are characterized by distributed forces with magnitudes and orientations that vary spatially and with time. The stress induced on a fracture surface by thermal or seismic load depends on the location of the fracture, the attitude (orientation and dip) of the fracture surface, the stiffness of neighboring rock bodies, and the occurrence and nature of movements on neighboring fractures. Consequently, the distribution of seismically or thermally induced fracture-surface stress in a rock mass cannot be correctly represented using a uniform strength reduction of all fracture surfaces. As a result, the thermally or seismically induced failure mechanisms and failure potential of an underground opening and the associated rockfall are likely to be misrepresented using an analysis procedure in which thermal and seismic loads are represented through fracture-strength reductions applied uniformly.

The stress induced by thermal loading may reduce the potential for slip on subvertical fractures as indicated in the AMR (p. 39), but the thermal stress would also induce slip on the subhorizontal fractures and may, as a result, create favorable conditions for the fall of multiple blocks. The approach used to simulate thermal loading in the AMR (uniform reduction of fracture cohesion) does not recognize the important characteristics of thermally induced stress. As a result, this approach is likely to misrepresent the mechanisms and potential for thermally induced fracture slip.

The verification analyses presented in Attachment V of the AMR are inadequate for the following reasons.

(1) The failure mode obtained from Case 1 (p. V-6) is controlled by the fracture pattern and initial (vertical) static load. The failure mode is independent of the applied loading (subsequent to the initial static load). Therefore, Case 1 cannot be used to determine the equivalence of the two sets of loading compared in the analyses.

RESPONSE: The failure mode obtained from Case 1 is not controlled by the fracture pattern and initial (vertical) static load. In this case, failure occurs when either the dynamic load is applied, or when the friction angle is reduced from 41 degrees to 18 degrees. Therefore, Case 1 is a valid and appropriate case.

(2) The only conclusion that can be drawn from Case 2 (p. V-9) is that both sets of loading were insufficient to induce failure. There is no basis for any comparison of the two loading sets.

RESPONSE: Case 2 is used to show that not only does the reduced friction angle approach work for the unstable condition, but it also works for the stable condition.

If the dynamic event occurs and blocks do not fall, then when the friction angle is reduced, blocks should not fall. Case 2 shows this to be true.

(3) The test cases did not include thermal loading.

RESPONSE: It is true that the test cases did not include thermal loading, but if thermal loading were applied to these cases, fewer blocks would fail because of the confinement provided by the thermal load. For these cases, not including thermal loading is conservative.

Paths to Resolution

The DOE may adopt one or more of the following options towards resolving this problem.

(1) Develop a verification of the current approach (key-block analysis with fracture-strength reduction). An acceptable verification would consist of a mechanical analysis of at least one of the simulated fracture networks used in the key-block analysis. Both thermal and seismic loads should be represented explicitly in the mechanical analysis. The key-block approach would be considered verified if the block-size distributions and collapsed-drift geometries predicted from the mechanical and key-block analyses are equivalent.

RESPONSE: DOE considers the rock fall analyses presented in the Drift Degradation Analysis is adequate for Site Recommendation. To increase confidence and remove uncertainty, additional verification of the current approach is being considered in support of any potential license application. To develop a comparable mechanical analysis, a 3-dimensional approach is required that can model a complex fracture pattern and apply both thermal and seismic loads explicitly. 3DEC is an example of a code that may be able to do this.

(2) Abandon the key-block approach and conduct the progressive-failure and rockfall-prediction analyses using a mechanical approach.

RESPONSE: For option 2, it would be difficult to fully capture the range of fracture conditions using a mechanical approach, and therefore this approach is not believed to be beneficial or desirable.

(3) Abandon the progressive-failure analysis and develop a bounding analysis of rockfall. Such a bounding analysis may be performed through block-size distributions calculated from statistical analysis of fracture networks without using the key-block concept.

RESPONSE: For option 3, a bounding analysis might result in some unrealistic block size distributions. Using this approach, it would be difficult to assess the number of blocks occurring. Therefore, option 3 is not desirable.

RDTME SUBISSUE 3 NRC OPEN ITEMS

The following information is either unavailable to the NRC staff, or is yet to be provided by DOE. The open items related to the various components of the RDTME subissue-3 cannot be closed until DOE either provides the information listed, or commits to providing the information on a reasonable schedule, or provides adequate rationale as to why such information is not necessary to resolve the questions.

1. Thermal-Mechanical Effects on Design of Underground Facility (IRSR Section 5.3.1)

1.1 Thermal-Load Characterization

1. Provide a description of the waste-package thermal output history and the anticipated in-drift thermal flux used as the design basis for the GROA. This includes the technical bases for the projected heat-removal capability of the emplacement-drift ventilation system and for the approach used to represent ventilation in thermal modeling of waste packages and emplacement drifts.

Waste-package thermal output history in CRWMS M&O (1997a) may no longer be applicable considering changes made after the VA design. DOE indicated the possibility of fuel blending to homogenize WP thermal output and is expected to provide the appropriate decay curves. Also, application of line-load concept in EDA II design relied on end-to-end spacing of 10 cm or less between WPs, but it appears that DOE is considering an increase in the end-to-end WP spacing. The spacing affects the in-drift thermal flux and the applicability of the concept of uniform line load in thermal modeling.

The analysis documented in the Ventilation Model Report (CRWMS M&O, 1999a) does not provide adequate technical basis for the projected heat-removal capability of the emplacement-drift ventilation system because of problems with the appropriateness of the numerical algorithm used for the analysis (IRSR Rev 3, p. 94 for details). The Ventilation Model report was audited during the EBS audit (M&O-ARP-00-06, February 2000), at which the DOE technical auditor for the report concluded (and the NRC technical observer concurred) that, although the report may be adequate for a scoping evaluation of the emplacement-drift ventilation concept, the analysis documented in the report is insufficient as a technical basis to support a conclusion on the heat-removal capability of the ventilation system.

It appears that TM and TH process models implement ventilation as a reduction in the waste-package heat output during the ventilation period (e.g., CRWMS M&O, 2000a). Using a reduced waste-package heat output in analysis may satisfy the energy balance but may give incorrect temperatures because of incorrect representation of the WP-to-driftwall temperature gradients.

RESPONSE: Waste package heat output history and the anticipated in-drift thermal flux were provided in Attachment II of the Ventilation Model analysis and model report (ANL-EBS-MD-000030 Rev 00). The technical bases for the projected heat-removal capability of the emplacement-drift ventilation system and for the approach used to represent ventilation in thermal modeling of waste packages and emplacement drifts were documented in the following documents:

Repository Heating and Cooling Scoping Analysis Report (BC0000000-01717-5705-00007 Rev. 00)
Repository Subsurface Waste Emplacement and Thermal Management Strategy (B00000000-01717-5705-00007 Rev. 00)
Ventilation Model AMR (ANL-EBS-MD-000030 Rev 00)

With respect to Viability Assessment analysis, the waste-package thermal output history used at that time

was applicable. Future thermal/ventilation analyses will use the most current WP and repository design information.

DOE has checked and evaluated the ventilation model in question extensively since its development in 1995, and is confident that it produces valid results. In order to build confidence that the model is sufficient, the model results are to be compared with another model, developed independently at the University of Nevada - Reno, which performs similar calculations. In addition, the currently ongoing 1/4-scale testing at the Atlas Facility will provide data that can be used to gauge the accuracy of the model. Pre-test predictions were run using the model, and the test results will be compared to these predictions to confirm the model, or allow it to be "re-calibrated", as necessary. The combination of these two confirmatory activities will provide additional confidence in the model's results.

Additional details are provided in the presentation materials for Subissue 3, Component 1, Acceptance Criterion 7, and Subissue 3, Component 3, Acceptance Criterion 4.

1.2 Characterization of Seismic Loading

1. Provide a description of the seismic input parameters used for design and performance analyses [e.g., in the Drift Degradation AMR (CRWMS M&O, 1999b)] to show that the parameters adequately represent the magnitude, frequency content, and duration of the site-specific seismic loading.

Seismic loading information (e.g., ground-motion time histories) are given in CRWMS M&O (1998) but are considered preliminary. Another seismic-design input report is expected from DOE (DOE commitment delivered at the October 2000 DOE/NRC technical exchange on SDS) prior to the eventual release of Seismic Topical Report 3 that is expected to provide the final seismic design data for the site.

Because of limitations imposed by numerical-modeling codes, the design-basis ground-motion data may at times have to be simplified to develop the input information for a numerical model. It is necessary to establish that any such simplified model-input parameters are representative of the site-specific seismic data.

RESPONSE: As noted, seismic loads are based on documented preliminary results (DTN MO0004MWDRIFM3.002 and DTN MO0004MWDRIFM3.002, Preliminary seismic inputs). These loads will be updated based on completion of seismic design inputs (Seismic Topical Report 3) as discussed at the Structural Deformation and Seismicity Technical Exchange, October 2000. Additional discussions on the use of seismic inputs in design analysis is provided in the presentation materials for Subissue 3, Component 1, Acceptance Criterion 5, "Justify Thermal-Mechanical Modeling."

1.3 Mechanical Properties for Continuum Rock-Mass Modeling

Provide justification for the values of the following rock-mass mechanical parameters:

1. Thermal expansivity
2. Young's modulus
3. Strength parameters (e.g., friction angle and cohesion)

Sufficient information should be provided for each parameter to account for the variations of rock-mass mechanical properties from

1. differences in intact-rock properties between the various stratigraphic units;
2. the frequency, surface characteristics, and continuity of fractures;
3. the volume fraction, and size and shape distributions of lithophysae; and
4. time-dependent mechanical degradation of the rock mass.

Intact-rock thermal-expansivity data are given in CRWMS M&O (1997b) but information has not been provided on rock-mass thermal expansivity, nor has adequate rationale been provided for using intact-rock thermal expansivity in rock-mass modeling.

The DOE has presented a proposal for determining the values of rock-mass Young's modulus and strength parameters through empirical relationships with rock-mass quality indices such as Q or RMR (CRWMS M&O, 1997c). The quality indices were, however, developed for characterizing the effects of fractures and fracture properties on rock-mass behavior, and there is no precedence for their use in characterizing the effects of lithophysae (or any similar large void space). Therefore, DOE needs to provide technical basis for the application of the quality indices (e.g., Q or RMR) to the characterization of the lithophysal rock units, which are the anticipated host rock for about 75% of the emplacement area.

The proposed DOE approach for determining values of rock-mass Young's modulus from Q or RMR relies on an empirical relationship from the literature, without sufficient site-specific data to establish the applicability of the empirical relationship (page 25 of IRSR Rev 3).

The DOE also proposed to determine rock-mass strength parameters through an empirical approach such as proposed by Hoek and Brown (1997). The values of rock-mass strength parameters currently proposed for YM (CRWMS M&O, 1997c; 2000c) are too high (discussed in detail on page 26 of IRSR Rev 3). For example, table 6 of CRWMS M&O (1997c) give a friction angle of 48° for TSw2 intact rock and 57–58° for the rock mass. The high values for the rock-mass strength parameters probably resulted from three causes: (1) the intact rock m_i was set to about 20 whereas the available YM data (e.g., Brechtel et al., 1995) suggests a value of about 8.0; (2) the in situ value of σ_{ci} (unconfined compressive strength of intact rock) was set equal to the laboratory value instead of about 50% of the laboratory value as explained subsequently; and (3) an inappropriate range of confining pressure was used in the data-reduction process. The revised strength parameters in CRWMS M&O (2000c) appear to have addressed the third problem (range of confining pressure) but did not address the first two (values of m_i and σ_{ci}).

Laboratory testing of intact rocks under different loading rates (e.g., see reference cited on p. 26 of IRSR) indicates that the in-situ unconfined compressive strength of intact rock is smaller than the unconfined compressive strength from conventional laboratory testing, because of the difference between rock behavior under rapid-loading (i.e., laboratory) and sustained-loading (i.e., in situ) conditions. DOE has not provided any data to evaluate this effect for the YM rocks, and has assumed a ratio of 1.0 between the laboratory and in-situ unconfined compressive strength of intact rock, notwithstanding that the available data from literature suggests a ratio of about 0.5 (page 26 of IRSR Rev 3). Additional reduction of rock-mass strength from time-dependent degradation of fracture-wall rock is also anticipated, but DOE has not presented an approach (with technical justification) to account for such degradation.

RESPONSE: Rock mass mechanical properties derived based on the empirical approach are considered to be appropriate, particularly for the non-lithophysal rock. Further classification analyses are planned, particularly for the lithophysal rock. Internal friction angles for the rock mass have been derived using the rock mass quality index approach and field mapping data (DTN: MO0001SEPSRMPC.000). The derived values are very sensitive to the range of confining stress used. Use of a confining stress range of 0 to 3 MPa will lead to a friction angle of 56 to 58 degrees, while a confining stress range of 0 to 42 MPa will

result in a friction angle of 37 to 43 degrees. The friction angles based on both confining stress ranges were used and discussed in ground control analyses. Additional details are provided in the presentation materials for Subissue 3, Component 1, Acceptance Criteria 4 and 5.

1.4 Mechanical Properties for Discontinuum Rock-Mass Modeling

Provide justification for the values of the following fracture mechanical parameters with sufficient information to describe the variability of each parameter (including time-dependent mechanical degradation):

1. Shear and normal stiffnesses
2. Strength parameters (e.g., friction angle and cohesion)

The values of fracture normal stiffness under a normal stress of 2.5 MPa are given in CRWMS M&O (1997b) based on laboratory test data from 11 core specimens of TSw2 rock. There is no data provided for shear stiffness or for the variation of shear and normal stiffnesses with normal stress. The technical basis for the representativeness of the fracture stiffness data is also not provided.

CRWMS M&O (1997b) give a fracture-surface friction angle of about 41° for TSw2, based on five Tptpln, five Tptpll, and two Tptpmn core specimens. CRWMS M&O (1997c) also give fracture-surface friction angles of about 60–64° for TSw2 fractures, but these values are inapplicable, having been determined based on an incorrect assumption that the residual friction angle of fractures is equal to the rock-mass friction angle. The fracture shear strength data in CRWMS M&O (1997b) may be applicable if adequate technical basis is provided to show that the data is representative of the YM site.

RESPONSE: The availability of test data on mechanical properties of joints (fractures) is very limited. The shear stiffness value was assumed to be the same as the normal stiffness. Both normal and shear stiffness values are dependent on the normal stress level. The higher the normal stress, the higher the normal stiffness. The stiffness value corresponding to a low normal stress level was used and considered to be conservative. The fracture friction angle value used in the ground support analysis (CRWMS M&O. *Ground Control for Emplacement Drifts for SR.* ANL-EBS-GE-000002 Rev. 00) were based on the laboratory tests on 12 samples (CRWMS M&O 1997b). Considering the scattering and stress-dependent nature of mechanical properties for joints, values selected for ground control analyses were considered to be adequate. Additional discussions are provided in the presentation materials for Subissue 3, Component 1, Acceptance Criterion 5.

1.5 Mechanical Degradation for Rock-Support Materials

Provide a description of the time-dependent mechanical degradation of the ground-support system and the technical basis for the description.

RESPONSE: DOE has adequately documented the basis for mechanical degradation of rock support materials (Longevity of Emplacement Drift Ground Support Materials ANL-EBS-GE-000003 REV 01). Completion and documentation of sensitivity studies on ground support material properties will confirm the approaches handling mechanical degradation. Additional details are provided in the presentation materials for Subissue 3, Component 1, Acceptance Criterion 5.

1.6 Thermal-Mechanical Modeling

1. Provide a description of DOE's modeling approach with technical basis to justify the following:

- Thermal and mechanical boundary conditions
- Representation of support systems

2. Provide technical basis to show that the fracture patterns used in discontinuum modeling are representative of the site-specific fracture distributions.

A drift-scale model presented in CRWMS M&O (2000c) indicates that DOE intends to use a zero-displacement boundary at 50 m below the drift axis and a boundary constrained by in-situ stress at 50 m above the drift axis. These boundary conditions are inappropriate because they interfere with the development of thermally induced stress.

DOE has presented discontinuum models based on a regular fracture pattern developed from mean fracture orientations and dips (CRWMS M&O, 2000c). Alternative studies cited in the IRSR (Chen, 1999; Chen et al., 2000), however, indicate that the randomness of fracture orientations and dips has a significant effect on the calculated mechanical response.

RESPONSE: Two dimensional modeling for emplacement drifts is considered to be adequate. A combination of both continuum and discontinuum modeling approaches allows for realistically analyzing drift and ground support behaviors. Considering the total length of emplacement drifts, fracture patterns have to be idealized or simplified such that least favorable patterns expected from the field are considered. The corresponding results are conservative, and ground support is designed for such scenarios. Proper use of simplified regular joint patterns is believed to be conservative. Additional details are provided in the presentation materials for Subissue 3, Component 1, Acceptance Criterion 5.

2. Effects of Seismically Induced Rockfall on the Engineered Barrier System Performance (IRSR Section 5.3.2)

This component of subissue 3 concerns DOE's evaluation of rockfall events and consequences. NRC concerns on the evaluation of rockfall consequences have been addressed through the CLST KTI. Therefore, only the concerns on the evaluation of rockfall events will be addressed through this component of subissue 3. The following should be provided to resolve these concerns:

1. Technical basis for rockfall size distributions and the design-basis rockfall.
2. A description of the static loading for representing the effects of drift collapse on waste packages and drip shields, and the technical basis for the loading.

The analyses presented in the Drift Degradation AMR are inadequate to support a conclusion on the effects of thermal loading or seismic loading on rockfall. The key-block analysis code used for the analyses is not capable of representing either thermal or seismic loading. The AMR acknowledged these limitations of the code, but indicated that both thermal and seismic loading were represented in the analyses through a reduction of fracture shear strength. The analyses were reviewed by the DOE technical auditor for the AMR as part of the EBS Audit (M&O-ARP-00-06, February 2000), who concluded (and the NRC technical observer concurred) that the representation of thermal and seismic loading through a reduction of fracture shear strength is inappropriate, and that the AMR is inadequate to support a conclusion on thermally or seismically induced rockfall.

RESPONSE: The response to NRC concerns with respect to rockfall analysis are addressed in responses to separate question lists received from NRC. Additional details are also provided in the presentation materials for Subissue 3, Component 2, Acceptance Criteria 1 and 4.

3. Thermal-Mechanical Effects on Flow into Emplacement Drifts (IRSR Section 5.3.3)

This component of subissue 3 concerns DOE's evaluation of TM effects on drift geometry and rock-mass hydrological properties and the representation of these effects in DOE's performance assessment abstractions. To address NRC concerns on this component of subissue 3, DOE needs to

1. develop a description or bounding characterization of the anticipated changes in drift geometry (size, shape, surface roughness) after permanent closure;

2. develop a description or bounding characterization of the anticipated TM-induced changes in hydrological properties, including the magnitude and nature of the changes, and the geometrical characteristics of the rock-mass zones affected by such changes; and

3. implement these changes in PA abstractions of (i) Degradation of the Engineered Barrier, (ii) Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms, and (iii) Spatial and Temporal Distribution of Flow.

The current DOE assessments of these effects are based on the analyses of drift-geometry changes reported in the Drift Degradation AMR (CRWMS M&O, 1999b), and the analyses of TM induced fracture-permeability changes documented in a series of reports [Blair (in Hardin, 1998); Berge et al. (1998, 1999); CRWMS M&O, 2000b]. However, these analyses are not adequate to support any of the DOE conclusions (see discussion in Section 5.3.3 of IRSR Rev 3). The calculation documented in CRWMS M&O (2000b) was reviewed by a DOE technical auditor as part of the NFE audit (M&O-ARP-00-08, July 2000). The audit, which was observed by NRC, identified several technical problems with the calculation, including incorrect boundary conditions and inappropriate thermal loading, mechanical properties, and fracture pattern. The DOE technical auditor concluded (and the NRC technical observer concurred) that the calculation is inadequate to support a conclusion on thermally induced changes in hydrological properties.

The loading combinations and thermal and mechanical characteristics discussed in Item 1 should be adequately represented in the analyses used to develop the characterizations of TM effects on drift geometry and rock-mass hydrological properties.

RESPONSE: DOE has described the approach to TM effects in the presentation materials for Subissue 3, Component 3 and in a new analysis and model report *Coupled Thermal Hydrological Mechanical Effects*, ANL-NBS-HS-000037 (in preparation). The drift degradation analysis is discussed in presentation materials for Subissue 3, Component 2 and in responses to separate question lists received from NRC. Issues related to coupled thermal-hydrologic-chemical effects were discussed extensively at the Evolution of the Near Field Environment Technical Exchange, January 2001.

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